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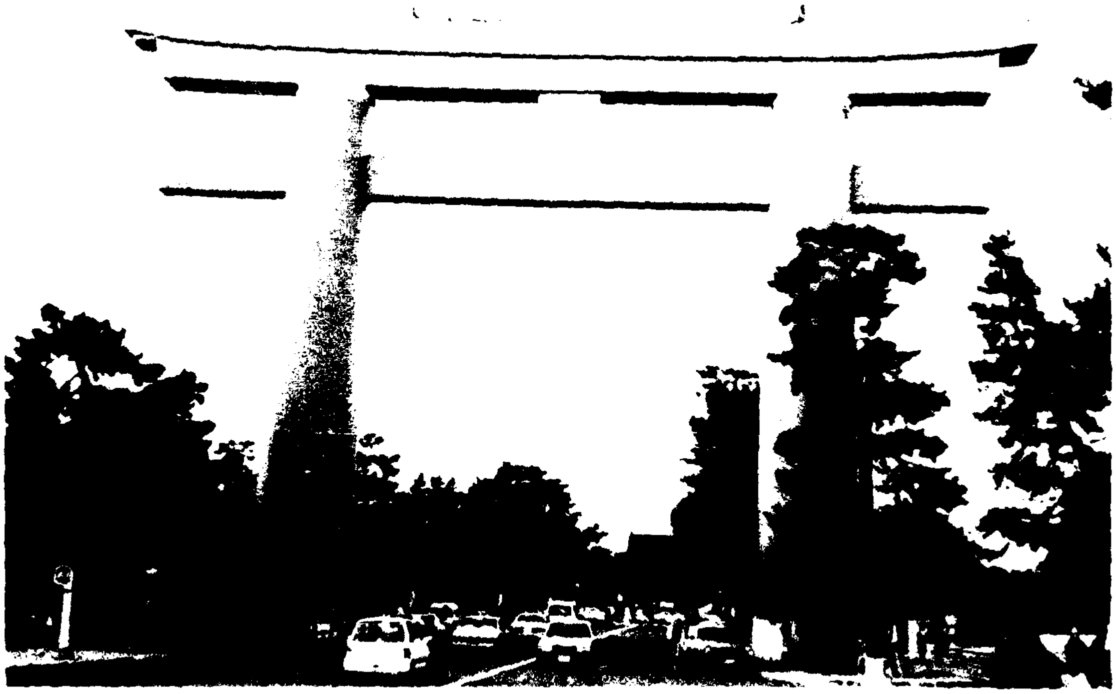

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This is a quarterly publication presenting articles covering recent developments in Far Eastern (particularly Japanese) scientific research. It is hoped that these reports (which do not constitute part of the scientific literature) will prove to be of value to scientists by providing items of interest well in advance of the usual scientific publications. The articles are written primarily by members of the staff of ONR Far East, the Air Force Office of Scientific Research, and the Army Research Office, with certain reports also being contributed by visiting stateside scientists. Occasionally, a regional scientist will be invited to submit an article covering his own work, considered to be of special interest. This publication is approved for official dissemination of technical and scientific information of interest to the Defense research community and the scientific community at large.

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Cover: Torii at Heian Jingu, Kyoto. Heian Jingu, built for Kyoto's 1100th anniversary in 1895, enshrines Emperor Kammu, who started Kyoto, and Emperor Komei, the father of Emperor Meiji. The enormous torii gate spans the road approach to Heian Shrine. Courtesy of Earl Callen.

THE 1989 KYOTO PRIZES

Sandy Kawano

The Laureates for the 1989 Kyoto Prizes are "Mr. Switching," Amos Edward Joel, Jr., a pioneer in the field of electronic switching for telecommunications networks; Professor Izrail Moiseevich Gelfand, an outstanding contributor to the advancement of mathematical sciences; and John Cage, a renowned composer of contemporary music.

On 23 June 1989 the Inamori Foundation announced this year's winners of the Kyoto Prizes, which are international awards presented to a group or an individual who has contributed significantly to the scientific, cultural, and spiritual development of mankind. The prizes are awarded in three main categories: Advanced Technology, Basic Sciences, and Creative Arts and Moral Sciences. Within each of these three categories a specific field is selected. The Laureates for the 1989 Kyoto Prizes and their respective fields are:

- Amos Edward Joel, Jr., electrical engineer, in the field of Electronics, Telecommunications, Lasers, and Control Engineering (Advanced Technology)

- Izrail Moiseevich Gelfand, mathematician, in the field of Mathematical Sciences (Basic Sciences)

- John Cage, composer, in the field of Music (Creative Arts and Moral Sciences)

Mr. Amos Edward Joel, Jr., from the United States, is a pioneer in the field of electronic switching for telecommunications networks. He was instrumental in conceiving and developing electronic switching technology. He has been a leader in its introduction throughout the world. His achievements, along with his gentle and sincere personality, are internationally known, and he is affectionately called Mr. Switching.

Joel is a graduate of the Massachusetts Institute of Technology (MIT), from which he received a master's degree in 1942. After receiving his bachelor's degree from MIT in 1940, Joel joined Bell Telephone Laboratories, where he remained until his retirement in 1983.

Joel's first paper on the subject of electronic switching, which disclosed the principal concept for the current system, was published in the *Bell System Technical Journal* in September 1956. He was an advocate of the concept of Stored Program Control, which opened the door to upgrading and freely modifying electronic switching to meet public needs. Without this breakthrough concept it would have been impossible for the communications network to remain congruent with our diverse and enhanced society. As a result, major advances over the communications network of this earlier period were realized, including automatic announcement of telephone number changes and the continuity of cellular phone connections for automobiles traveling long distances.

By 1965 the switching system based on this Stored Program Control was used as the electronic switching system for the United State's public communications network. Joel played a central role throughout the process of this development, especially as supervisor for the development of operator support electronic switching.

The development of the electronic switching system at Bell Laboratories was a great influence throughout the world. Prior to this development, only a small number of specialists were engaged in switching system research around the world; since that time large-scale research has been undertaken in every nation. Further research, to enhance the capability of communications networks using advances such as the introduction of the digital switching system and the adoption of the Integrated Services Digital Network, is also underway.

Joel proposed the establishment of the International Switching Symposium (ISS) to encourage international exchange in research and has made notable efforts to promote the diffusion of electronic switching technology. In 1984 he was awarded the Columbus Medal by the City of Genoa, Italy, in recognition of his contributions to the development of electronic switching, and in 1987 he was honored as the Father of ISS.

The achievements of Joel as an engineering researcher are not limited simply to technological research. His brilliant foresight, in combining research with the demand for communications within society, made him the forerunner in a new field of technology and industry and surely makes him deserving of the Kyoto Prize in Advanced Technology.

Izrail M. Gelfand, through pioneering work in functional analysis, has made outstanding contributions to the advancement of mathematical sciences. In the course of his creative career, he has taught and inspired many prominent mathematicians who continue to play leading roles in mathematical sciences.

Professor Gelfand, who was born in the U.S.S.R., received his undergraduate and Ph.D. degrees from Moscow University, where he has been a professor since 1935. From 1968-70 he was president of the Moscow Mathematical Society. His doctoral thesis in 1938 on commutative normed rings and his work on the noncommutative rings of linear operators on Hilbert spaces provided decisive steps for subsequent developments in functional analysis and deeply affected such areas as algebraic geometry and physics.

Groups, which describe symmetries in nature, are basic objects of study in mathematics and physics. Gelfand obtained numerous fundamental results on unitary representations of locally compact groups, semisimple Lie groups, and even infinite dimensional groups. His work not only brought about revolutionary changes in representation theory and physics but had enormous impact on number theory and geometry as well.

The six volumes on generalized functions, published in collaboration with several coauthors, contain accounts on such diverse topics as differential equations, representations, homogeneous spaces, integral geometry, automorphic functions, and stochastic processes and continue to be rich sources of inspiration.

The extraordinary collection of over 460 research papers and monographs by Gelfand contains remarkable results on the inverse spectral problem, topological invariance of the index of elliptic operators, geodesic flows on homogeneous spaces, cohomology of infinite dimensional Lie algebras, integral geometry, differential operators on homogeneous spaces, combinatorial geometry, and numerical analysis. The breadth and depth of his achievements are astonishing.

For over 40 years Professor Gelfand has been conducting an extremely creative and inspiring seminar at Moscow University that has turned out many prominent Soviet mathematicians. He is still at the forefront of creative activity in research on hypergeometric functions. Key ideas and deep insights provided by Gelfand are expected to have a lasting influence on the development of mathematical sciences.

John Cage, who was born in Los Angeles, CA, is a great composer representing modern America. His works are identified far beyond the concept of western music in its traditional sense. His debut performances in various parts of Europe in 1954 had a strong impact on European composers. Since then, his "Chance Music" has become one of the main styles of contemporary music. His performances have been a great influence on the various styles of postwar composition.

Cage studied modern music under Henry Cowell from 1931-34. From 1934-35 he studied 12-tone music under Arnold Schoenberg at UCLA. His interest in folk music of various countries and his study of 12-tone music inspired him to compose some works reflecting these interests. Besides studying music, he was also an enthusiastic student of architecture, poetry, painting, and mushrooms. In 1945 he turned his attention to the spiritual aspects of life and studied Zen Buddhism under Daisetz T. Suzuki at Columbia University. This, combined with his interest in Indian music, led him to compose non-Western music. From 1950-60 he was a lecturer at the New School for Social Research in New York. In 1988 he became a professor of poetics at Harvard University. Cage's creative activities and philosophy of art have widely influenced not only musicians but also artists in other fields, such as dancers, poets, painters, sculptors, and photographers. In fact, his work has always been done in collaboration with various artists from other fields.

Many of Cage's early compositions are dance music for percussion ensembles, written while he was interested in complicated rhythmic structures. He wrote pieces for so-called prepared piano, whose strings change pitches and tonal colors by inserting various objects between the strings (screws, wooden and rubber pieces, etc.). These experiments were totally outside conventional styles of Western music.

Cage composed music by changing sounds (chance operation) in accordance with I Ching (Chinese Book of Change), and he used a variety of sounds from radio broadcasts to vary noises. In his performances improvisation and chance are frequently used, so his music is also known as "Indeterminacy Music." He invented a form of graphic notation to replace standard musical notation and he has been involved in creating and performing electronic and computer music since his earlier works.

Introducing non-Western musical ideas and expressions into Western music has been a general tendency since World War II. John Cage has been a pioneer in such evolutionary movements and has shown his strong influence in the most progressive group of modern composers. He is a Fellow of the Center for Advanced Studies at Wesleyan University, the American Academy and Institute of Arts and Letters, and the American Academy of Arts and Science.

Sandy Kawano has been the editor of the Scientific Information Bulletin *since October 1986. Before coming to Japan, she worked for the Naval Civil Engineering Laboratory, Port Hueneme, CA, as a technical writer-editor. She has a bachelor of arts degree in liberal studies from California State University, Northridge.*

SHAPE MEMORY

Earl Callen and Fred Pettit

Shape memory alloys can be formed at a high temperature into some shape to be remembered, and can then be cooled and deformed. When heated they spring back to their original shape. They are "superelastic"--at an appropriate temperature they respond elastically to applied stress, but their deformation can be as much as 20 times as large as the strain of ordinary metals. Shape memory alloys can also be trained to remember two shapes, a high temperature and a low temperature shape. With no applied stress, when the temperature is cycled the sample switches back and forth between the two shapes. Certain compositions of Ti-Ni alloys, alloys of precious metals, and alloys of Cu and Fe exhibit shape memory behavior. Ferroelectrics, antiferroelectrics, some other ceramics, and thermoelastic resins can be trained to have these properties.

INTRODUCTION

Imagine a strip of ordinary metal, clamped at one end and with a force applied at the other end transversely to the axis of the strip, deflecting it sideways. The deflection is proportional to the applied force. As long as the force is small, so that the strain induced in the strip is less than its elastic limit, when the force is removed the strip returns to its original straight shape. If the strain exceeds the elastic limit the strip is deformed due to irreversible plastic deformation via dislocation generation and flow.

There is a special class of metals (and of some nonmetals, to which we shall return later) with properties that allow them to "remember" a shape. A rod or wire of a shape memory alloy (SMA) is formed into some desired shape--let us say for simplicity a straight strip--at a high temperature and cooled. As before, the strip is clamped at one end and deflected at the other. For small deflections the strip returns to its straight shape when the force is removed. For large deflections the strip remains bent when the force is removed. However, when the strip is heated it jumps back to its original straight shape! Of course the deformation cannot be so extensive as to cause irreversible plastic flow; shape memory alloys also have elastic limits. Up to 7 percent strains are typically recoverable, but in some materials strains as large as 10 percent are recoverable (Ref 1).

Shape memory alloys can be "trained" to have a "two-way" memory. In the example above, continuing into a second cycle, if the straight strip is again cooled it does not spontaneously assume the bent shape; it remains straight. But if it is again bent the same way and reheated (it straightens again) and the cycle repeated several times, the strip "learns" both configurations. Without applied stress the strip switches back and forth between the straight high temperature and bent low temperature shapes. And of course both shapes can be more complicated than simply "straight" and "bent."

The shape memory effect (Ref 1-3) was first discovered in 1951 in a Au-Cd alloy (Ref 4) and soon after in In-Tl (Ref 5). But the attention the effect received became worldwide and intense with Buehler's announcement (Ref 6) of Nitinol, a nickel titanium alloy with superior mechanical properties, named after his employer, the U.S. Naval Ordnance Laboratory (Ni-Ti-NOL).*

There are several families of SMAs. Almost all SMAs are cubic in a high temperature phase. Some (Ag-Cd, Cu-Zn, Ni-Al, Ti-Ni) are ordered bcc, CsCl B2 structure, and some (In-Tl, Mn-Cu, Fe-Pd, Fe-Ni-Co-Ti, Fe-Ni-C, Fe-Mn-Si) are disordered fcc. Miyazaki and Otsuka (Ref 2) give a table of structures and describe the crystallography of the transformations. In Ti-Ni the SMA effect is obscured by other accompanying transformations. To clarify the basic phenomena one wants single crystals, which were more difficult to make from Ti-Ni than from the Cu-based alloys. On these latter materials the source of the shape memory effect was first exposed: the effect arises from a martensitic transformation, and the transformation is thermoelastic (Ref 7).

Martensitic Transformation

A martensitic transformation is diffusionless, being a structural distortion with the same constituent composition as the parent phase. In the symmetry lowering and structural distortion considerable elastic energy is stored. The major and significant strainlike distortion in martensites is a shear. The shear deformation can be as large as 20 times the maximum elastic deformation (Ref 2). There is both a temperature width in the transformation in each direction and hysteresis in the transformations between the high temperature parent phase and martensite. As one lowers the temperature of the high temperature phase there is a threshold temperature, M_s, at which martensite begins to form. The transformation is not substantially complete until the temperature is reduced to the "finish" temperature, M_f. M_s-M_f is the transition width in this direction. Upon heating, the high temperature phase begins to form at temperature A_s (different from M_s; there is hysteresis) and is substantially complete at A_f. For example, in a Ti-Ni single crystal studied by Takei et al. (Ref 8), M_s = 236 K, M_f = 103 K, A_s = 216 K, and A_f = 265 K. M_s and A_s depend upon applied stress. When the stress aids in the formation of martensite the M_s and A_s temperatures are higher with higher stress, as the low temperature phase can persist against greater thermal disorder.

The notation comes from common iron alloys, in which the parent phase is austenite (fcc). The transformation is martensitic, but many iron alloys are not SMAs. In the martensitic transformation of Fe-29% Ni, a non-SMA, A_s is over 400° higher than M_s. Supercooling and superheating are required to offset surface energies of nucleation and stored elastic energy.

Thermoelasticity and Superelasticity

In SMAs the phenomenon called thermoelasticity is complicated. When the material is deformed at a temperature below M_s elastic energy is stored reversibly. But

*NOL was later renamed the Naval Surface Weapons Center and is now the Naval Surface Warfare Center. One of the authors (Earl Callen) was employed there. Buehler had as a demonstration a crumpled twist of wire which, when heated, straightened out to spell NOL with a nice Navy anchor decoration. Nitinol stores so much energy that it was dangerous to machine. Bits of the metal would fly off the machine tool and streak like shrapnel through the shop.

the reversibly stored elastic energy is fully released only when the material is heated above A_f, completing the transformation back to the parent phase. Stored elastic energy lowers A_s relative to M_s, so that characteristically in thermoelastic substances thermal hysteresis is reduced. In some instances M_s even exceeds A_s. When the shape of the deformed but unloaded specimen is restored by heating the phenomenon is called shape memory. When the temperature is held constant at an ambient temperature such that a load shifts the martensitic transformation temperature above the temperature of the sample, then removing the load allows reversion to the parent phase. Since the deformations developed in the transformation process are very large compared to normal elastic strains the phenomenon is called superelasticity, or pseudoelasticity.

There are several mechanisms for memory and for superelasticity. One we have described is stress-induced growth of martensite. Another mechanism is growth and decay of variants and twins by interface movement in existing martensite plates. There are numerous crystallographically permitted directions of shear. In the parent-to-martensite transition in the untrained specimen, in the absence of applied stress there is no spontaneous shape change because on average variants with all senses of distortion grow and arrange themselves to accommodate and compensate each other's shapes. But when the sample is stressed those variants favorably oriented with respect to the stress will grow by interface movement. A third mechanism is transformation between different types of martensite (Ref 2). In some systems there can be two or more crystallographically distinct martensite phases. Stress can cause one of these to grow at the expense of another.

Figure 1, from Wayman (Ref 1), illustrates the relation between stress and strain at three temperatures, with the lowest temperature at "below M_f." When the temperature is below M_f an applied stress induces the growth of sympathetically oriented martensite platelets (Ref 7). There is a residual strain when the stress is removed. If the temperature is then increased, at A_s the strain begins to relax as some of the martensite transforms to the high temperature phase. The process is completed at A_f. This is the shape memory effect.

Superelasticity is illustrated in the constant temperature cycle at a temperature above A_f. We have remarked that the martensite start temperature is an increasing function of stress. But there is a limit, since slip deformation at high stresses and temperatures will occur before stress-induced martensite formation. The central hysteresis loop of Figure 1 is at a temperature below this limit. Applied stress shifts the martensite start temperature at finite stress, M_s^σ, above the ambient temperature, so that martensite is formed, with its large shear distortion. But when the stress is relieved parent phase reforms.

The stress-strain curve at the highest temperature is above this limit. The material remains parent phase at all stresses. The elastic response is small, reversible, and normal up to the irreversible plastic flow regime.

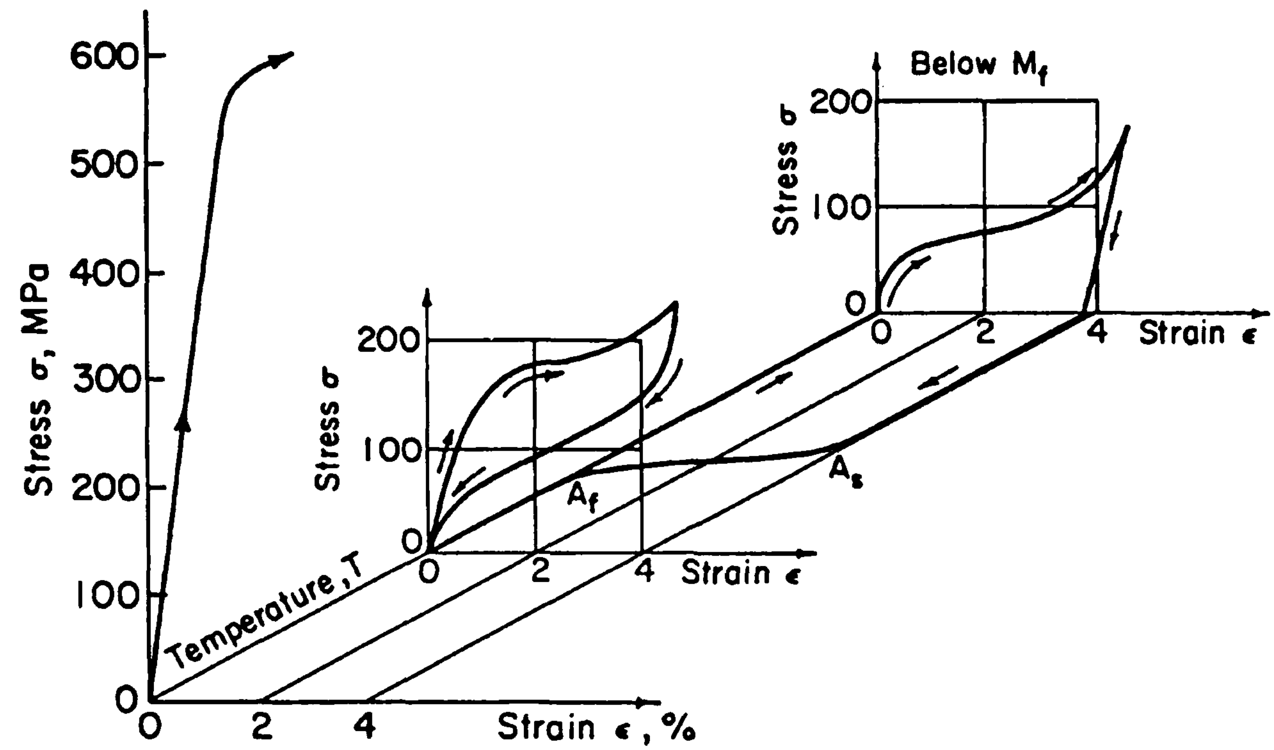

Figure 1. Stress-strain-temperature diagram for a shape memory alloy. Increasing temperature is toward the reader. The cycle at the lowest temperature shown, below M_f, illustrates shape memory. Imposed stress transforms variants. When the stress is removed a residual strain maintains the deformed shape. When the temperature is raised to A_s and to A_f the transformation to austenite begins and completes. The strain and deformation are relieved. The constant temperature cycle in the middle of the figure illustrates superelasticity. The temperature is above M_s, but application of stress raises M_s^σ above the ambient temperature. Stress-induced martensite is formed but reverts to austenite when the stress is removed. The highest temperature trace shows normal elastic response. At some large stress, the critical slip stress, the austenite deforms plastically and irreversibly. (Courtesy of C.M. Wayman, to be published.)

Figure 2 shows the stress-dependent martensite start and austenite finish temperatures, M_s^σ and A_f^σ. (In this section through the three-space of Figure 1 the induced strain is a free variable.) The thermodynamically well-defined phase boundaries M_s^σ and A_s^σ satisfy Clausius-Clapyron equations, and the experimental evidence is in good agreement (Ref 1). M_s^σ is, of course, also the martensite start stress as a function of temperature. In Figure 2, above the (temperature dependent) critical slip stress line, σ_{slip}(parent), irreversible flow occurs. The useful regime is below this stress. The superelastic region of complete elastic recovery when the load is removed is to the right of A_f, the austenite finish temperature at zero stress. In the trapezoidal region between A_s and A_f some strain remains in the specimen. It is clearly desirable that the critical slip stress be as large as possible and necessary that the temperature at which M_s^σ and σ_{slip}(parent) intersect be greater than A_f.

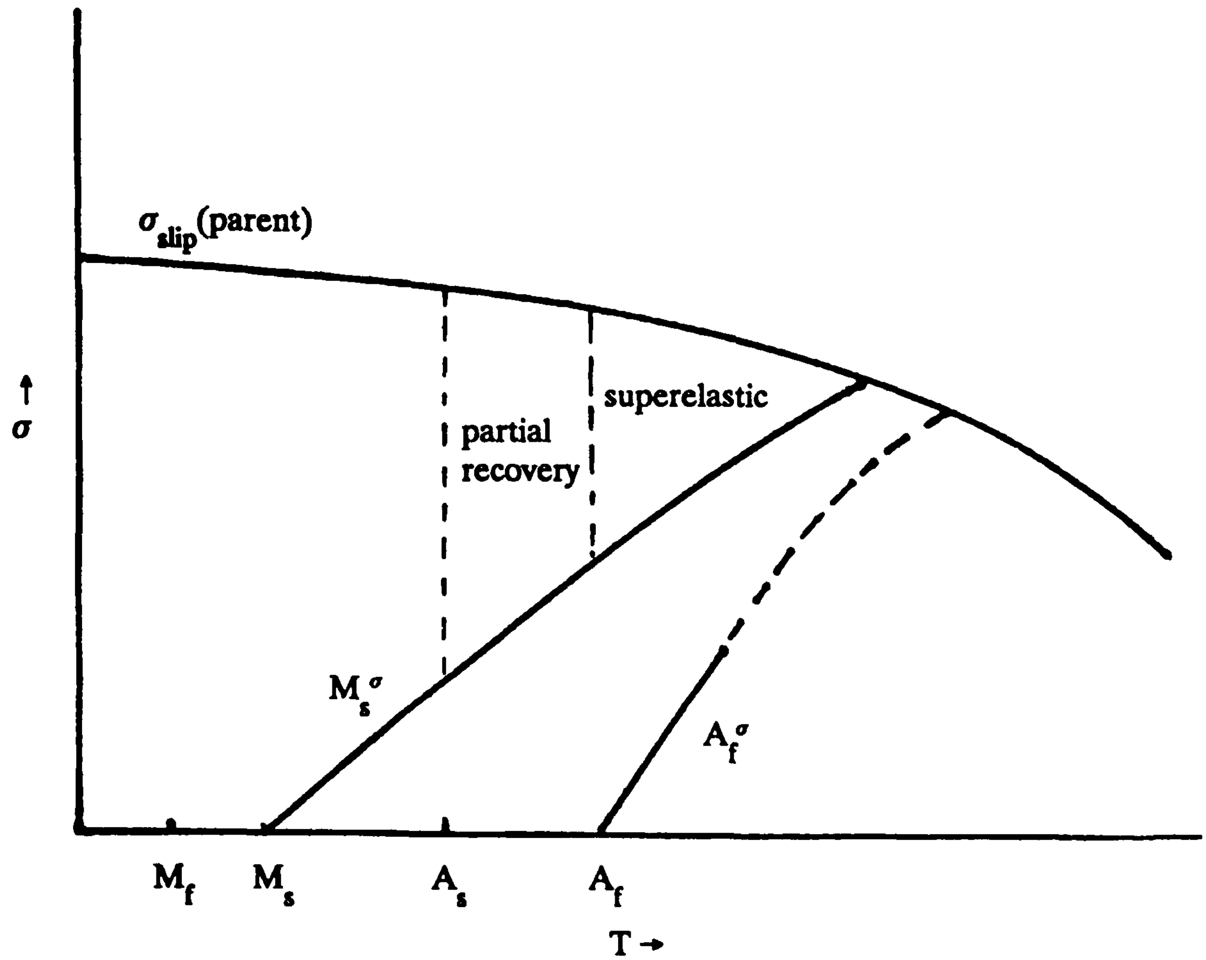

Figure 2. Stress-temperature phase diagram. The figure shows the zero-stress martensite and austenite start and finish temperatures and the stress-dependent phase boundaries M_s^σ and A_f^σ. At fixed stress, martensite starts forming on lowering the temperature through M_s^σ, and the formation of austenite is essentially complete on raising the temperature through A_f^σ. The figure shows the austenite critical slip stress, above which austenite deforms plastically. To be a useful superelastic material the intersection of σ_{slip}(parent) and M_s^σ must occur at a temperature higher than A_f. Useful superelastic response with complete recovery will occur in the triangle between the two solid lines and at temperatures above A_f. Partial recovery upon removal of the stress will occur in the trapezoid between A_s and A_f.

Two-Way Memory

A sample can be trained to remember both high and low temperature shapes by repeated temperature cycling and deformation in each phase. The martensitic transformation mechanism described above explains memory in the high temperature, parent phase. For there to be memory in the martensite phase another mechanism is required. Something in the structure must remain through the temperature cycle that encourages nucleation of martensite plates in the same location and with the same orientation as in the previous low temperature leg of the cycle. Wayman (Ref 1) illustrates the preferential evolution of variants observed by optical micrographs of a Cu-39.8%Zn alloy under several thermomechanical cycles. Initially one observes equal population of all variants. A sample is deformed in the martensite phase, heated to the parent phase, and cooled again and deformed as before. After several such cycles, without external stress one observes spontaneous preferential growth of those variants whose shapes conform to the deformation stress of previous cycles. Wayman (Ref 1) attributes the preferential growth of favorably oriented variants to microstresses induced by distortion and retained. Tadaki, Otsuka, and Shimizu (Ref 2) propose that repeated deformation introduces dislocations that stabilize a particular martensite plate configuration and remain to guide the same configuration in subsequent martensite stages. Tadaki et al. (Ref 2) reference a number of other proposed mechanisms.

CURRENT RESEARCH

In Asia there is a great deal of activity in SMAs. For example, at the Materials Research Society Conference in Tokyo in May-June 1988, 95 papers were presented in the 9 sessions on SMAs: 43 of these were from Japanese groups; 21 from the People's Republic of China; 16 from the United States; 3 from Taiwan; 3 from Korea; and a scattering from Australia, Pakistan, Italy, Belgium, Argentina, and the U.S.S.R. Some of this effort is on applications, but a great deal of research still goes on, almost 40 years after their discovery, devoted to elucidating fundamental causes and mechanisms of SMAs. For example, there is still no well-established theory of the martensitic transformation itself.

Research on Ti-Ni

R-Phase, the Transformation. The parent phase of Ti-Ni (49 to 51 at. % Ni) is of CsCl, B2 structure. Under certain circumstances, Ti-Ni (and Ti-Ni-X ternary alloys) undergoes a sequence of phase transitions. First a "premartensitic" incommensurate phase evolves. Although the fundamental cubic B2 structure remains, additional x-ray reflections appear. These superlattice reflections are at general positions but close to the 1/3 positions, indicating a modulation whose wavelength is incommensurate with the lattice period. As the temperature is lowered the superlattice reflections intensify and shift continuously to the commensurate 1/3 positions, the cubic reflections disappear, and rhombohedral reflections appear. The unit cell has now tripled in size, and the symmetry has lowered from cubic to rhombohedral in the so-called R-phase (Ref 9,10). The transition between B2 and incommensurate is second order; from incommensurate to commensurate rhombohedral the phase transition is first order. The R-phase can be reversibly and isothermally stress-induced. It is mechanically, thermally, and crystallographically fully reversible (Ref 11). It is independent of the martensitic transformations, as has been shown by the substitution of Fe, which suppresses the martensitic transformation although the R-phase still forms (Ref 12). In a Ti-Ni polycrystal the self-accommodation of martensite variants and twins is complicated; in a single crystal the twinning modes are more readily decipherable. Three self-accommodating variants form in a triangular morphology (Ref 13). When the system is loaded, that martensite variant which is most favorably oriented with respect to the stress grows by interface movement at the expense of the other two variants. When the stress is removed the favored variant remains. Upon heating the interface reverses and R-phase forms. This produces about 90 percent of the shape recovery. The rest of the recovery occurs when the R-phase is converted to B2 by further heating.

Phase Diagram, Metastable Phases. Although it has the best SMA properties, Ti-Ni is a difficult material to use. At high temperatures Ti combines readily with oxygen, nitrogen, carbon, and other elements. Whether or not the R-phase develops--and thus the SMA performance--depends upon treatment. There are several metastable phases, and at least one of these strongly affects the SMA behavior. To understand and control all of this it is necessary to know not only the phase diagram but the metastable extensions thereof and the metastable phases. The equilibrium phase diagram of the Ti-Ni system is not yet fully known, let alone the full metastable behavior. Nishida et al. (Ref 14) describe the important metastable phase Ti_3Ni_4 and the metastable phase Ti_2Ni_3. After long aging these metastable phases transform to equilibrium $TiNi_3$.

Critical Stress. Figure 1 illustrates a material in which the critical stress for irreversible slip in the parent phase is well above the load stress to be applied in superelastic response or in deformation for shape memory. It is, of course, necessary that this be the case in a practical material. Figure 2 shows the useful region of superelastic response below the critical slip stress boundary. Near room temperature critical slip stress generally falls gradually while M_s^{σ} rises with increasing temperature. For superelastic applications it is necessary that the critical slip stress of the parent phase exceed the applied load stress at the ambient temperature, which must be above A_f. For shape memory use, in which one cycles from below M_s to above A_f, if the ambient temperature is above M_f the critical slip stress must exceed the deformation stress at the ambient temperature so that no residual parent phase material is irreversibly deformed. Critical slip stress in the parent phase must be as high as attainable. Annealing temperature, aging temperature, and Ni concentration affect critical slip stress (Ref 15). In annealing below the recrystallization temperature, dislocations migrate to more favorable locations. Aging causes precipitation hardening by precipitation of fine Ti_3Ni_4 deposits. By impeding dislocation movement these deposits raise the critical stress for slip.

Cycling Deterioration. A certain amount of irreversible deterioration accompanies continued thermal or stress cycling. For example, M_s and A_f usually decrease. With repeated stress cycles a residual strain gradually builds up, and the useful area under the hysteresis loop decreases (see Figure 1). In some ordered SMAs the degree of order decreases under thermal cycling. In others precipitation is induced. Miyazaki et al. (Ref 16) and Tadaki et al. (Ref 17) show that in Ti-Ni alloys neither disorder nor precipitation are the causes of thermal cycling deterioration; rather, dislocations are introduced and these and their accompanying stress fields are responsible for the deterioration.

Fatigue. Although Ti-Ni SMAs have long useful lives, inevitably after prolonged usage the alloy undergoes fatigue failure. Miyazaki et al. (Ref 18) have reported on the factors that affect fatigue life and the mechanism of fatigue crack nucleation and propagation. The authors subjected a Ti-Ni alloy to repeated load-unload cycles. Plotting the load stress as a function of number of cycles until fatigue cracking, Miyazaki et al. found two ranges of straight line behavior with different slopes: a high stress, cyclic superelastic deformation regime of shorter lifetime and a lower stress, elastic regime of longer lifetime. At the test temperature, which was above A_f, the intersection of these two straight lines was close to the critical stress for inducing martensite. This was confirmed at a series of test temperatures. The authors have compared the efficacy of various thermomechanical treatments in increasing lifetime. For superelastic applications, the lifetime of cold worked and annealed (1 hour at 673 K) specimens was a factor of 10 greater than that of solution-treated (1 hour at 1,273 K) and annealed specimens. Thus fine precipitation and dislocation redistribution not only improved shape memory and superelastic behavior but increased lifetime.

Addition of a Third Element, Cu. Addition of some elements (Au, Pd, Zr) raises the M_s temperature while addition of others (Fe, Al, Co, V, Mn, Cr) lowers it. What does a third element do to the mechanical properties (Ref 19)? Saburi et al. (Ref 20) and Miyazaki et al. (Ref 20) have studied the effect of Cu substitution for both Ti and for Ni in Ti-Ni alloys. Substitution of Cu for Ni has almost no effect on M_s, but in substitution for Ti, Cu acts like the transition metals: it lowers M_s rapidly. M_s drops 120 K from the 350 K of the Ti-Ni pure binary to 230 K of the alloy with 1 at. % Cu substituted for Ti. Efficient superelastic energy storage requires minimum loss per cycle. Cu substitution strongly alters loss. Over a narrow composition range Cu decreases the hysteresis loss by a factor of four. Cu substitution also improves the mechanical properties. Cu-substituted specimens are stabler against repeated stress cycling than are the pure binaries. An initial footnote recalled the early difficulty of machining Ti-Ni. Good cold workability not only allows practical forming of desired shapes but cold work also improves shape memory and superelasticity by introducing a high density of dislocations. Miyazaki et al. show that up to about 10 at. % substituted for Ni, and up to about 1 at. % substituted for Ti, Ti-Ni-Cu alloys have good cold workability.

Research on Ti-Pd Alloys

Ti-Pd-alloys are in many ways like Ti-Ni (Ref 21). The parent phase is of B2 structure. There is an intermediate incommensurate phase above the martensitic transformation. Fe, Ni, Cr, Co, and V substitutions have been investigated. Many are shape memory alloys. Ti-Pd-Ni exhibits shape memory at 810 K, which may make for useful high temperature applications.

Research on Cu-Based Alloys (Ref 22)

Both Ti-Ni and the Cu-based alloys have electron per atom ratios of about 1.5 and, disregarding atomic ordering, are bcc in the parent phase. These are called β phase alloys. Those alloys like Ti-Ni, of about 50:50 composition and CsCl B2 superlattice structure, are classified as β_2 phase, while those with about 75:25 composition and Fe_3Al-type DO_3 superlattice ordering are called β_1 phase alloys.

Cu-Al-Ni. The SMA Cu-Al-Ni is a β_1 phase alloy. Its composition is about 28 at. % Al and 2 or 3 at. % Ni. In the martensitic phase, which inherits the atomic site ordering of its parent, the lattice structure is HCP, of Cu_3Ti (or 2H stacking order) type. It was discovered early that for compositions near 14 wt. % Al in a particular temperature range, stress induces a crystallographically different martensite structure (Ref 2,3,7).

Fracture and Fatigue. While commercialization of Ti-Ni has been retarded by its high price, Cu-based alloys are inexpensive. Cu-Al-Ni is brittle. Ductility and fracture stress are low because of intergranular fracture. This was once thought to be due to the large elastic anisotropy of β phase alloys, and elastic anisotropy is indeed a contributor, but a far more important cause of intergranular cracking and fatigue is the transformation strain due to stress-induced martensite formation (Ref 23 and 24).

Another important cause is large grain size. Fracture strength of fine-grained (30μm) specimens is about twice that of coarse-grained (200 to 2,000μm) specimens. Grain size can be reduced by adding an element that increases nucleation rates by providing nucleation sites. Insoluble elements (B, Cr, Se, Pb, V) (Ref 25) or elements that combine with major constituents in the alloy to form fine compounds (Ti) (Ref 26) will reduce grain size. An alloy of composition Cu-12Al-5Ni-2Mn-1Ti (at. %) has good hot and cold workability (10 percent strain at room temperature) and convenient M_s temperature (the purpose of the Mn addition) (Ref 27). Rapid quenching such as splat cooling (Ref 28) and high pressure sintering of fine particles (Ref 29) also reduce grain size.

Transformation Temperature. M_s and the other transformation temperatures of the Cu-based alloys are sensitive to composition. They also depend upon quench rate, aging temperature, and time. Thermal and stress cycling can shift the phase boundaries. The causes of the shifts are changes in the degree of order and the dislocation density (Ref 23 and 24). X-ray diffraction confirms that in the Cu-Al-Ni alloys increasing DO_3 order increases M_s (Ref 30). Electron irradiation can either increase or decrease M_s, depending upon whether the irradiation increases or decreases the degree of order (Ref 31). In some alloy compositions heat treatment can also change the kind of martensite that is formed (Ref 32) and, thereby, the superelastic behavior (Ref 33). T_0 curves are the composition-temperature lines along which the Gibbs free energies of two phases are equal. T_0 curves are important aids in understanding equilibrium and metastable behavior (Ref 34). By applying stress and extrapolating back to zero stress, Sakamoto et al. (Ref 35) have been able to plot T_0 curves at various temperatures on the Cu-Al-Ni ternary diagram. The stress-composition-temperature phase diagram of Cu-Al-Ni is now mapped out to some extent.

Cu-Zn-Al. If it can be made thermally stable Cu-Zn-Al (Ref 36) will be a commercial SMA. Depending upon the alloy composition and heat treatment, two types of superlattice ordering, B2 and DO_3, can be formed (Ref 37). Tadaki et al. (Ref 38) have investigated the effect of thermal cycling on Cu-Zn-Al samples with both types of ordering. Their behavior is quite different. Where M_s of B2 phase samples increases with the number of thermal cycles, M_s of DO_3 ordered samples goes down. But in each case after 1,000 cycles the change from the initial M_s is less than 15 K. A_f in each case follows the same trends. In the DO_3 phase material, decreasing M_s with thermal cycling is consistent with the same behavior in DO_3 ordered Cu-Al-Ni. After thermal cycling, increasing disorder is found in the parent phases of both the DO_3 and B2 alloys. The authors conclude that the changes in M_s are due to the increased disorder. With increasing thermal cycling the density of dislocations increases in each type sample, but the dislocation density is much higher in the B2 alloy than in the DO_3 alloy.

Nakanishi et al. (Ref 39) compare the mechanical and shape memory properties of Cu-25Zn-9.25Al (at. %) prepared by powder metallurgy (P/M) and by melting and casting. With master-alloying the sintered compact achieves a relative density of 98 percent. The grain size of P/M-prepared alloys is 20 to 100 μm, much finer than that attained by other methods. The temperatures M_f, A_s, M_s, and A_f are more spread out in the P/M than in the cast alloy. Comparing stress-strain curves at a temperature below M_s (in the shape memory domain), the authors report about 25 percent greater strain achieved at one-third the stress in the P/M sample than in the cast sample. In the superelastic regime above A_f, stress-strain curves show more than twice the strain at comparable stresses in the P/M sample as compared to the cast sample. Resistivity and A_s measurements indicate rather good stability with aging.

Cu-15Sn (at. %). Miura et al. (Ref 40) have studied Cu-15Sn (at. %). This alloy shows two-stage superelasticity due to the successive transformations β_1 (DO_3) $\rightarrow$ γ_1' (2H) $\rightarrow$ β_1' (18R). Shape memory and superelasticity are strongly affected by aging of the β_1 phase. Kato et al. (Ref 40) describe the way aging changes the stress to induce the transformation and the M_s temperature. Stress to induce the transformation increases and M_s decreases linearly as the logarithm of the aging time. That the decrease of M_s corresponds to an increase in stress to induce the transformation is consistent with inhibiting the formation of martensite on aging. Activation energies obtained from the change of M_s and from the temperature dependence of the stress to induce the martensite transformation ranged from about 0.33 eV in the early stages of aging to 0.53 eV in later stages. It was proposed that Sn atoms diffuse to and pin interfaces between the parent and transformed phases, thereby inhibiting further transformation. The smaller activation energy in the early stage of aging is believed to be the enthalpy of formation of a Sn-vacancy complex, whereas the higher activation energy is for the diffusion of Sn-vacancy pairs.

Research on Fe Alloys

Of the iron alloys, numerous systems exhibit recoverable shape memory: Fe-Pt (Ref 41), Fe-Pd (Ref 42), Fe-Mn-Si (Ref 43), Fe-Ni-Ti-Co (Ref 44), Fe-Ni-C (Ref 45), Fe-Al-C (Ref 46), and Fe-Cr-Ni-Mn-Si-Co (Ref 47). Maki (Ref 44), Maki and Tamura (Ref 44), and Miyazaki and Otsuka (Ref 2) provide current (1989) reviews. In ferrous alloys the parent phase is an fcc austenite (γ). Depending upon alloying elements and compositions this transforms to three martensites with different crystal structures: (1) bcc or bct (α' martensite)--the most common form, found in Fe-C-X, Fe-Ni-X alloys; (2) hcp (ϵ martensite)--found in Fe-Cr-Ni and in high Mn alloys; and (3) fct martensite--found only in the Pd and Pt alloys. All ferrous SMAs except Fe-Pt are disordered in the fcc austenite phase. Fe-Pt, Fe-Pd, and Fe-Ni-Co-Ti are thermoelastic with a small thermal hysteresis. Maki (Ref 44) gives a table of Fe SMA alloys with structure, composition, nature of transformation, and transformation temperatures. The shape memory mechanism is a reverse (from martensite back to austenite) transformation of stress-induced martensite. For this to occur the shape strain of the stress-induced martensite must be reversible. Forward and reverse transformations occur by mobile movement of the martensite/austenite interface, which appears to be favored by the thin plate martensite morphology and planar interface observed in Fe alloy SMA systems. For the shape memory effect to be complete, stress due to the transformation strain must be accommodated by elastic deformation, not slip. Thus the yield stress of the austenite matrix must be as high as possible. This is accomplished by ausforming (Ref 45) or ausaging.

Systems With α' (bcc or bct) Martensite. **Fe-33Ni-10Co-4Ti** (wt. %) is thermoelastic but with a disadvantageously low M_s. **Fe-31Ni-10Co-3Ti** (wt. %) has a higher (but still too low--193 K) M_s and is not thermoelastic (Ref 44). Both compositions are hardened by ausaging at an elevated temperature. Fine particles of Ni_3Ti precipitate coherently in the austenite matrix. Otsuka and Kajiwara (Ref 45) report on **Fe-26Ni-12Co-4Al-0.4C** (wt. %) and nearby compositions. With ausaging, fine perovskite-type precipitates form in the austenite matrix. Ausaging increases M_s to 255 K by increasing the tetragonality of the martensite and thereby increasing the mobility of the γ/α' interface.

Systems With ϵ (hcp) Martensite

Fe-Mn-Si. Fe-Mn-Si with 28-33Fe and 4-6Si (wt. %) exhibits nearly complete shape memory (Ref 43). Mn and Si reduce the stacking fault energy of the austenite and raise its yield stress. Mn reduces M_s but increases the energy of antiferromagnetic ordering and hence increases the temperature below which the material is antiferromagnetically ordered, the Néel temperature T_N. If antiferromagnetic ordering becomes energetically favorable to martensite formation, that is if T_N is greater than M_s, the martensitic transformation is suppressed. Si reduces T_N. Thus the right balance of Mn and Si concentrations is required. In the appropriate composition range, M_s = 320 K, A_s = 390 K, A_f = 450 K, and although at room temperature martensite does not form spontaneously, austenite is metastable. Stress-induced ϵ martensite is easily formed and reverts wholly elastically. Since this martensite is not thermoelastic, thermal hysteresis is relatively large (i.e., there is no large elastic energy shift downward of A_s relative to M_s to compensate for the normal austenite/martensite thermal hysteresis due to nucleation interface energy). Otsuka el al. (Ref 43) report that thermomechanical treatment greatly improves shape memory. The sample is slightly deformed (2 or 3 percent) and annealed at 873 K. Over a half dozen training cycles the degree of restoration improves from an initial 60 percent to 98 percent or so. Thermomechanical treatment suppresses slip deformation by introducing dislocations that increase the strength of the austenite matrix. Stacking faults are created in the austenite. These act as nucleation sites for ϵ martensite plates of particular orientation and allow the generation of martensite at lower stress.

Fe-Cr-Ni-Mn-Si-Co. In the composition range 7-15Cr, < 10Ni, < 15Mn, 7Si, < 15Co the alloy shows complete shape memory when the strain does not exceed 4 percent (Ref 47). M_s is in the convenient range, between 173 and 323 K. Polycrystalline samples have good corrosion resistance, comparable to that of stainless steel. A proposed application is for pipe joints.

Research on Thermoplastic Resins

This article has been concerned with metals. Other materials, polymers and ceramics, also show shape memory. Shape memory resins (Ref 48) usually consist of two components, a stationary, structural component such as polystyrene, which prevents the flow of resin and fixes the shape, and a reversible component such as polybutadiene, which melts and solidifies at a lower temperature than the structural component. In fabricating a shape memory unit the two components are melted at high temperature and solidified in the shape to be remembered. Memory is improved by a series of cooling and heating cycles in which the higher temperature is sufficient to melt only the resin component. The element can then be deformed by applied stress at this higher temperature. In this deformation the structural component is deformed elastically. Upon cooling to room temperature the structural component is held in the deformed shape by the solidified resin and the load can then be removed. But when the unit is heated to the intermediate temperature at which the reversible resin softens, the unit returns to its remembered shape.

Under stress deformation these thermoplastic elastomers respond as resins at a lower temperature, exhibiting large residual strain, but as elastomers (rubber) at temperatures high enough to melt the resin. Four Japanese companies, Asahi Chemical Industries, Kuraray, Mitsubishi Heavy Industries, and Nippon Zeon market shape memory resins. The resins can be fabricated to perform at various temperatures, depending upon need.

Research on Antiferroelectrics

$BaTiO_3$ is a ferroelectric with perovskite structure. It undergoes a large displacive transition spontaneously at its Curie temperature, and electric polarization can also be induced by an electric field. There are electrostrictive terms in the free energy coupling electric polarization components to the strains. A ferroelectric can undergo spontaneous strain in the ferroelectric/paraelectric transition and can remember a distortion induced by an electric field in the polarized state. In the Landau free energy expansion for antiferroelectrics (Ref 49) there are terms both in the (stress- or electric-field-induced) net electric dipole moment and in the antiferroelectric order parameter, the difference between sublattice polarizations. Both order parameters couple to the strains, but with different coefficients. Since the antiferroelectric coupling coefficients can be large, some antiferroelectric materials such as lead zirconium titanate (PZT) produce larger distortions and larger shape memory and superelasticity than do ferroelectrics. In a shape memory ceramic the high temperature phase is the paraelectric phase above the Curie (Néel) point. PZT is cooled through the ordering temperature into the antiferroelectric phase. The polarizations and strains cancel. An electric field is applied, inducing a ferroelectric moment and a lattice distortion that remain when the electric field is turned off. The displacement and polarization can be turned off either by application of an oppositely directed electric field at a temperature below the transition or by heating above the critical point.

Research on Other Ceramics

Mica Glass Ceramics. In 1977, Ashbee et al. discovered shape memory and superelasticity in a mica glass ceramic (Ref 50). At best the effect is only one-fourth as large as in the best shape memory metals; under compression mica glass strains are fully recoverable up to 2 percent distortion and under torsion up to 0.5 percent distortion (Ref 51). The material deforms irreversibly under tension (Ref 51). The advantage of the mica glasses is in high temperature applications. The mica glasses recover shape at reheating temperatures up to 1,000 K. A consensus is not yet complete as to the mechanism, but the evidence is strong that in a qualitative sense the situation is like that in the polymers; mica glass is a two-component system, with the suspended and interlocked mica granules performing as the structural "memory" spine and the glass serving as the accommodating resin. By using different glass matrices Miwa et al. (Ref 52) show that shape memory recovery is maximum at the glass transition temperature.

Sintered Ceramics. The most recent research of Miwa et al. (Ref 53) is quite remarkable and seemingly in contradiction to the "two-component" hypothesis. Sintered single-component ceramics display shape memory! The effect is small--a factor of 10 less than in the mica glasses--but reproducible. Si_3N_4, SiC, Al_2O_3, ZrO_2, and no doubt many other sintered ceramics not yet explored all show shape memory. The material must be sintered or perhaps in some form of compressed powder. Single crystals and large crystallites do not behave in this way. The Miwa group conjectures that the material in the grain boundaries acts as the "resin binder" and has a lower softening temperature than the crystallites.

CONCLUDING REMARKS

Shape memory alloys have been with us now for almost 40 years, thermoplastic resins for 25, and ceramics for almost as long. Despite initial high expectations inspired by their novelty, up to now shape memory materials have been like Pirandello's "Six Actors in Search of an Author"--materials looking for uses. It has been a long evolutionary process of improvement of material performance and reliability and reduction of cost, on the one hand, and of imaginative search for applications on the other. On both hands the Japanese have been patient and preeminent. Shape memory metal alloys are now finding markets as positioners, in robotics, in orthodontics, and in medicine (for example, as prostheses). Thermoplastics are sold for surgical implant use and for manufacturing novelty toys, particularly by Nippon Zeon. Mitsubishi Heavy Industries is manufacturing small engines with thermoplastic resin automatic chokes. Changes in the engine temperature cause the thermoplastic polymer to change shape and adjust the air/fuel ratio. The market will grow.

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INTERNATIONAL WORKSHOP ON INTELLIGENT MATERIALS

Craig A. Rogers, Edward S. Chen, and Arthur F. Findeis

The Science and Technology Agency of Japan has initiated a program to investigate the feasibility and utility of a new class of materials called intelligent materials. A committee was formed several years ago to evaluate and report on the need and opportunities for "materials that can manifest their own functions intelligently depending on environmental changes." To refine the concept and stimulate research in this area, the Society for Non-Traditional Technologies, along with other professional organizations of Japan, hosted the first International Workshop on Intelligent Materials. The workshop consisted of invited presentations from five countries and covered areas of science and technology from biomimetics, molecular physics, and neural networks to control of large flexible structures. This summary will focus on the concepts and definitions used to define and characterize the activities associated with intelligent materials. A brief summary of selected technical presentations is included to illustrate the diversity of this concept. An attempt has been made to compare the concepts and research approaches of the Japanese and U.S. researchers.

INTRODUCTION

"Smart," "intelligent," "sense-able," and "adaptive" have all been used to describe and/or classify materials and structures that contain their own sensors, actuators, and computational/control capabilities. The definition of intelligent materials, at this workshop, may be materials that possess adaptive capabilities with inherent response to external stimuli such as load or environment. The intelligence of the material could perhaps be "programmed" by material composition, processing, defect of microstructure, or conditioning to adapt in a controlled manner to stimulus. Intelligent structures may have dedicated or integrated actuators, sensors, and "intelligence." Whatever the definition, the development and subsequent production of this class of materials could impact on several diverse technological fields (i.e., materials science, vibration and control, ocean and aerospace structures, biotechnology) and may stimulate development of new devices.

At this workshop, the focus was on the current state-of-the-art and research activities that can be applied to advance the field of smart materials. The primary objectives of the workshop were to: (1) review and identify smart materials that contain the capability to adapt to external or internal conditions such as strain, temperature, chemical composition, etc.; (2) review and evaluate computational issues related to incorporating "software systems into materials"; and (3) review applications of concepts such as stiffness as a function of temperature and time. A list of invited presenters is given in the Appendix.

JAPAN'S CONCEPT OF INTELLIGENT MATERIALS

Harumitsu Yoshimura of the Science and Technology Agency (STA) welcomed the participants and gave a brief introduction to Japan's interest in intelligent materials. A few years ago STA began investigating the feasibility of developing "materials that can manifest their own functions intelligently depending on environmental changes." Since then the concept of intelligent materials has been extensively studied by STA and the Council for Aeronautics, Electronics and Other Advanced Technologies (CAEAT); the results of these studies were presented by Toshinori Takagi, chairman of the workshop. Yoshimura acknowledges that the concept is still not clear.

Takagi's paper is an interim report detailing the discussion and conclusions of CAEAT on the motivation and concepts for intelligent material activities in Japan. The motivation seems to have come from an assessment of the history of materials science and of the future in areas where the Japanese have developed great strength. "The history of materials science shows that there is a distinct trend in development from structural materials to functional materials." For the future, activities will be directed toward the creation of "hyper-functional materials which surpass even biological materials in some respects." The focus within the Japanese scientific community appears to be on materials development while the focus in the United States has been on purpose, function, and application. The difference between these two approaches is that the U.S. scientific community is looking at nature for ideas on how to perform various functions, whereas the Japanese scientific community is looking for ideas on new synthetic materials that can perform the same adaptive functions as biological materials.

The CAEAT "concept" of intelligent materials was explained by classifying the "intelligence" of materials into three categories:

- Primitive Functions--essentially adaptive functions related to sensor, effector, and processor capabilities.

- Macroscopic Functions--this level contains the intelligence inherent in materials.

- Social Utility--considers the intelligence of materials from the viewpoint of human beings and refers to material "properties" that are to be classified as "friendly," "rational or irrational," and are "harmonious."

These three categories have a hierarchy of intelligence and, presumably, utility. The primitive functions are the foundation on which the macroscopic functions are realized by a step called *incorporation of software systems into materials*. However, "even if the macroscopic functions category fulfills its function successfully ... these functions may not appear to be intelligent from the viewpoint of human beings." In order to instill intelligence in a material, a step called *manifestation of intelligence* is employed to impart functions such as reliability, rationality, and judgment.

The intelligence at the most primitive levels in materials consists of three functions: sensor, effector or actuator, and processor functions including the memory function. This is essentially the same definition that has been widely accepted in the United States for several years to describe the area of smart or *intelligent materials.* Even with this definition, the concept is not entirely clear. Takagi stated that intelligent materials may be feasible "if the materials can have some built-in intelligence such as self-diagnosis, self-learning, prediction/notification, ability to stand by, stimulus-reactiveness, and the ability to recognize/discriminate." His examples included:

- Materials whose surface color or luster varies according to the applied load.
- Materials whose appearance varies according to the internal degree of damage.
- Materials whose mechanical and/or electrical properties vary according to their surroundings.
- Materials whose mechanical and/or electrical properties vary according to the applied load.
- Materials whose chemical composition varies according to its surroundings and/or operating conditions, thus being able to decompose by itself or to restore the degraded properties.

This description of materials is that of sensor materials, which is but one of the primitive functions that act as the foundation of the concept. The concept paper even assessed the utility and feasibility of biomaterials with self-adjustable functions. Examples of such materials are:

- Biomaterials that have a self-adjustability function to promote bone growth in the human body.
- Biomaterials that have a self-adjustability function to substitute human skin, liver, kidney, pancreas, etc.
- Drug delivery systems.

This concept does not mention any structural concepts or even "composite" systems but relies totally on the materials science of essentially monolithic materials to provide intelligent functions.

WORKSHOP CONCEPTS ON INTELLIGENT MATERIALS

The focus of the committee's concept--that individual materials may contain all of the primitive functions and in some way integrate the *abstract social utility* functions as well--was not necessarily a view shared by all those present.

Kiyoshi Takahashi suggested that intelligent materials may be defined as materials that possess characteristics close to or exceeding those found in biomaterials. He also suggested a hierarchy of materials beginning with structural materials, then progressing to functional materials, followed by intelligent materials and, finally, resulting in "fuzzy" materials. The concept of intelligent materials involved expanding on the utility offered by functional materials by incorporating additional capabilities such as stimulus/response functions, self-restoration functions, and self-diagnostic and time-dependent functions.

Isao Nakatani stated: "Materials possessed of 'intelligence' are such materials that can make the suitable responses by processing the various types of signals, environmental conditions and its objectives." Such materials have a characteristic autonomy, flexible versatility, and high adaptability to mankind and nature. Even though the interim report of STA focused on essentially monolithic materials, Nakatani suggested that innovative development of materials toward the intelligence might not be attained by uniform phase or single constituent but can only be realized for complex multicomposite structures.

Three scientists, one each from the United Kingdom, United States, and Japan, discussed the concept of using biomimetic routes to design intelligent materials and structures. Hideo Okamoto explained that clues to the development of new composite structures can be obtained through investigations of structure in biological systems. Biological systems are assumed to have structures with optimum design (e.g., the principle of minimum-material/maximum-strength), adapting to their environment as a result of natural selection. Moreover, biological systems maintain their shapes by growing continuously, self-diagnosing, self-repairing, and reproducing depending on their surroundings. In this sense, those biological elements can be identified as intrinsic intelligent materials.

Julian Vincent described intelligent materials as being materials that can feel the equivalent of pain (i.e., overloading) and that can be used to make a self-designing structure. Using the same sort of feedback concepts as are found in biological materials (e.g., cellulose and collagen form piezoelectric fibers, though probably transduced in a different manner), such materials could adapt and respond to their environment and, if the feedback loop was closed with a computer, resist and respond to fatigue, overloading, etc., essentially making structures self-protecting.

Paul Calvert discussed the difference between nature's approach to structural materials and the classical engineering approach. He stated that biology has displayed little versatility in the chemistry of structural materials but shows great subtlety in processing to obtain different properties. Man-made materials have tended to follow the opposite track.

S. Tripathy described intelligent material as a material with enough information content to define its own organization and behavior and that can further draw upon this organization the ability to perform and improve such intelligent functions as recognition. This particular definition is very limited and essentially includes only one of the important elements (primitive functions) of intelligent materials, the sensors.

A number of presentations at the workshop described research activities in the biomaterials area. Typically, supramolecules, bacterial flagella, and liposomes were discussed along with a rationale for calling them "examples of intelligent materials." Adopting the name "intelligent" puts a premium on biological models and the desire to duplicate biomaterials on a molecular or cellular level.

In order to keep these ideas in the proper context, it is important to note the researchers invited to present their work at the workshop had not heard of the term "intelligent materials" before being invited.

There have been two meetings on the concepts of intelligent materials and structures within the past 9 months: the Army Research Office (ARO) workshop in September 1988 and this workshop. Future workshops (i.e., ARO Workshop on Smart Materials to be held tentatively in January 1990) may reach a consensus but this is an optimistic view.

TECHNICAL PRESENTATIONS

The workshop consisted of 34 technical presentations over 3 days. The Plenary Lecture was given by Toshinori Takagi in which he explained the concept of intelligent materials in Japan. The Keynote Lecture was given by Leon Cooper, the 1972 Nobel Prize Laureate from Brown University. Cooper gave a brief overview of the current state-of-the-art and the potential of the next generation of neural networks. Neural network systems, working with current computers, may represent the next generation of computer architecture. Neural network systems are touted to be a natural extension of the intelligent system concept in that there is an implied condition that the material systems can have the ability to learn.

Kiyoshi Takahashi presented a philosophical view of intelligent materials. His paper described a hierarchy of materials and compared the utility and features of biomaterials to synthetic materials. He concluded that in an attempt to demonstrate intelligent materials, researchers have borrowed directly from biomaterials to produce biosensors and make biochips that can serve as computer elements.

Isao Nakatani described the need to study the evolution of organisms in order to gain insight on possible materials science approaches to developing intelligent materials. The evolution of organisms is a process that results in acquired complex structures through the adaptation and competition between genotypes. This yields a complex microstructure that is highly efficient and versatile. Examples of using this concept typically require the chemical synthesis of microstructure to produce exotic or functional materials. Nakatani presented results and descriptions of the microstructure synthesis of heat-resistant materials, fine particles of ferromagnetic substances, and other unique microcomposite materials.

Paul Calvert gave a description of a number of biological materials, magnetic bacteria, sponge spicules, mollusk shell, bone, macadamia shells, and others. In each of his examples and descriptions, the fundamental principles of material and structural design and processing were explained. One of the many functions of biomimetics in the field of intelligent materials as explained by Calvert is to duplicate the natural systems that provide the necessary function or quality of the material.

One of the "themes" of the workshop was the role of biomaterials. S. Tsuyoshi Ohnishi described the essential features of "live" intelligent materials through a review of the functions and repair mechanisms of living cells. However, the cell as a single entity does not fall into the category of materials defined by the U.S. or Japanese concepts.

T. Yamane discussed intelligence in terms of sensory and motor adaptations of microorganisms, such as chemotactic responses (in which cell movement is oriented toward or away from a specific chemical), chemotaxis (movement towards higher concentrations of nutrients), phototaxis (movement towards or orientation with respect to a light source), and others. Yamane also described other "active systems" such as echolocation and vision to illustrate the complex systems and "composite" of receptors, messengers, and actuators that make up these intelligent systems.

A. Kokubu and T. Furuya described a system referred to as the *microBRAIN*, a connectionist system capable of symbolic and subsymbolic processing. Akio Kawana provided an interesting contrast to the previous paper by presenting results of his work investigating the function of the brain. His approach is to culture neural cells from the brain and form synaptic connections and neural networks in vitro. These networks are then used to investigate cell and network functions. Kawana showed systematic ordered arrangements of neural cells and networks with which the activity of individual cells can be investigated.

Craig Rogers described different scales of embodiments of the intelligent materials and structures concepts ranging from shape memory alloy reinforced composites to large variable geometry space trusses. The focus of the paper was that intelligent systems must contain sensor, actuator, and control functions. Demonstrations of such systems were presented including active structural acoustic control for large flexible space structures and geometric shape management of large structures.

The paper by Hideo Okamoto demonstrated the utility of design based on biomimetic routes. Examples of biological composites such as bamboo and shells with high performance were presented to illustrate the "growing-reforming" mechanism of biological systems to achieving optimum adaptable structures.

Julian F.V. Vincent described work associated with the toughness and fracture strength of biological materials and what we can learn from them. Vincent focused on the ability of biological structures to recognize various types of loading and accommodate to it--resulting in what he called "self-designing structures." He hypothesized that, using the sort of feedback concepts as found in biological materials, synthetic materials could adapt and respond to their environment and, if the feedback loop were closed with a computer, learn to resist fatigue, overloading, etc., essentially making structures self-protecting. This might also allow the advantages of more complex materials such as soft tissues to be used since they could accommodate high strains. The widespread use of such materials in nature suggests their advantages in terms of structural efficiency.

One of the most promising processing ways to order the molecular structure of polymeric films is the Langmuir-Blodgett (LB) method. An example of a class of ordered electroactive material with "novel functional behavior" was presented by S. Tripathy. The material was a multilayer structure of 3-hexadecyl pyrrole and ferrocene-derivatized pyrrole surfactant system. The 3HDP/pyrrole mixed system was shown to form large area thin films in a structural organization that was substantially different from the bulk polymerized films. These systems are able to self-assemble into a complex structure and could provide a means for chemical and biochemical sensing.

Seizo Miyata presented a paper on the design of molecular assemblies based on the LB trough technique. Miyata described their modifications of the LB trough using moving sidewalls and zone-heating to control flow stress and enhance in-plane orientation and multilayer structuring. The authors have obtained well-ordered structures of cadmium stearate consisting of three, five, and seven layers through a single transfer operation. The zone-heating approach is a novel development in LB technology. Its advantage lies in the potential to eliminate defect propagation associated with the conventional layer-by-layer assembly.

Gerhard Wegner discussed current research directed towards realizing polymeric molecules (or self-assembled structures) that can be designed to conduct electricity and whether these can be laid down similar to a network of wires forming "intelligent connections" useful for information storage and processing on other functional materials. Wegner presented many concepts for LB assemblies that may yield novel material characteristics and functions. Applications of CHEMFETs, silicon-based chemical sensors that can be combined with conducting-polymer "conducting wires" as signal processing circuitry on the same chip were discussed.

There were several papers addressing activity in the area of biomaterials and bioelectronics. Hiroyuki Sasabe presented work highlighting bioelectronic devices with photoactive and electroactive proteins. Kuniaki Nagayama presented a paper on protein crystals as self-organizing systems. He described experiments to make two-dimensional crystals of various proteins. J.V. Bannister described his effort in using DNA electrochemistry to study "structural defects induced by various agents such as ionizing and ultraviolet radiation" and understanding genetic mechanisms, particularly gene switching on and off mutations. Hiroshi Miyamoto showed a film on transformations in bacterial flagella and liposomes and proposed that such studies will provide a basis for the development of intelligent materials.

Melvin Pomerantz provided a summary of the state of molecular electronics. Processing techniques such as the LB, self-assembly, and thermal evaporation methods were described in the preparation of molecular scale objects. He also described current work using a scanning transmission microscope as a molecular scale electrode to observe the electrical properties on a molecular level. Masuo Aizawa described his activities associated with electronic modulation of biomaterial functions and presented concepts for molecular information transduction in biological receptor systems. Aizawa showed that enzyme oxidation state in a conducting polymer (polypyrrole)/ enzyme (glucose oxidase) molecular assembly can be controlled reversibly by potential-modulation.

A.J. Freeman reviewed the current state-of-the-art in computational hardware and methods, highlighting some of the advances in materials science and computational capabilities. Freeman discussed high T_c superconducting materials; the design of new intermetallic compounds; surfaces, interfaces, and superlattices; and chemisorption and catalysis.

Shin-ichi Shirasaki discussed new concepts of controlling electronic and ionic processes with high-dimensionality microstructures of inorganic materials. C. Weisbuch described four devices and the science behind their existence: (1) an electromechanical switch, (2) a FET transistor, (3) an electro-optic device with waveguide, and (4) an integrated optical-optical switch. These devices were made with multilayer construction with some layer thicknesses controlled down to the single atomic layer precision resulting in new physical phenomena.

The last session of the workshop was devoted to applications. The first paper, which was presented by Sung Wan Kim, was based on a drug delivery system design concept first introduced by Brownlee and Cerami in which a maltose insulin conjugate would bind to Con A and be released by the competitive binding of glucose to the same molecule. In Kim's approach, the glycosylated insulin-Con A complex is enclosed in a polymer membrane permeable to both glycosylated insulin and glucose. Glucose diffuses through the membrane. Once inside the device the glucose competes with glycosylated insulin from the Con A; the glycosylated insulin is then free to diffuse out of the device. Thus, insulin release in response to glucose concentration is obtained. This paper was one of the few presentations that described a system as having sensing and actuation capabilities and the potential of becoming postimplant programmable.

Danilo De Rossi uses a biomimetic route to the design of artificial tactile sensors. His approach is to closely parallel the human anthropomorphic sensor, which is composed of two subsystems. The first is the "pseudoepidermal layer," which requires the equivalent of a stress tensor sensor. The second subsystem is the "pseudodermal pad," which is a rheological skin-analogy. The stress tensor sensor is accomplished by means of piezoelectric polymer elements sensing space and time with six independent components of the stress tensor field generated within the sensor by the object contact in spatially discrete volumes. The "skin" of the tactile sensor is made of a water-swollen polyelectrolyte gel that possesses a biphasic rheological behavior that mimics human skin. The gel has electromechanochemical transduction properties that can be exploited to locally sense strain rate and dilatation (the trace of the strain tensor) originated in the gel by the contact process. De Rossi also discussed other refinements including sensory fusion such as thermotactile interactions.

Hiroyuki Fujita reported on integrated micro motion systems. Fujita stated that while sensors and logic circuits on silicon is a mature field, the study of micro actuators on silicon has just started. He reviewed several actuation concepts and devices such as electrostatic drive, micro motors and servosystems, superconducting actuators, and artificial muscles.

Paul Hagenmuller gave an overview of selected sensing and actuation materials. In particular, he reviewed thermochromic devices, material systems, nonlinear dielectric materials, piezoelectric bimorphs, and electro-optical ferroelectrical materials.

K. Watanabe presented results from a study of the restoration effects of SMAs in a neutron irradiation environment. Use of SMAs within nuclear irradiation environments has been of considerable interest to Japanese researchers for several years. Watanabe's paper describes the effect of irradiation on the electrical resistivity, shape recovery, and recovery stress of nickel-titanium alloys. Results of this study have helped support a program called Quick-Replacement-Technology (QRT), which uses

SMAs as driving elements to replace damaged components within the fusion reactors. Neutron irradiated SMAs showed characteristics that compromise the negative temperature dependence of electrical resistivity, the elastic deformation behavior within a recoverable strain of 5 percent, the highly strained condition of a parent phase, and the restoration effect at temperatures above 523 K.

Nonlinear optical materials provide many new concepts for intelligent material systems. Yasushi Mori discussed a number of different classes of material under investigation including ferroelectrics, inorganic semiconductors, organic conjugated polymers, and molecular crystals. Mori focused almost exclusively on the conjugated polymers and, in particular, polyarylene vinylenes (PPV). Results show that PPV is not only a relatively easy material to form but also produces exceptional third-order nonlinear optical properties as well.

The last three papers of the workshop addressed issues related to various polymer gels. Y. Osada described a gel based on an ionic polymer that can convert chemical energy directly into mechanical work. This concept was demonstrated in several devices including a mechanical muscle that is the simplest application of electroshrinkable gels. The ionic gels were also used in a chemical valve membrane that reversibly expands and contracts pore size by electric stimulus. Using a similar concept, the gel was also used in a slow-release control system for drug delivery.

Aizo Yamauchi presented the results of his work on heat-sensitive gels that have been applied to the separation of liquids from solids-liquids mixtures and the development of chemical valve devices and actuators. Such gels are expected to evolve into thermo-memory materials.

Lastly, Makoto Suzuki described an investigation of the mechanical energy efficiency of new polymer hydrogels for use as a mechanical actuator. In his study new ways were examined for the synthesis and control of the hydrogel. Hydrogels have potential for mechanical actuation; however, before they will be adopted, situations in which large strains are acceptable (as in human muscle fibers) will have to be investigated.

The workshop concluded with a panel session in which many selected panel members restated their definitions of intelligent materials or expressed reservations about ever producing so-called intelligent material. There were two points of interest from the panel discussion. The first is that individual materials will never be intelligent, but material systems (composites) are well within the range of possibilities, and the second is that better communication routes be established.

SUMMARY

The first International Workshop on Intelligent Materials consisted of a diverse group of scientists who attempted to relate their research activities to the proposed field of "intelligent materials."

While Japan has made a significant commitment to the research and development of materials, systems, and component technologies, the individual Japanese scientist, for the most part, did not have a firm understanding of intelligent materials prior to the workshop. Thus one of the objectives of this workshop was to educate the researchers on the concept of intelligent materials and the critical needs related to materials science.

The Japanese approach is a materials science approach, searching for materials that can support functions essential to the intelligent concept. Their activity in sensor materials, actuators, biological materials, and neural networks is dynamic but a bit unfocused. Some of this may result from the relative newness of the concept in Japan and elsewhere and because of the philosophy and abstract functions that the Japanese have tried to integrate into their concept. The U.S. activity is directed more toward larger activities that include composite materials and structural systems. The advantage of the U.S. approach is that we can begin to investigate the new paradigms needed to integrate the "primitive" functions that are a part of the concept. However, many researchers in the field will voice their concern over the lack of material development in areas of sensors and actuators. The implementation of intelligent or adaptive systems has centered on relatively old technology that has never been optimized for use with these new concepts.

The motivation to exploit intelligent materials, in common with many new initiatives in Japan, is government driven. At this point in time the Japanese do not have any significant advantage. They have defined a new area for themselves and seem ready to make a large commitment developing it. The United States is slow to organize intelligent materials and structures research in a formal manner. U.S. researchers have been working on design philosophy and interdisciplinary paradigms for several years and are able to react quickly to new advances in distributed sensing, actuation, and parallel processing. To date, no one has taken the leadership in commercializing smart materials; however, several defense and material/chemical companies have begun in-house research programs. The ARO University Research Initiative program focus on smart materials and structures has generated interest by university researchers in this emerging field. ARO will support a second workshop in this area in January 1990.

Craig A. Rogers, Assistant Professor of Mechanical Engineering and Director of the Smart Materials and Structures Laboratory, received his B.S. degree in mechanical engineering from New Jersey Institute of Technology in 1981 and his M.S. degree in mechanical engineering and Ph.D. from Virginia Polytechnic Institute and State University (VPI&SU) in 1982 and 1987, respectively. Dr. Rogers has been on the Mechanical Engineering faculty at VPI&SU since 1983. He worked for 3 years at Bell Telephone Laboratories in Holmdel, NJ, prior to joining the faculty at VPI&SU. Dr. Rogers' primary research interests are in the areas of intelligent material systems and structures, design of composite structures, structural dynamics and active control of adaptive composite structures, and tribology. He developed the composite material system containing shape memory alloy (SMA) "fibers" that are used as distributed actuators for motion, vibration, acoustic, and damage control and has published several technical papers on modeling, applications, and implementation of this material system. He was awarded a 1988 Office of Naval Research Young Investigator Award for research related to his development of the novel SMA composite. He is a member of numerous professional and honor societies and keeps active in organizing national technical sessions related to recent developments and trends in the area of intelligent material systems and structures. Dr. Rogers is the author of over 30 technical papers and journal articles and is presently the founding Editor-in-Chief of the Journal of Intelligent Material Systems and Structures.

Edward S. Chen, Associate Director of the Office of Naval Research, Air Force Office of Scientific Research, and Army Research Office (ARO), Far East Liaison Office in Tokyo since December 1986, has been a program manager in the Materials Science Division at ARO in North Carolina since April 1986. He attended Rensselaer Polytechnic Institute where he received a B.S. degree in chemical engineering in 1959 and a Ph.D. degree in physical chemistry in 1964. From 1964 to 1986 Dr. Chen worked at Benet Weapons Laboratory in New York, initially as a group leader studying dispersion-strengthened materials, as Chief of Electrochemical Processing in 1973, and as Chief of the Physical Sciences Section in 1983. Dr. Chen is a member of the Electrochemical Society and ASM. His research interests currently include the relationship between processing parameters and mechanical properties of ceramic and composite materials and electrochemical processing in the electronics industry.

Arthur F. Findeis is the director of the Office of Naval Research Far East. From 1967 to 1988 he was with the Division of Chemistry, National Science Foundation, where he was head, Office of Special Projects, and involved with the interface between chemistry and other disciplines. This activity involved managing the Chemistry of Materials and Chemistry of Life Processes initiatives. He received his B.S. degree in chemistry from Capital University in 1952, an M.S. degree from Purdue University in 1955, and a Ph.D. degree in chemistry in 1957. During the period 1970-72 he was a staff associate with the NSF-Tokyo office. From 1984-85 he was Fellow of Churchill College at the University of Cambridge where he worked in the University Chemistry Laboratory on fast atom bombardment mass spectrometry. He is a member of the American Chemical Society and the American Association for the Advancement of Science.

Appendix

LIST OF INVITED PRESENTERS

- Opening Remarks, Harumitsu Yoshimura, Director-General, Research and Development Bureau, Science and Technology Agency, Japan

- Plenary Lecture - "A Concept of Intelligent Materials in Japan," Toshinori Takagi, Chairman, Materials Technology Committee, Council for Aeronautics, Electronics and Other Advanced Technologies, Japan

- Keynote Lecture - "Neural Networks in Real World Applications: Intelligent Systems for the Next Century," Leon Cooper, '72 Nobel Prize Laureate in Physics, Brown University, U.S.A.

- "Electronic Materials for the Future--Intelligent Materials," Kiyoshi Takahashi, Tokyo Institute of Technology, Japan

- "Trend Toward Intelligence in the Research and Development of Metallic Materials," Isao Nakatani, National Research Institute for Metals, Japan

- "Bio-Mimetic Processing of Ceramics and Composites," Paul Calvert, University of Arizona, U.S.A.

- "Biochemistry, Pathology, Pharmacology of Intelligent Materials," S. Tsuyoshi Ohnishi, Membrane Research Institute, U.S.A.

- "Design of Molecular Assemblies to Attain Intelligent Materials," Seizo Miyata, Tokyo University of Agriculture and Technology, Japan

- "Intelligent Materials in Nature," Tetsuo Yamane, AT&T Bell Laboratories, U.S.A.

- "A Structured Neural Network for Connectionist Intelligent Systems," Akio Kokubu, Electrotechnical Laboratory, Japan

- "Artificial Extracellular Matrices for Guiding Growth Direction of Nerve Fibers in Cell Culture," Akio Kawana, NTT Basic Research Laboratories, Japan

- "Dynamic and Structural Control Utilizing Smart Materials and Structures," Craig Rogers, Virginia Polytechnic Institute & State University, U.S.A.

- "Structural Design Biomimetic Composites," Hideo Okamoto, Sumitomo Chemical Co., Ltd., Japan

- "Toughness in Biological Materials," Julian F.V. Vincent, University of Reading, England
- "Cognition and Order in Langmuir-Blodgett Films of a 3-Hexadecyl Pyrrole and Ferrocene-Derivatized Pyrrole Mixed Monolayer System," Sukant Tripathy, University of Lowell, U.S.A.
- "Toward Intelligent Biomaterials," Yasuhisa Sakurai, Tokyo Women's Medical College, Japan
- "Advanced Design Criteria for Organic and Polymeric Intelligent Materials," Gerhard Wegner, Max-Planck-Institut für Polymerforschung, West Germany
- "Control of 2-Dimensional Array of Protein Molecules for Bioelectronic Application," Hiroyuki Sasabe, Institute for Physical and Chemical Research, Japan
- "Protein Soft Crystals as a Self-Organizing System," Kuniaki Nagayama, Jeol Ltd., Japan
- "DNA Electrochemistry and its Application to the Study of Intelligence," Joseph Bannister, Cranfield Institute of Technology, England
- "Dynamic Biomolecular Assemblies as Intelligent Materials," Hirokazu Hotani, Kyoto University, Japan
- "Molecular Electronics," Melvin Pomerantz, IBM Research Center, U.S.A.
- "Electronic Modulation of Biomaterial Functions," Masuo Aizawa, Tokyo Institute of Technology, Japan
- "Materials Design by Supercomputer: Physics and Chemistry for the Future," Arthur Freeman, Northwestern University, U.S.A.
- "Design of High-Dimensionality Microstructures Supposed for Inorganic Intelligent Materials," Shin-ichi Shirasaki, National Institute for Research in Inorganic Materials, Japan
- "Low-Dimensionality Semiconductor Heterostructures: Man-Designed Electronic Materials with Ultimate Properties," Claude Weisbuch, Thompson-CSF, France
- "A Self Regulated Drug Delivery System-Artificial Pancreas," Sung Wan Kim, University of Utah, U.S.A.
- "Biomimetic Approaches to the Design of Materials for Artificial Tactile Perception," Danilo De Rossi, Universita degli Studi di Pisa, Italy

- "Integrated Micro Motion Systems Using Silicon and Related Materials," Hiroyuki Fujita, Tokyo University, Japan
- "A Selection of Intelligent Materials Used in Practical Applications," Paul Hagenmuller, Laboratorie de Chimie du Solide du CNRS, France
- "Restoration Effects of Shape Memory Alloys in a Neutron Irradiation Environment," Taiji Hoshiya, Osaka University, Japan
- "Nonlinear Optical Properties of Precursor-Route Conjugated Polymers," Yasushi Mori, Cambridge University, England
- "Mechanochemical Devices Using Polymer Gels," Yoshihito Osada, Ibaraki University, Japan
- "Heat-Sensitive and Responsible Polymer Gels," Aizo Yamauchi, Research Institute for Polymers and Textiles, Japan
- "Mechanical Energy Generation by Hydrogel, Approaches to Higher Efficiency and Higher Controllability," Makoto Suzuki, Mechanical Engineering Laboratory, Japan

INDIAN NATIONAL AERONAUTICAL LABORATORY (BANGALORE)

H. Yoshihara

The facilities and research at the National Aeronautical Laboratory (NAL) in Bangalore, India, are described. Research covered includes boundary layer transition, spectral method for the Boltzmann equation and the infinitely strong shock, and modeling of chaos. This research was directed by Professor R. Narasimha. Other research efforts described are experimental results on lee-side separated flow over sharp-nosed delta wings at supersonic speeds and transonic airfoil calculations programmed in a parallel fashion for the 8-CPU minicomputer designed and built at NAL.

INTRODUCTION

Aeronautical research in India is primarily undertaken at five Indian Institutes of Technology (IIT) located at Bombay, Delhi, Kharagpur, Kampur, and Madras; the Indian Institute of Science (IISc) at Bangalore; and at the National Aeronautical Laboratory (NAL), a government laboratory also located in Bangalore. The IITs are engineering universities, while the IISc also covers the sciences. NAL is the dominant aeronautical research organization in India and functions much like the former National Advisory Committee for Aeronautics (predecessor of the National Aeronautical and Space Administration) in the United States, carrying out inhouse basic and applied research and supporting the aerospace development efforts. It covers aerodynamics, materials, propulsion, structures, and systems engineering. Bangalore is also the center of the aeronautical industry where the principal aeronautical company, Hindustan Aeronautics Ltd., is located.

Present advance of the aeronautical sciences and technology in India must be in large part credited to Professor Satish Dhawan, who was the director of the IISc (Bangalore) and chairman of the National Space Commission and the Indian Space Research Organization. He is presently formally retired but is actively serving as a consultant to the Space Commission. He was a student of Professor Hans Liepmann at the California Institute of Technology. It was here that I first met Professor Dhawan. During a recent visit to Bangalore, he recounted his early experiences to establish computational fluid dynamics at the IISc with the only available computer located at a remote distance from Bangalore. He negotiated an interdepartment agreement for his students to use the remote computer and obtained travel and per diem funds to support their stay at the computer site. Professor Roddam Narasimha, present director of NAL, and a former student of Professor Dhawan and Professor Liepmann, is carrying on the efforts of Professor Dhawan. I will describe Dr. Narasimha's accomplishments in the next section.

In the following the National Aeronautical Laboratory is described in terms of its principal test facilities, computing center, and inhouse basic and applied research.

FACILITIES AT THE NATIONAL AERONAUTICAL LABORATORY

Wind Tunnels

The principal wind tunnel facility at NAL is the 1.2- by 1.2-meter trisonic blowdown wind tunnel. Its Mach number range is 0.2 to 4.0 with the corresponding Reynolds number range of 8 to 80 million per meter. It has perforated walls for transonic operation and a flexible nozzle for supersonic operation. The test duration is typically 30 seconds, allowing most aspects of aerodynamic testing. Special features include a captive trajectory rig permitting testing of stores separation and a forced oscillation rig for dynamic stability testing. This facility has been in operation since 1967, and over 12,000 blowdowns have been logged to date. A quarter scale of the above facility is available for fundamental testing.

Another significant facility is the transonic/supersonic cascade tunnel capable of testing turbine and compressor cascades with blade chords of up to 75 mm in the Mach number range of 0.4 to 1.5 and the Reynolds number range of 0.5 to 1.5 million per blade chord.

Computing Center

The main computer at the NAL Computing Centre is a Sperry Univac 1100/60-HI system. The clock cycle time for this computer is 116 ns, and the memory is 2 megawords. There is also an Autotrol AD/380 graphic system based on a Varian V77/600 computer with 256 KB memory. Neither of these systems suffices for present day requirements, but planning is in place to acquire greatly increased capability. Three years ago arrangements were completed for NAL to acquire the NEC SX-2 computer, which is still an outstanding supercomputer, but at the last moment NEC withdrew its offer. NAL is presently seeking a new supercomputer.

PROFESSOR NARASIMHA'S RESEARCH AT NAL

Examples of NAL accomplishments at the forefront of fluid dynamic research are next described. The first is efforts directed by Professor R. Narasimha, director of the National Aeronautical Laboratory. He is an acquaintance of many years, and it was at his invitation that made my recent trip to India possible. Professor Narasimha, despite his highly responsible and time-consuming position, is able to participate actively in the research to be reported. The competent administrative and managerial assistance of Mr. Narasimha Swamy makes this participation easier. The recent research to be described covers boundary layer transition, spectral method to solve the Boltzmann equation, and chaos modeling.

Transitional Flow (Ref 1)

Professor Narasimha is a recognized expert on transition. His accomplishments include the resolution of a long-standing inconsistency between the growth of turbulent spots and the intermittency originally set forth by Professor H. Emmons of Harvard University. (Here intermittency is the percentage of time that the flow is turbulent at a given point in the transition zone.) In the case of a flat plate, Professor Narasimha postulated that the spots can originate only in the near-neighborhood of a given line, the transition line, and not randomly over the transition region as assumed by Professor Emmons. This then essentially removed the inconsistency.

Also well-known is Professor Narasimha's method for transitional flows using an empirical model for the intermittency. This method, however, requires the location of the beginning of the transition region.

During a review lecture at NAL, I described the severe overshoot phenomena experienced in hypersonic transitional flows. Professor Narasimha, during the question period, noted that a similar overshoot occurred in low speed transitional flows. He attributed the cause of the overshoot, not to any mechanism specific to hypersonic flow, but simply to assigning wrongly the origin of the turbulent flow at the leading edge of the surface instead of at the beginning of the transition region. This lowering of the run of the turbulent flow then eliminates the overshoot and explains the observed low-Reynolds number features.

Spectral Method for the Boltzmann Equation and the Infinitely Strong Shock (Ref 2)

Two significant contributions of Reference 2 are as follows. The first is the development of a spectral method to solve the Boltzmann equation for molecular flows that significantly depart from equilibrium. The resulting complex algebra is made more compact using the theory of irreducible tensors with Dirac's "bra" and "ket" notations. In this way extraneous modes are eliminated at the beginning, thereby removing unnecessary clutter in the subsequent algebra. The second is the use of the spectral method to solve the hitherto unsolved problem of the infinitely strong shock. Here the key was to express the hard sphere distribution function as the sum of the "molecular beam" distribution for the supersonic upstream flow and a background distribution as a series of Burnett functions (spherical harmonics). Six terms were employed in the example, yielding a shock thickness of 6.7 "hotside" mean free paths.

A Chaos Model (Ref 3)

The theory of chaos is formally a relatively new discipline. It considers, at its simplest, a system of two first-order nonlinear ordinary differential equations with nonhomogeneous (forcing function) terms. The system of equations will be labeled as the mechanical system. The surprising aspect is that for a certain range of the problem parameters, the initially "smooth" solution erupts into a "turbulence-like" solution. Fluid dynamicists were quick to seek a connection between chaos and turbulence. The mechanical systems proposed prior to Reference 3 lacked two essential ingredients of turbulent flow, namely the cascading of energy from low to high wave numbers and the dependence of the "Reynolds number" for chaos onset on the forcing function. The contribution of Reference 3 was a mechanical system that removed these shortcomings. There still remains a long road ahead to connect mechanical chaos to physical turbulence, one large obstacle being the turbulent spot phenomenon.

Finally, for the reader confused by the jargon used in chaos as strange attractors, fractals, bifurcations, etc., Reference 4 by Professor Narasimha is recommended as an exceptionally lucid and well written paper.

OTHER NAL RESEARCH

Two research accomplishments are described typifying the experimental capabilities at NAL and the computational fluid dynamics efforts being undertaken in preparation for the increased computer power soon to be acquired.

Lee-Side Flows Over Delta Wings at Supersonic Speeds (Ref 5)

A thorough wind tunnel test was completed by Dr. K. Narayan and Dr. S. Seshadri on a series of sharp leading edge delta wings with leading edge sweeps ranging from 45° to 70°, a range of Mach numbers normal to the leading edge of 0.35 to 2.1, and an angle of attack normal to the leading edge of up to 44°. Surface oil flow pictures and pressure distributions were obtained. The tests were carried out in the 0.3- by 0.3-meter trisonic wind tunnel. The primary contribution of these tests was the determination that the morphology (structure) of the lee-side flows was the same for both thin and thick wings contrary to the earlier results. Nine separate classes of lee-side flows were distinguished. Several new flow structures were found in the transition between leading edge attached flow and leading edge separation vortex flow including a nonconical mixed-type flow with shed vortices. Additional diagnostics to determine the off-surface features and a more detailed determination of the nature of the boundary layer would have been useful.

8-CPU Minicomputer (Flosolver Mk1B)

NAL is in the process of acquiring a supercomputer as well as a powerful graphics work station. In preparation for this, graphics software is, for example, being developed on the "mainframe" Univac computer despite the slow turnaround. Similarly, experience in the use of multiple-CPU computers is being acquired by designing and constructing from off-the-shelf components an 8-CPU parallel minicomputer and using it to solve simple fluid dynamics problems, gaining experience in parallel programming.

For example, the Flosolver computer was used to compute the transonic flow over an airfoil using the Gauss/Seidel column relaxation method to solve the transonic small perturbation equation. A partitioning of the flow domain into streamwise blocks was used with each block assigned to a CPU. The blocks were then solved sequentially in the streamwise direction in a pipeline fashion. After the pipe fill-up time, the time for one relaxation was reduced essentially by a factor one over the number of CPUs, that is with a parallelization efficiency of 96 percent. Dr. U. Sinha and Dr. M. Deshpande were responsible for this effort.

CONCLUSIONS

The research at the National Aeronautical Laboratory is guided by an experienced management that is knowledgeable of the ongoing world research. On the experimental side experienced researchers are on hand to carry out sophisticated experiments. On the computational fluid dynamics side, the efforts at NAL are greatly handicapped by the lack of suitably powerful supercomputers. Relevant experience is nevertheless being acquired until suitable facilities are on hand.

In countries lacking a major aerospace industry, there is usually a reluctance on the part of the national government to develop large scale testing and computational facilities. India, however, seems to be an exception.

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3. R. Narasimha and G. Bhat, "A dynamical system that mimics shear flow turbulence," *Current Science* 57 (1988).

4. R. Narasimha, "Order and chaos in fluid flows," *Current Science* 56 (1987).

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Hideo Yoshihara arrived in Tokyo in April 1988 for a 2-year assignment as a liaison scientist for the Office of Naval Research. His assignment is to follow the progress of advanced supercomputers and to review and assess the viscous flow simulation research in the Far East. Dr. Yoshihara formerly was with the Boeing Company, where he was Engineering Manager for Applied Computational Aerodynamics. He was also an affiliate professor in the Department of Aeronautics and Astronautics of the University of Washington, an AIAA Fellow, and a former member of the Fluid Dynamics Panel of AGARD/NATO.

HIGH TEMPERATURE MATERIALS RESEARCH AND DEVELOPMENT IN JAPAN

Fred Pettit and Edward Lenoe

Research and development (R&D) in Japan on metallic alloys, ceramics, and composites for use at high temperatures (~600 °C and above) is described by considering the government programs concerned with such materials and then describing investigations at government institutes, industrial laboratories, and universities. Various R&D programs are briefly described and investigators are identified. Much of the research on high temperature metallic alloys and coatings is based upon developments in the United States, with efforts to establish and expand such technical capabilities in Japan. In the case of ceramics and composites, however, the R&D efforts are more independent. A significant technical base has been established in Japan in the area of high temperature materials. New government programs are placing more emphasis on high temperature materials, and important advances are expected.

INTRODUCTION

High temperature materials is a very broad topic. Metallic alloys, ceramics, and polymers should be considered. Moreover, while the effects of temperature must be the dominating factor, these effects are manifested through physical and chemical properties. It is therefore necessary to decide what properties are to be examined. When materials are used at elevated temperatures, strength, as reflected in tensile strength, stress rupture lives, or fatigue lives, is of prime importance. It is also likely that corrosion processes affect strength; therefore, high temperature corrosion resistance is critical. In this article the strengths and corrosion resistances of materials will be the primary properties examined in assessing high temperature materials in Japan.

Maximum use temperatures for materials are different. What is a high temperature for one material can be a low temperature for another. In Figure 1, tensile strengths for a number of different metallic alloys are shown as a function of temperature. Refractory metals have high strengths at 1,200 °C, but oxidation resistance is poor. Nickel- and cobalt-base superalloys have good strengths up to 1,000 °C with reasonable oxidation resistance. Titanium alloys and some steels can be used to temperatures of about 600 to 700 °C. Aluminum alloys cannot be subjected to high loads at temperatures much above about 200 °C, but fiber-reinforced aluminum has flexural strengths as high as about 300 to 400 MPa at 300 °C. In the present assessment of metallic alloy research in Japan the alloy systems in Figure 1 will be considered.

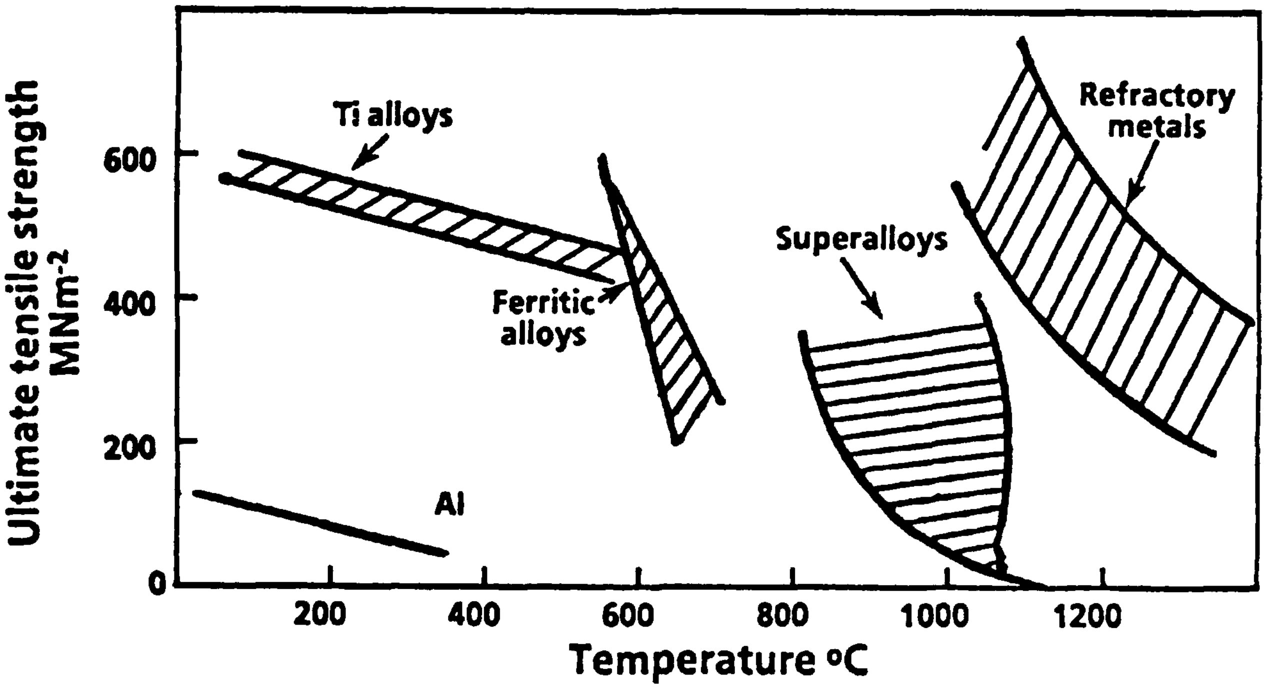

Figure 1. Tensile strengths of a number of alloys as a function of temperature to indicate temperature ranges over which different alloy systems may be used.

As is evident in Figure 2, at temperatures above about 1,200 °C the superalloys do not possess sufficient strengths, and ceramics such as SiC or perhaps Si_3N_4 must be considered. Refractory metals (e.g., niobium-base alloys) and some intermetallic compounds (e.g., NiAl, $MoSi_2$) also merit consideration. The status of research in Japan on SiC and Si_3N_4 as high temperature load bearing materials will be discussed.

Carbon and ceramic fibers can be used to prepare metallic and ceramic composites. While carbon fibers have very attractive strengths at elevated temperatures (Figure 3), they cannot be used in oxidizing environments unless coated with a resistant material. Some ceramic fibers are much more resistant to oxidation, but their mechanical properties are inferior to those of carbon fibers. Fiber research and technology in Japan for high temperature applications will be examined.

Finally, as is evident upon inspection of Figure 4, some polymer composites have strengths that permit their use up to temperatures of 200 to 300 °C. This is especially attractive when one considers densities. It is beyond the scope of this paper to consider polymer composites in depth. Only research in the MITI program on high performance polymers that is directed specifically at improving the high temperature capabilities of polymers and polymer composites will be considered.

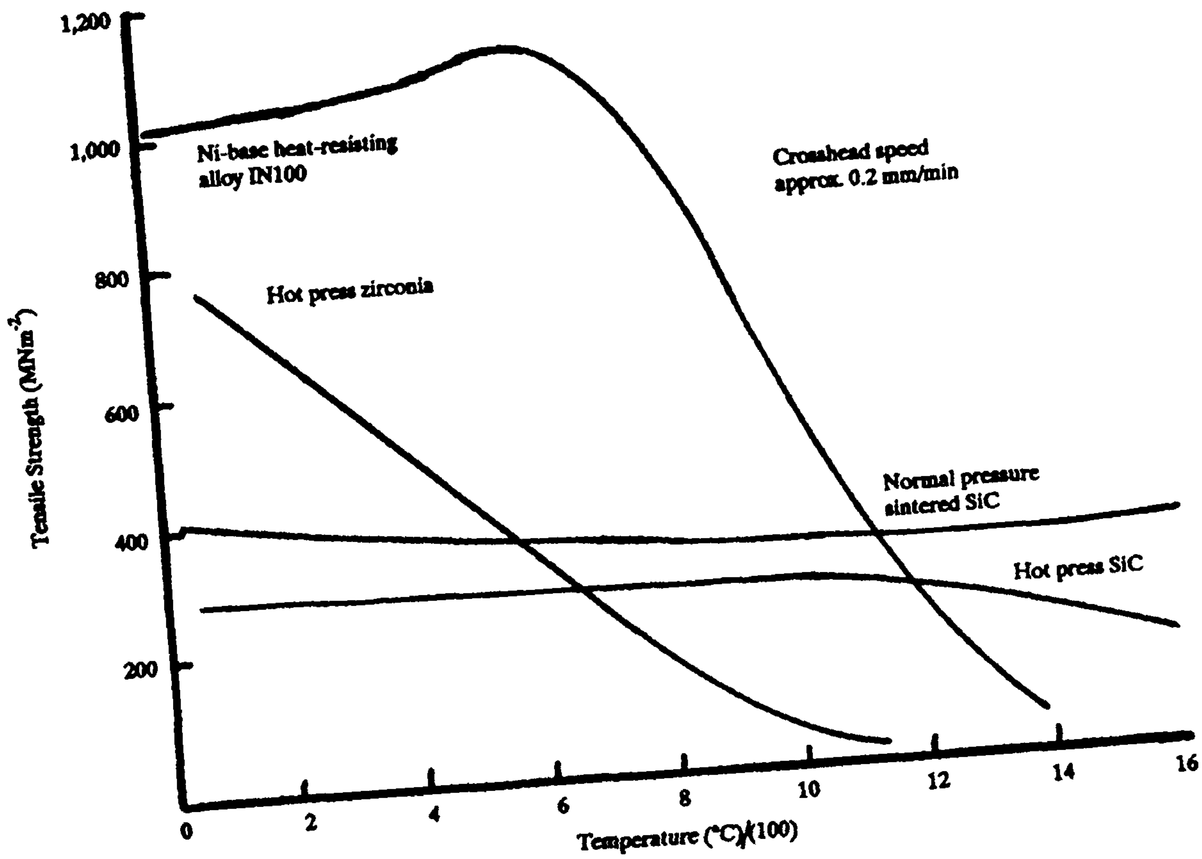

Figure 2. Comparison of tensile strengths as a function of temperature of some ceramics and a typical nickel-base superalloy. This shows that ceramics such as SiC have strengths superior to those of superalloys at temperatures above about 1,100 °C.

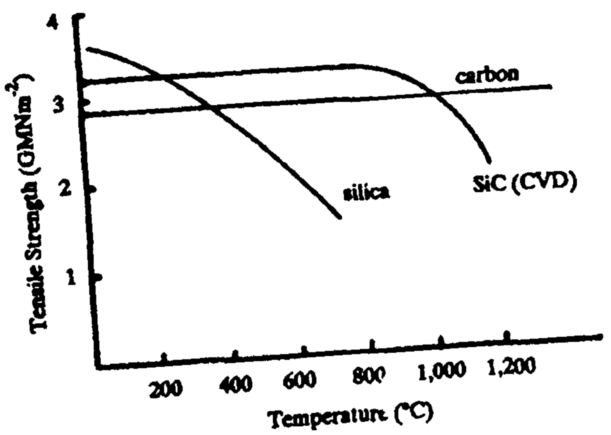

Figure 3. Comparison of tensile strengths of some ceramics and carbon that shows that carbon has good strengths at temperatures well above 1,200 °C.

GOVERNMENT-SUPPORTED PROGRAMS TO DEVELOP IMPROVED HIGH TEMPERATURE MATERIALS

Before discussing specific research programs in Japan on high temperature materials, the funding available for this research will be discussed. About 70 percent of the funding for research and development (R&D) in Japan comes from industry (Ref 1). This industrial-supported research is product oriented. Since the available markets for high temperature materials in Japan are not nearly as extensive as in the United States due to the lack of defense-oriented industries, the government-supported research on high temperature materials may equal or be greater than that of industry. In the following some of the government programs on high temperature materials are briefly described.

The Moonlight Project involves R&D for energy conservation. It is promoted by the Agency of Industrial Science and Technology (AIST) of the Ministry of International Trade and Industry (MITI). Within the Moonlight Project research is being performed on high temperature materials under the Ceramic Gas Turbine and the Advanced Gas Turbine programs.

The Sunshine Project is also under AIST. It is directed at attempting to solve basic energy problems. High temperature materials R&D is being performed in programs concerned with utilization of geothermal energy and gasification and liquefaction of coal.

AIST is supporting a number of programs on high temperature materials under the Project on Basic Technology for Future Industries. This project is the major source of funding for high temperature materials research. In this project parts of the programs on Advanced Alloys with Controlled Crystalline Structures, High Performance Ceramics, Advanced Composite Materials, and High Performance Plastics are concerned with high temperature materials.

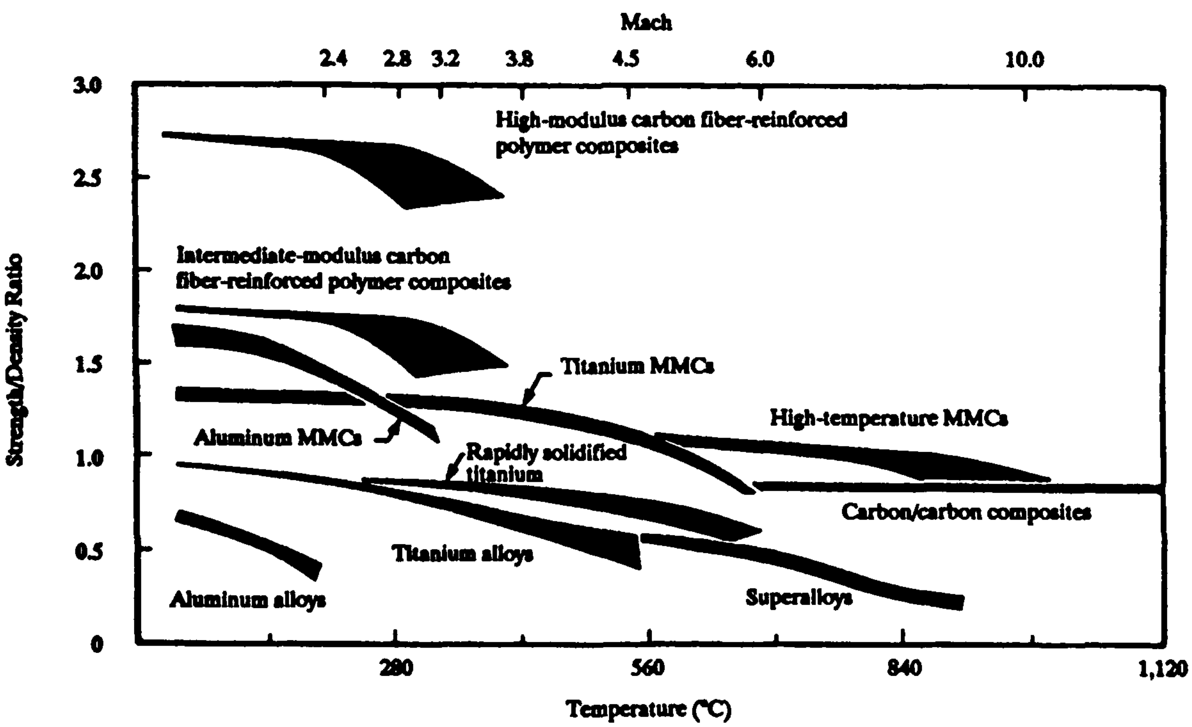

Figure 4. Comparison of strength-density ratios for a number of materials as a function of temperature. Reinforced polymer composites have very high values at temperatures up to about 250 °C. Courtesy of Boeing Commercial Airplane Co.

The program on Advanced Alloys with Controlled Crystalline Structures is attempting to develop new alloys that have excellent heat resistance, toughness, and strength by controlling microstructure in addition to compositions. Single-crystal nickel-base superalloys have been obtained in turbine blade shapes at an 80-percent yield. Investigations are being conducted on the superplastic forming of nickel- and titanium-base alloys. Oxide dispersion strengthened (ODS) alloys have been fabricated with properties superior to MA 6000. The present technology is being extended to fabrication of hardware. The national institutes are emphasizing research on alloy design, ceramics mold technology, and control of microstructure for superplasticity. Production technology is covered by industrial laboratories. Much of the work on superalloys is now being directed to new systems. Recently defined research themes include: intermetallic compounds of niobium, molybdenum, aluminum, and silicon, with heat resistances of 1,800 °C; and titanium-aluminum intermetallic compounds with heat resistances of 1,300 °C.

The goal of the High Performance Ceramics program is to develop new ceramics with high reliability and toughness when used as high temperature structural materials under severe conditions such as in a gas turbine. Basic and evaluative research is being performed at the national research institutes, while the Engineering Research Association for the High Performance Ceramics, which is composed of 16 private companies, is responsible for developing elementary technologies. Specific tasks for the national research institutes and the Engineering Research Association for High Performance Ceramics are as follows:

National Research Institutes

- Studies on high-temperature fracture mechanisms
- Technology for production processes
  - Evaluation of process technology
    - Design of microstructure
    - Explosion forming/sintering technology
  - Machining technology
- Evaluation technology
  - Starting powder
  - Sintered body
    - Strength, corrosion resistance
    - Corrosion resistance against high temperature gases
    - Wear resistance

Engineering Research Association for High Performance Ceramics

- Research into conceptual design of ceramics
- Process technology
  - Material powder synthesis
  - Forming and sintering
    - High strength materials
    - High corrosion-resistant materials
    - High wear-resistant materials
    - High toughness materials
  - Machining and joining
    - Machining
    - Joining
    - Surface technology

- Reliability evaluation
  - Proof test
  - Nondestructive test
- Application technologies
  - Design technology
    - Design standards
    - Structure analysis and design criteria
  - Model evaluation
    - High strength model
    - High corrosion-resistant model
    - High wear-resistant model

The advanced composites program has goals for developing resin and metal matrix composites, as well as evaluation of various characteristics of these composites. Various organizations are involved in this program including 6 governmental research institutes (Mechanical Engineering Laboratory, National Chemical Laboratory for Industry, Government Industrial Research Institute-Osaka, Research Institute for Polymers and Textiles, Industrial Products Research Institute, and National Research Institute for Metals); 3 universities (University of Tokyo, University of Osaka Prefecture, and Kanazawa Institute of Technology); and 12 private companies (Toray Industries Inc., Teijin Ltd., Mitsubishi Chemical Industries Ltd., Nippon Carbon Co. Ltd., Ishikawajima-Harima Heavy Industries Co. Ltd., Kawasaki Heavy Industries Ltd., Fuji Heavy Industries Ltd., Mitsubishi Heavy Industries Ltd., Toshiba Machine Co. Ltd., Mitsubishi Electric Corp., Toyota Motor Corp., and Kobe Steel Ltd.). With regard to fiber-reinforced polymers, work has been focused on developing heat-resistant resins. The work on metal matrix composites has emphasized wettability and the affinity between the fibers and metals. New research themes include: carbon fibers sheathed in ceramics for oxidation protection, high strength silicon carbide fibers, carbon fiber-carbon composite materials with heat resistances of 2,000 °C, and intermetallic compounds reinforced with silicon carbide fibers.

The High-Performance Plastics program was initiated in 1981 and is a 10-year program. This research is directed at developing polymeric materials with mechanical characteristics equivalent to those of metallic materials. Specific research now in progress includes the development of rigid polymers, crosslinking between polymer chains, synthesis of macromolecular composites, new molding and processing techniques, and documentation of various polymer properties and characteristics. Advances include: polyimide films (~10 μm) with a tensile elastic modulus of 161 GPa; the production of high modulus polyacrylate (41.6 GPa) sheets (~2 mm); the development of laminating techniques under high temperature and pressure to produce a polyimide sheet with an elastic modulus as high as 101 GPa; and the development of an isotropic material by compression molding of aluminum polyacrylate and calcium polyacrylate powders at 200 °C and 7,000 kg/cm^2 with a flexural modulus of 36 GPa at 200 to 300 °C.

The programs that have been described are the major government programs providing support for high temperature materials research. There are other government programs that are important. For example, the national universities in Japan have numerous faculty members performing research on topics relevant to high temperature materials development. Also, the Japanese Research Center for Metals is attempting to establish research companies to advance and transfer technology in certain critical areas. The Research Institute for Metal Surface of High Performance (RIMES) (Ref 2) is an example of such a company established to advance the technology for forming silicon carbide coatings on alloys. Such efforts contribute to the development of high temperature materials.

In the following section of this paper research at different institutions on high temperature materials will be described. These descriptions are not intended to be inclusive but to indicate scope and provide sufficient information that those interested may contact the appropriate investigators.

METALLIC ALLOYS

Superalloys

Yamazaki and coworkers at the National Research Institute for Metals (NRIM) have been working on the development of advanced nickel-base superalloys for over 8 years (Ref 3-5). Regression analyses using data generated by microprobe analyses of various alloys have been used to determine the equilibrium compositions of the γ and γ' phases. This technique permits alloy compositions to be selected for which deleterious phases such as sigma will not be stable. The volume fractions of γ and γ' in the alloy can also be controlled as well as the lattice parameters of these phases. This design procedure permits certain properties of the alloys to be estimated, such as density, creep rupture life, and hot corrosion rate. By using such procedures coupled with testing of experimental alloys, new alloys have been obtained with creep lives and hot corrosion properties competitive with some of the current nickel-base superalloys. For example, conventionally cast, directionally solidified, single-crystal alloys and ODS alloys have been developed with properties equivalent to or better than Mar M 247, Mar M 247 DS, PWA 1480, and MA 6000, respectively.

Ohno and Watanabe at Hitachi Metals are also involved in the design of superalloys with high creep strength and good microstructural stability. A nickel-base single-crystal alloy has been developed for which the concentrations of elements such as W, Ta, and Mo have been optimized (Ref 6,7). This alloy contains Ni-6.4Cr-5.1Al-7.3W-7.3Ta-4.3Mo-1.0Co-0.1Hf* and has a 1,000-hour creep rupture life at 1,070 °C for a tensile stress of 137 MPa. These investigators have also designed a low-nickel iron-base superalloy with properties equivalent to those of A-286 but with a lower cost (Ref 8).

Ohno and Watanabe are also investigating the effect of aging heat treatment on the creep rupture properties of nickel-base single-crystal superalloys (Ref 9,10). The morphological change of γ' particles has been found to be strongly influenced by the lattice mismatch between the γ and γ' phases; therefore, the optimum heat treatment temperature varies depending on lattice mismatch. For alloys with a larger lattice mismatch a lower temperature heat treatment is desirable, whereas for alloys with smaller mismatch a higher heat treatment temperature is necessary. These investigators have also been involved with the development of die materials for forging of

*All compositions are presented in weight percent.

superalloys. A Ni-11.3W-10.1Mo-6.Al-0.01Y alloy permitted forging of IN 100 (Ref 11) and Waspaloy (Ref 12) in air with no significant damage or oxidation of the die.

Nakagawa and coworkers at Ishikawajima-Harima Heavy Industries (IHI) have investigated a number of factors concerned with superalloy processing, properties, and microstructure (Ref 13-19). These investigators are studying and utilizing casting equipment, solidification modeling, phase stability analyses, and mechanical anisotropy phenomena to obtain cleaner alloys, higher temperature gradients during solidification, and improved quality castings with lower rejection rates. At temperatures between 760 and 850 °C the creep behavior of nickel-base single-crystal superalloys has been found to be sensitive to crystal orientation (Ref 15) and to γ' precipitate size. For a γ' size between 0.35 and 0.5 μm the highest creep strength is obtained near the [001] direction, whereas for a γ' size of 0.2 μm the highest creep lives in decreasing order are obtained with crystals oriented along the [$\bar{1}$11], [001], and [110] directions, respectively. At temperatures between 980 and 1,050 °C, creep behavior of single-crystal superalloys is much less sensitive to orientations and γ' size (Ref 15).

Abnormal grain growth in ODS superalloys enhanced by boron doping or torsional strain (Ref 16) also has been studied. These investigators have developed an ODS Ni-Co-Cr-W-Ta-Al-Ti-Y_2O_3 alloy with superior creep rupture strength over a wide temperature range by increasing the tantalum concentration to a level higher than that of other ODS alloys (Ref 20).

Nakagawa and coworkers also have investigated directionally solidified eutectic alloys (Ref 19,21). These studies were performed over 5 years ago, and at present it is believed the use of such technology to prepare gas turbine engine hardware is not feasible due to technical shortcomings and cost.

R&D on new superalloy compositions, directional solidification, and single-crystal fabrication techniques is also being performed by Nishiyama and coworkers at Kawasaki Heavy Industries (KHI) and by Kawai and coworkers at Mitsubishi Heavy Industries (MHI). The nature of this work is similar to that described previously for NRIM and IHI.

A substantial amount of R&D on superalloys is being performed at Kobe Steel (KOBELCO). Atomization of superalloy powders, consolidation of powders by hot isostatic pressing (HIPing), and superplastic forming of superalloys are some of the subjects being investigated (Ref 22). The effects of defects such as porosity, nonmetallic inclusions, and precipitates on the properties of powder metallurgy (P/M) superalloys are also being studied (Ref 23).

Yukawa and coworkers at Toyohashi University have performed an extensive amount of research on the design of superalloys emphasizing phase stability. Superalloy limiting compositions, for which undesirable phases such as topologically close packed (TCP) phases (e.g., sigma phase) or eutectic γ' can be formed, have been determined by using a d-orbital energy level calculation (Ref 24-28). The approach is similar to that for the average electron vacancy number used in the PHACOMP calculation (Ref 29) but with more precise control of compositions, and it is applicable to cobalt- and iron-base alloys as well as nickel-base alloys. These authors also propose that solid solution strengthening of the γ-phase is the most crucial factor for strengthening nickel-base single-crystal superalloys and use calculations to determine strength of ionic and covalent bonds to estimate certain physical and mechanical properties of alloys.

Yukawa and coworkers have also examined the stability of carbides in nickel-base alloys (Ref 30-32) by using x-ray diffraction techniques. At temperatures of about 1,000 °C monocarbides often transform to other carbides such as $M_{23}C_6$ and M_6C due to reaction with the alloy. The stability of the monocarbides is strongly dependent upon composition since their transformations are influenced by coherency strains as well as the standard free energies of formation of the various carbides. Consequently, the lattice parameters of monocarbides and their stabilities in superalloys are related, namely, the larger the lattice parameter, the greater the stability. These investigators have also examined the Hf-containing phases present in cast IN-100 (Ref 33). The intermetallic compound Ni_7Hf_2 transformed to a hafnium-rich monocarbide during annealing at 1,000 °C.

The hot corrosion of nickel-base single-crystal superalloys has been studied by a number of the groups involved with superalloy development. The experimental approach usually consists of coating superalloy specimens with Na_2SO_4-25 percent NaCl followed by oxidation in air at 900 °C. At NRIM and some industrial laboratories burner rig tests are used. Yukawa and coworkers (Ref 34) have studied the hot corrosion of superalloys using the approach involving oxidation of Na_2SO_4-NaCl specimens in air. These investigators used the weight gain (mg/cm^2) of specimens after 20 hours in this test as the hot corrosion index to examine the effects of various elements on the hot corrosion process. This hot corrosion index increased with W concentration; decreased with Ti, Mo, and Co additions; and was not substantially affected by Cr and Al. The addition of up to 1 percent Re reduced the hot corrosion index by over an order of magnitude. These results must be used with care because the test is very severe, and the hot corrosion index is based on rates of hot corrosion. Usually most superalloys undergo hot corrosion at rates so large that hot corrosion cannot be tolerated. Nevertheless the results obtained with Re are significant.

Doi and coworkers have been investigating the coarsening of precipitates in elastically constrained systems for over 5 years (Ref 35-41). Special emphasis has been placed upon the coarsening of the γ' phase (Ni_3Al) in nickel-base superalloys. It was shown that in elastically constrained systems such as a solid alloy coarsening theories based upon Ostwald ripening are inapplicable. The important characteristics of precipitate coarsening in an elastically constrained system have been identified and include:

- The coarsening rate varies with volume fraction of precipitate.

- Extremely slow coarsening can be realized near the center of the miscibility gap in the presence of strongly constrained elastic fields.

- Deceleration of the coarsening rate of precipitates occurs when the precipitate particles become large.

- Splitting of a single precipitate into two or eight small particles during coarsening can be observed.

The effects of elastic interaction effects have been explained by constructing bifurcation diagrams composed of two regions, one where large particles grow at the expense of smaller particles and another where smaller particle growth is favored.

Studies on high temperature metallic materials for use in the high temperature gas-cooled reactors (HTGR) have been in progress in Japan for more than 15 years. Research activities have been classified into three categories (Ref 42,43), namely, near-term structural alloys, long-term heavy duty structural alloys, and cladding alloys for neutron absorber rods. In Table 1 the status of these efforts is summarized and compositions of some of the alloys are presented. The environments in which these alloys are to be used have extremely low oxygen pressures, and carburization and decarburization processes are important. Kondo and coworkers at the Japan Atomic Energy Research Institute have been studying the corrosion behavior (Ref 44-45) of alloys in these environments as well as the effects of the environments on mechanical properties such as fatigue (Ref 46,47), creep (Ref 48), and tensile strength (Ref 49,50). A substantial amount of data has been accumulated for alloys such as Hastelloy X and Hastelloy XR. No significant difference has been observed between long-term creep-rupture testing of Hastelloy XR in the helium and air environments. These results have been attributed to the improved oxidation resistance of this alloy. It was also found that depletion of boron during melting had an adverse effect on the creep strength of this alloy. Research is now emphasizing the Ni-Cr-W alloy system where the effect of elements such as Nb, Fe, Mn, Si, Ti, B, and Y on creep rupture strength, tensile strength, hot workability, and corrosion resistance is being examined. The elements B and Y have been found to improve creep strength, tensile ductility, corrosion resistance, and hot workability.

Table 1. High Temperature Alloys for HTGR Applications

Category	Material	Status
Near-Term Structural Components of High Temperature Engineering Reactor (850-950 °C)	Hastelloy XR Ni-23Cr-10Mo-1W-20Fe-0.3Si-1Mn-0.1C	Obtaining design data and quality assurance oriented studies
Long-Term, Heavy Duty Structural Components (1,000 °C)	Ni-Cr-W Superalloys	Alloy optimization and screening tests
Cladding Materials for Neutron Absorber Rods of High Temperature Test Reactor	Alloy 800H	Irradiation tests & postirradiation creep tests

Titanium Alloys

In discussing titanium alloys there are two distinct areas of interest, namely, the conventional alloys, such as Ti-6Al-4V, with use temperatures of about 600 °C, and intermetallic compounds, such as TiAl, which are being developed with goals for use at temperatures up to 1,000 °C or higher.

Since the fabrication and machining costs of the currently available titanium-base alloys (e.g., Ti-6Al-4V) are high, superplastic forming is a means to reduce costs. There is also a need to increase the strengths of such alloys at temperatures in the range between 400 and 600 °C. As one of the programs in the National Project on Advanced Alloys with Controlled Crystalline Structures, the three national research institutes and seven industrial companies are working together on nickel-base superalloys and titanium-base alloys. The objectives for the titanium alloy effort are to obtain superplastic behavior with improved strength-to-density ratios. Much of this work has been performed at NRIM under the direction of M. Yamazaki (Ref 51-53) and has been described in a previous *Scientific Information Bulletin* article (Ref 54).

There are numerous investigators in Japan who are working on titanium-based intermetallics. Some of these investigators are identified in Table 2.

Tsujimoto (Ref 55,56) and coworkers at NRIM are studying the effects of elements such as Mn, Nb, V, and Zr on the structures and mechanical properties of TiAl-base alloys. Some of this work has been described previously (Ref 54). These investigators propose that the elements that improve the ductility of TiAl are those having smaller atomic size than both Ti and Al and that occupy Al sites in the crystal structure. By replacing some of the aluminum in TiAl with Mn, an elongation of 3 percent has been obtained at temperatures below 800 °C.

Izumi and coworkers at Tohoku University have been concerned with the fracture mechanism of TiAl (Ref 57,58). They have found that the ductility of Ti-34Al (Ti-48 at. % Al) is improved by the use of high purity base metals, which causes the flow stress in grains to be decreased. Ductility is also improved by developing a lamellar structure in the matrix phase (TiAl) and in the Ti_3Al second phase, which supposedly lowers the flow stress.

Yamaguchi and coworkers at Osaka University are systematically investigating the plastic deformation behavior of Al_3X compounds with the DO_{22} structure (Ref 59-61). The ductility of Al_3V has been found to be improved by the replacement of some of the vanadium with titanium. This improvement in ductility arises from a substantial increase in the activity of ordered twinning, which is not operative in pure Al_3V. The major mode of deformation of Al_3Ti has been determined to be ordered twinning of the type $(111)[11\bar{2}]$, which does not disturb the DO_{22} symmetry of the lattice. Alloying additions of Hf, Zr, Li, and B have been found to improve ductility of Al_3Ti with B yielding the best results. Addition of some rare-earth elements may also increase the activity of ordered twinning and improve the ductility of Al_3Ti.

Table 2. Investigators Studying TiAl-Base Alloys in Japan

Location	Researchers	Type[a]
Universities		
Tohoku Univ.		
Inst. for Mater. Res.	O. Izumi	B,C
	T. Kawabata	
Dept. Mater. Sci.	H. Oikawa	K
Tokyo Inst. of Tech., Res. Lab. Precision Mach. & Elec.	T. Suzuki	C
Yokohama National Univ.	R. Tanaka	F
	H. Fukutomi	D
Toyohashi Univ. of Tech.	M. Morinaga	A
Kyoto Univ.	M. Yamaguchi	B,C
Ritsumeikan Univ.	M. Tokizane	G
Osaka Univ.	Y. Umagoshi	B,C,F
Univ. of Osaka Prefecture, College of Eng.	Y. Nakayama	C
National Research Institutes		
National Res. Inst. for Metals	T. Tsujimoto	C
	K. Hashimoto	C
	M. Nobuki	D,E
	Y. Kaieda	G
Mechanical Eng. Lab.		D,E
Government Ind. Res. Inst., Nagoya		G
Materials Fabricators		
Nippon Steel Corp., Central R&D Bureau	M. Tanino	B,C
	S. Matsuo	
	T. Hanamura	
Nippon Kokan K.K., Tech. Res. Center	C. Ouchi	D,E
	S. Mitao	
Kobe Steel, Ltd., Mater. Res. Lab.	M. Tsukuda	E
	K. Ashida	
Sumitomo Light Metal Ind., Ltd., Tech. Res. Lab.	K. Sato	G
	K. Shibue	
Daido Steel Co., Ltd., Central Res. Lab.	S. Isobe	E,H
Mitsubishi Metal Corp., Central Res. Inst.	Y. Mae	G
Materials Users		
Kawasaki Heavy Ind., Ltd., Mater. Res. Tech. Inst.	S. Nishiyama	I
	T. Miyashita	
Mitsui Eng./Shpbldg. Co., Ltd., Adv. Mater./Prod. Div.	T. Degawa	H
Mitsubishi Heavy Ind., Ltd.		I
Nissan Motor Co., Ltd.		I
Toyota Motor Corp.		I

[a]A - alloy theory; B - plasticity; C - alloy design; D - hot working (control of microstructures); E - hot working (production); F - oxidation; G - powder metallurgy (including ''combustion synthesis''); H - casting, melting; I - applications; J - project planning; K - creep

Courtesy of S. Fujishiro

Tanaka and coworkers (Ref 62) at Yokohama National University have studied the oxidation of TiAl at 900 °C in air. The oxidation was very rapid; for example, a weight gain of about 20 mg/cm^2 was observed after 150 hours. The aluminum was not selectively oxidized, and the oxidation products contained titanium oxides as well as aluminum oxides. The oxidation rate of TiAl was greatly reduced by pretreating specimens in reduced oxygen pressures (e.g., 6.7×10^{-3} Pa) at 1,000 °C. This pretreatment allowed a continuous layer of Al_2O_3 to be formed on the specimens that remained protective for 250 hours in the oxidation test. The protectiveness of this preformed Al_2O_3 layer was affected by the oxygen pressure and time at temperature during pretreatment. Since protective Al_2O_3 scales grow at very slow rates up to about 1,000 °C, and such thin layers are fairly resistant to cracking and spalling under the action of thermally induced stresses, preformed Al_2O_3 scales may be a means of developing some oxidation resistance in TiAl.

Intermetallic Compounds and Refractory Metals

A number of researchers are investigating other intermetallics in addition to the titanium-base intermetallics discussed in the previous section. Suzuki and coworkers have intensively studied the intermetallic compound Ni_3Al. The positive temperature dependence of strength (Ref 63,64), the effect of compositional deviations from stoichiometry (Ref 65,66), and ternary additions (Ref 67-69) on the magnitude of this anomaly have been thoroughly investigated.

Yamaguchi and coworkers have been comparing plastic deformation of Ni_2AlTi (Ref 70,71) and Co_2AlTi (Ref 72). The difference in the ease of slip between these two compounds has been attributed to the difference in the energies of the antiphase boundaries (APB) associated with the splitting of superlattice dislocations. Deformation and slip systems in FeAl (Ref 73) and FeCo (Ref 74) have also been described.

Izumi and coinvestigators have studied a number of intermetallic compounds, placing emphasis on grain boundary structure and procedures to control embrittlement in ordered alloys. Some recent research is concerned with the mechanical properties of Ni_3Al and the effects of carbon, boron, and beryllium (Ref 75-77) on flow strength, ductility, and fracture. Fracture in Ni_3Al single crystals containing titanium ($Ni_{75}Al_{20}Ti_5$) and tantalum ($Ni_{75}Al_{20}Ta_5$) is also being studied (Ref 78,79). Defect structures in intermetallic compounds such as Co_3Ti (Ref 80,81) are being studied to help account for defect solution strengthening effects in such compounds.

There has not been a significant amount of research performed in Japan on refractory metals such as niobium or intermetallic compounds containing elements such as Nb-Si, Nb-Al, or Mo-Si, although the Tsukuba Laboratory of NRIM has begun to characterize the structures and mechanical properties of some silicides and aluminides. These studies have emphasized the preparation of single crystals using the floating zone method. More R&D on intermetallic compounds and refractory metal alloys for use at very high temperatures is about to be initiated. In April of 1989, AIST announced a program for novel materials designed to be resistant against extreme conditions. This program is part of the Project on Basic Technology for Future Industries discussed previously in this paper. Targeted materials are Ti-Al intermetallics to withstand temperatures between 1,000 and 1,300 °C and Nb/Mo-Al/Si intermetallic compounds capable of use to 1,800 °C for potential applications in aircraft and aerospace equipment.

Heat-Resistant Steels

Heat-resistant steels can cover a very wide range of alloys. By restricting consideration to those alloys that can be used above 600 °C in oxidizing environments the range is greatly reduced since such alloys must contain enough Cr to form protective oxide scales rich in Cr_2O_3. Hosoi and coworkers at Nagoya University have been studying the mechanical properties of steels with chromium concentrations between 9 and 16 percent. The precipitation of Laves phase and its effect on toughness have been examined in a 9Cr-2Mo steel (Ref 82). The ductile-brittle transition temperature is increased and the upper shelf energy decreased when the Laves phase begins to precipitate during aging. By reducing the Si concentrations from ~0.6 to <0.001 percent the precipitation of Laves phase was reduced and good toughness was maintained. The tensile properties of Fe-12Cr-Mn alloys have been studied (Ref 83) in the temperature range between room temperature and 800 °C. The transformation from α'-martensite to austenite results in a large drop in tensile strength, and this transformation is affected by Mn concentration. Relatively high strengths were obtained with 5 and 10 percent Mn at 400 °C. Carbon and N additions improved the tensile properties of the 15 percent Mn alloy. The effect of microalloying with C, N, and V on the creep properties of 316 stainless steel has been investigated (Ref 84). It was found that the creep life at 600 °C was markedly increased by the combined alloying with a small amount of C, N, and V. The steady state creep rate was also decreased by cold working and aging at 973 K compared with the solution treated material. These improvements in mechanical properties were attributed to finely precipitated carbides.

Numerous other investigators in Japan are performing studies on heat-resistant steels. The work performed by Hosoi and colleagues is a good example of the type of investigations underway.

Coatings

Coatings R&D in Japan is extensive. The work on metallic coatings for high temperature applications involving deposition techniques such as low pressure plasma spray and aluminizing via chemical vapor deposition, however, has not received as much emphasis as efforts to develop coatings such as TiN, BN, TiC, SiC, and diamond for room temperature or low temperature applications (Ref 85). The work on coatings for high temperature applications is being performed mainly at companies involved with gas turbine technology, namely, IHI, KHI, and MHI, and at NRIM.

The coatings work at the gas turbine manufacturers consists of applying MCrAlY and diffusion aluminide coatings to superalloys. Much of the work involved with aircraft hardware is performed under license with U.S. gas turbine manufacturers and therefore does not involve development of new coating compositions nor new coating processes. As a result of these licensing agreements the Japanese gas turbine manufacturers possess excellent facilities and experience to fabricate state-of-the-art high temperature coatings.

Takei, Nii, and coworkers at NRIM are involved in a number of investigations concerned with high temperature coatings development and characterization (Ref 54). One program involves participation in a project involving U.S. and European investigators that is attempting to standardize burner rig testing. Platinum aluminide and Co-21Cr-10Al-0.3Y coatings on superalloys are being exposed to oxidation and hot corrosion conditions in burner rigs. Degradation characteristics of the coatings are being documented. Studies are also being performed to develop improved aluminide coatings for superalloys and to develop coatings for titanium-base alloys. Nii and coworkers are studying the adherence of sputtered Al_2O_3 layers on stainless steels and on the nickel-base superalloy MA 6000. Their results show that sulfur segregation to the Al_2O_3-alloy interface adversely affects the adherence of Al_2O_3 and that small (e.g., ~0.01 percent) additions of elements such La or Ce suppress the segregation of sulfur to the interface and improve the adherence of Al_2O_3. Good adherence of the sputtered Al_2O_3 was also observed on MA 6000, and it was proposed that the Y_2O_3 in this alloy prevented the segregation of sulfur to the alloy-Al_2O_3 interface.

Kitahara and coinvestigators at NRIM are studying plasma spraying processes for forming coatings (Ref 86,87). Techniques for the simultaneous measurement of coating thicknesses and deposition stresses during thermal spraying have been developed. Strip-shaped substrates were fixed upon a pair of knife edges and the displacements of the front and rear surfaces during thermal spraying were measured. The displacement of the surface upon which the coating was deposited was measured using a laser and a telescope with an image sensor. The displacement of the other surface was monitored by using a contacting displacement meter. Techniques have also been developed to measure the velocity and temperature of sprayed particles as a means of controlling the physical properties of the resultant coatings (Ref 88).

There is substantial activity in Japan on thermal barrier coatings. IHI, KHI, and MHI as well as NRIM and the National Aerospace Laboratory are all involved with such coatings in some manner. The thermal barriers being studied are ZrO_2 stabilized with Y_2O_3 as well as others. Experience is also being obtained with different bond coats used between the ZrO_2 and the superalloy substrate as well as the effects of graded versus abrupt, nongraded bond coat-ceramic interfaces. The studies at the National Aerospace Laboratory are involved with the same thermal barriers (Ref 89) but emphasize coolant flow schemes. Much of the work that is in progress in Japan on thermal barrier coatings is similar to that performed in the United States 5 to 10 years ago. A thorough knowledge of the fabrication procedures for these coatings has been established, and some of the limiting factors, such as thermal barrier adherence to complex air foil shapes, are just beginning to be addressed. While thermal barrier coating technology is considered to be behind that in the United States, a very large R&D effort is now in progress to obtain ultra heat-resistant materials with excellent thermal insulation. This program to develop functional gradient materials has been described in a *Bulletin Express* (Ref 90) and will be briefly described in the following paragraph.

A national effort has been established regarding the key technology of "functionally gradient materials" (FGMs). Such materials could be used at ultra high temperatures and would consist of layers of various different materials. The goals of the FGM Project are to obtain graded materials with thicknesses from 1 to 10 mm that can be used at temperatures up to 1,700 °C and sustain a temperature gradient of 1,000 °C. In order to achieve these goals sharp interfaces between different materials cannot be tolerated and processing techniques must be developed whereby continuous changes from one material, such as a ceramic, are gradually made at the microscopic level to another material such as a metallic alloy. This project, which was initiated in 1987, is organized in a fashion similar to other Japanese research thrusts. National laboratories, universities, and industry are participating. This first term of 3 years emphasizes fundamentals, which is to be followed by an applications period of 2 years. The first term efforts involve three distinct thrusts, namely, materials design, materials synthesis, and materials evaluation. The materials design thrust has as its goals to establish fundamental theory, to develop software for thermal stress analysis, and to begin to estimate physical properties based upon systems composed of graded materials. The materials synthesis thrust attempts to develop the technology to fabricate FGMs. Approaches being utilized consist of: chemical vapor deposition (CVD), powder metallurgical techniques but using ceramic as well as metallic powders, plasma deposition, and self-propagating high temperature synthesis whereby the heat generated by exothermic reactions is used in the consolidation of powders. The materials evaluation thrust is intended to establish a characterization technology for FGMs. In particular, thermal stress distributions in, and the insulation properties of, FGMs will be analyzed and documented. Furthermore, mechanical tests such as thermal fatigue and thermal shock tests will be performed to relate strength to gradient composition.

At present few papers are available in the literature that describe in detail results obtained from studies on FGMs. Niino (Ref 91) has prepared a recent status paper. M. Koizumi at Ryukoku University is the chairman of the Research Promotion Committee for the FGM Project. Y. Miyamoto of Osaka University is pursuing combustion synthesis using titanium diboride with additives such as nickel and titanium carbide. These studies are concerned with the preferred gradient distributions in various preforms for ultimate self-propagating high temperature synthesis (SHS) processing. T. Hirai of the Institute of Materials Research, Tohoku University, is using CVD to prepare FGMs. The National Aerospace Laboratory in conjunction with Daiken Industries has designed a thermal barrier, functionally graded Cu-TiB_2 capable of withstanding a temperature differential of 1,200 K. Unlike conventional two- or three-layer composite structures, the Cu-TiB_2 developed neither a tensile stress in the ceramic region nor high stress discontinuities. Numerous other investigators and organizations are working on FGMs. Detailed papers can be expected to appear in the literature in the near future.

CERAMICS

The R&D effort on ceramics in Japan is immense. Only ceramics for high temperature applications will be considered here. Moreover, only programs related to ceramic gas turbines or the National Project on High Performance Ceramics will be discussed.

R&D related to the manufacture of ceramic gas turbines (CGT) for use in automobiles is a national project under MITI (Ref 92). This project involves automobile manufacturers, petroleum companies, ceramics companies, and auto parts manufacturers. A 2-year preliminary study is about to be completed in 1989 and the full-scale 5-year program is planned to begin in 1990. The aim of the R&D is to produce a 100-kW CGT with certain target performances, one of which is a thermal efficiency of 40 to 42 percent requiring a turbine inlet temperature of 1,300 to 1,400 °C. Consequently, one of the research thrusts is to develop a variety of heat-resistant ceramic materials suitable for use in CGT high temperature components. In parallel with the effort to develop this automotive CGT, a 9-year program to develop a high efficiency 300-kW class turbine for use in electricity generation was initiated in 1988 as part of the Moonlight Project. This gas turbine has a proposed turbine inlet temperature of 1,350 °C. One research goal is to develop heat-resistant ceramic components with minimum strengths of 400 MPa at 1,500 °C.

Automobile manufacturers in Japan have been performing research on heat-resistant ceramics for over 10 years; some of the results from this research have been applied in their reciprocating engines to Si_3N_4 components such as glow plugs and rocker arms. Furthermore, Si_3N_4 ceramic turbochargers have been installed in numerous vehicles. The technology required to meet the requirements of the automotive CGT is not available, however, and currently ceramic components such as Si_3N_4 turbine rotors, combustors, and scrolls must be developed.

Toyota Motor Corp. commenced research on gas turbines in 1964. It displayed a gas turbine passenger car in 1987 at the Tokyo Motor Show. A ceramic materials development group has been established at the Toyota Central Research and Development Laboratories.

The Nissan Motor Co., Ltd., began work on gas turbines in 1963. A complex shaped and highly stressed radial turbine was seen as the most difficult component in developing and incorporating ceramic materials. Ceramic design and manufacturing techniques and testing and evaluation were initially performed with small diameter Si_3N_4 rotors. Stress analysis methods adapted to brittle materials were implemented. In-house work on ceramic processing at a level equivalent to that of ceramics manufacturers was initiated to build a base of fundamental technology on ceramics. Nissan now has a number of ceramic components for gas turbines, for example, Si_3N_4 seal rings, combustion chambers, turbine shrouds, axial turbine rotors, radial turbine nozzles, and radial turbine rotors. Using these capabilities Nissan developed a Si_3N_4 ceramic turbocharger, which was released in a passenger car in 1985. As of November 1987 more than 60,000 ceramic turbochargers were in service in three Nissan models. The technology acquired during this successful commercialization represents a major step forward in the development of the CGT.

Mitsubishi Motors Corp. began research on gas turbines in 1969. This company is working on making ceramic components that include, scrolls, nozzles, turbine rotors, turbine shroud, interstage ducts, and regenerators. The latest Si_3N_4 turbine rotor is 85 mm in diameter and during spin tests has achieved 550 m/s (tip speed) at 1,250 °C and 650 m/s at 1,200 °C.

The program for the 300-kW CGT is composed of the following three groups working independently:

IHI Group

- Ishikawajima-Harima Heavy Industries, Co., Ltd.
- NGK Insulators, Ltd.
- NGK Spark Plug Co., Ltd.

KHI Group

- Kawasaki Heavy Industries, Ltd.
- Kyocera Corp.
- Sumitomo Precision Products Co., Ltd.

Yanmar Diesel Engine Group

- Yanmar Diesel Engine Co., Ltd.
- Niigata Engineering Co., Ltd.
- Kyocera Corp.
- NGK Spark Plug Co., Ltd.
- NKK Corp.

Since this program has been initiated recently, very few results have been published. The goal is to develop ceramic materials with high temperature strength, high toughness, and corrosion resistance. Combustion chambers, turbine parts, and heat exchangers and other components that require reliability at high temperatures are to be fabricated from ceramic materials. IHI has been performing R&D on the application of ceramic Si_3N_4 materials to small radial turbine rotors, nozzles, casings, etc. since the early 1970s. Currently a circumferential velocity of 550 m/s with a turbine inlet temperature of 1,200 °C has been achieved. The technology acquired from this research has been applied to turbochargers, which are now commercialized. Ceramic components (Si_3N_4) have also been developed for small axial flow turbines including blades, disks, nozzles, and combustors. At present a circumferential velocity with a ceramic disk of 600 m/s at a turbine inlet temperature of 1,350 °C has been achieved. KHI is performing research to use ceramic materials for high temperature components such as a radial turbine rotor, turbine nozzles, and combustors of their 25-kW class small gas turbine. A ceramic turbine rotor of the same dimensions as the original metal rotor has been developed and tested with a turbine tip speed of 538 m/s and a turbine inlet temperature of 1,100 °C. This rotor was made from Si_3N_4. A turbine nozzle was made of one piece using Si_3N_4, as was a single-can-type combustor. Both have been tested in engine operation. KHI has developed a prototype axial flow turbine rotor with ceramic blades modified from the existing first stage metal turbine rotor of their current model 250-kW output industrial gas turbine. Cold spin tests have been performed with satisfactory results. It is planned to carry out actual 250-kW class engine running tests in the near future.

The term "fine ceramics" has been given to those ceramics fabricated through closely controlled forming and sintering of chemically synthesized high purity powders. Some of the major fine ceramics organizations in Japan are identified in Table 3. While fine ceramics (second generation) have much more reliable and predictable properties than conventional ceramics (first generation), which are made from natural materials, problems still remain in regards to reliability and brittle behavior. The task of the High Performance Ceramics, or Fine Ceramics, Project is to obtain silicon nitride and silicon carbide materials of markedly higher reliability (high Weibull modulus) for the following applications: high strength material required for high temperature engine hardware; high corrosion-resistant material for high temperature heat exchanger parts; and high precision, wear-resistant material for high temperature, high friction, machine parts. This 12-year project was organized in three phases. The first phase was completed in 1983 and the second in 1987. The performance properties to be obtained for these two phases were the same, as indicated in Table 4, but in the first phase these properties were to be demonstrated in test specimens in contrast to simple model practical geometries for the second phase. The targeted properties for phases one and two were achieved, but reproducibility and reliability in scale-up efforts were not achieved. During the current third phase, which is to be completed in 1991, the technology base is to be further improved and emphasis has been given to realization of properties in more complex shapes closer to anticipated component geometries. The performance objectives for the final phase are presented in Table 5.

The research projects being pursued in this third phase are presented in the Appendix, first by broad topic and institution, and then in terms of specific research programs with investigators. Recent research performed at universities and reported at a recent meeting of the Japan Ceramic Society is also included.

In closing this section on high temperature ceramics, Figure 5 is presented to illustrate the progress that has been made in processing silicon nitride. At temperatures in the range between 1,000 and 1,300 °C, the flexural strength has been increased by a factor of three. These data represent results obtained by various Japanese investigators using most recently developed materials. Figure 6 presents results on pilot plant stage silicon carbide and silicon nitride.

Table 3. Fine Ceramics Organizations in Japan

Government Agency	Research Facility	Key Person
Ministry of International Trade and Industry (Agency of Industrial Science and Technology)	Government Industrial Research Inst., Nagoya	Dr. Ishii
	Osaka	Dr. Hayami
	Kyushu	Dr. Kobayashi
	Ceramic Society of Japan	Prof. Saito, Dr. Ohba
	Japan Fine Ceramics Center	Drs. Morita, Okuda
	Japan Fine Ceramics Association	Drs. Suzuki, Iwata
Ministry of Education	Tokyo University	Prof. Yanagida
	Kyoto University	Profs. Soga, Sakka
	Osaka University	Prof. Kanamaru
	Tohoku University	Profs. Hirai, Shimada
	Nagoya University	Profs. Naka, Hirano
	Kyushu University	Prof. Kato
	Tokyo Institute of Technology	Profs. Kimura, Kato
	Nagoya Institute of Technology	Prof. Kato
	Kyoto Institute of Technology	Prof. Nishikawa
	Keio University	Prof. Yamaguchi
	Waseda University	Prof. Ichinose
Science and Technology Agency	National Inst. for Research in Inorganic Materials	Dr. Setaka
Defense Agency	National Defense Academy	Prof. Niihara

Table 4. Target Performance Properties of Fine Ceramics (for First and Second Phases)

Property	Objective
High Strength Materials	≥1,200 °C, in air, after 1,000 h exposure Weibull modulus ≥20 Average tensile strength ≥30 kg/mm^2
	1,200 °C, in air, after 1,000 h continuous loading Creep rupture strength ≥10 kg/mm^2
Corrosion Resistant Materials	≥1,300 °C, in air, after 1,000 h exposure Weibull modulus ≥20 Corrosion resistance (weight gain) <1 mg/cm^2 Average tensile strength ≥20 kg/mm^2
Wear Resistant Materials	Room temperature Wear resistance ≥10^{-3} $mm^{-3}/kg \cdot mm$ Surface flatness <2 μm
	800 °C, in air, after 1,000 h exposure Weibull modulus ≥22 Average tensile strength ≥50 kg/mm^2

Table 5. Performance Objectives for the Final Phase

Condition	Objective
Usable at Higher Than 1,400 °C in Air	Fast fracture; minimum guaranteed strength ≥400 MPa; rate of rejection <20%; Weibull modulus ≥20
	Stress rupture life of 10,000 h under loads of ≥250 MPa
	Oxidation, corrosion, and wear resistance--no degradation in strength nor microstructural changes after 200 h; exposure in combustion gas flow of ≥1,400 °C containing coal ash
	Fracture toughness ≥8 MPa$\sqrt{m}$ at room temperature
Usable at Higher Than 1,250 °C in Air	Fast fracture; minimum guaranteed strength ≥600 MPa; rate of rejection <20%; Weibull modulus ≥20
	Stress rupture life of 10,000 under loads of ≥250 MPa
	Oxidation, corrosion, and wear resistance--no degradation in strength nor microstructural changes after 100 h; exposure in combustion gas flow of ≥1,250 °C containing coal ash
	Fracture toughness ≥15 MPa$\sqrt{m}$ at room temperature

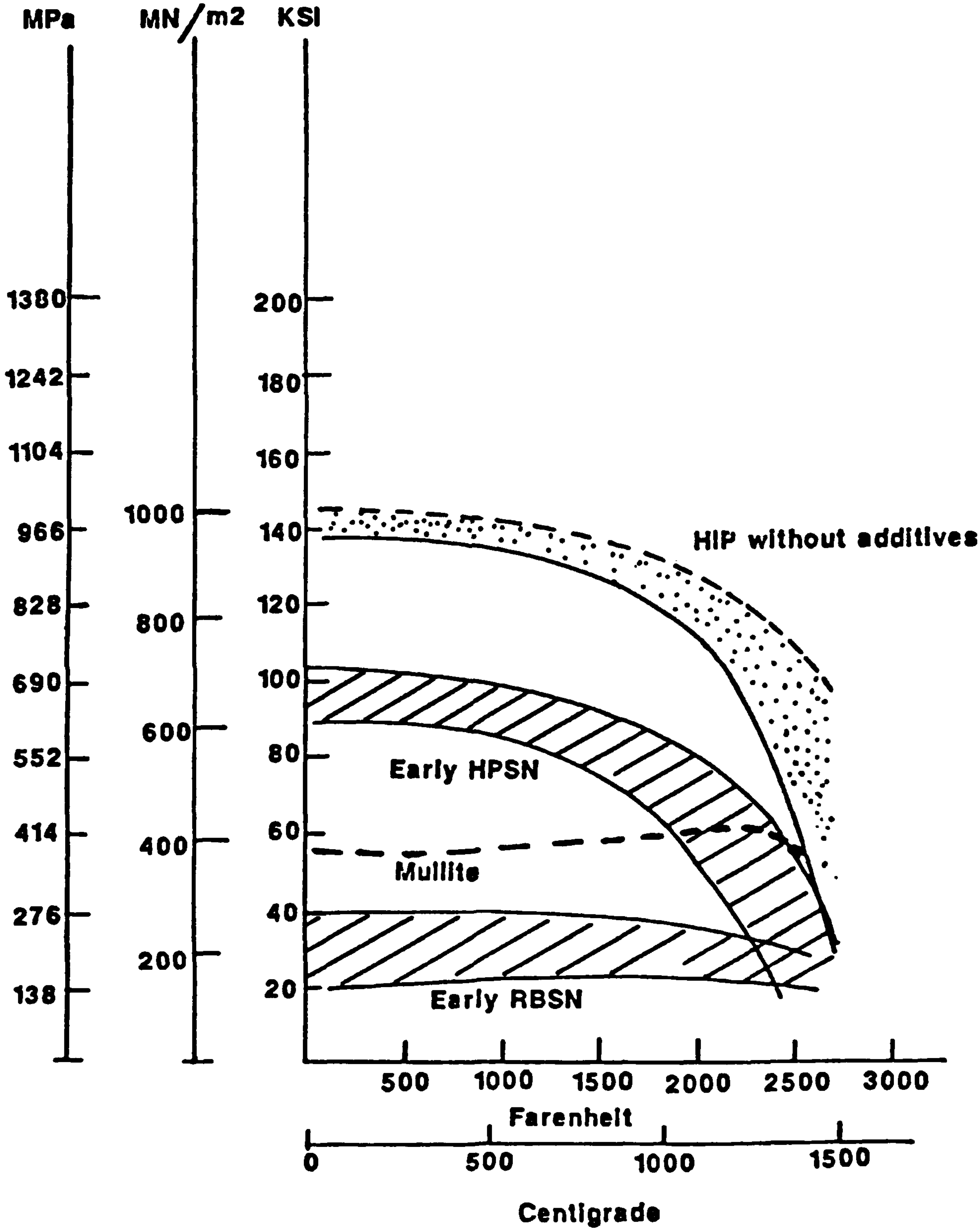

Figure 5. Flexural strength as a function of temperature for different varieties of Si_3N_4 that shows the improved properties of HIP-processed Si_3N_4.

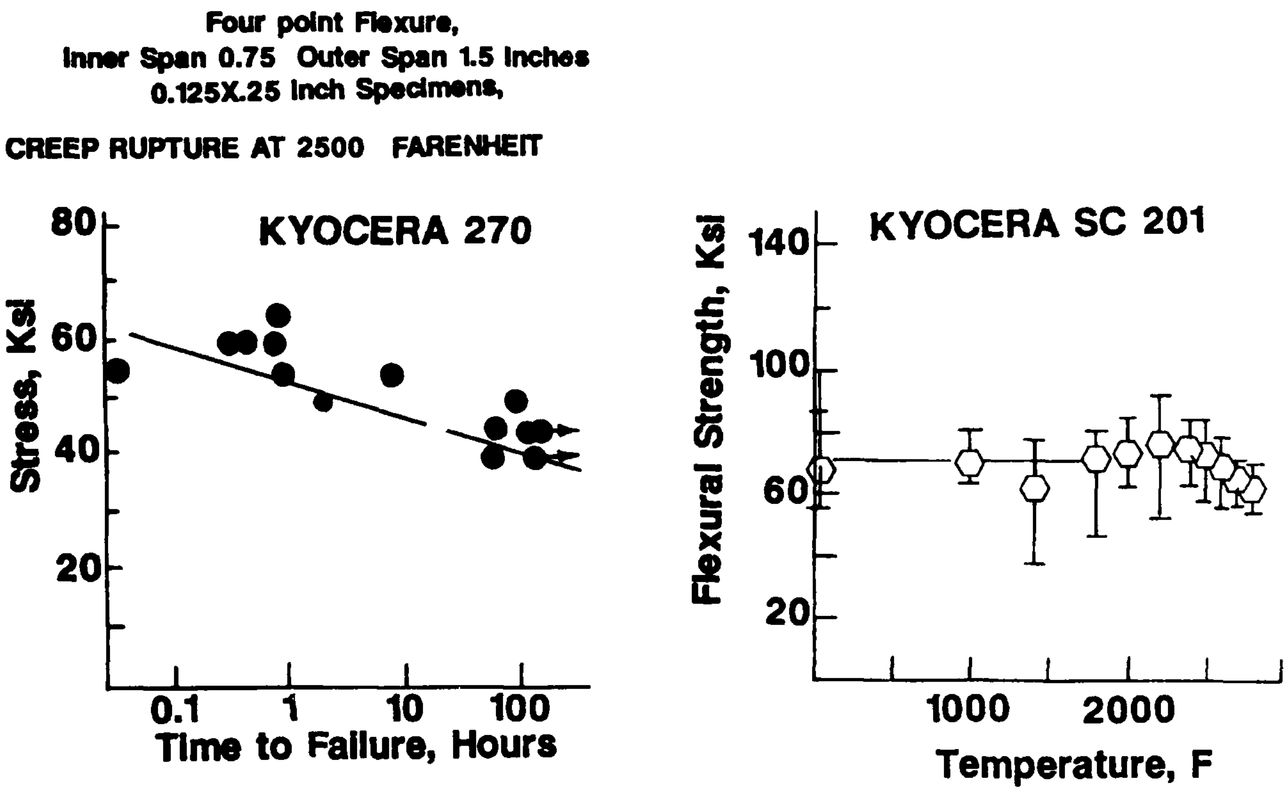

Figure 6. Stress rupture lives of Si_3N_4 at 2,500 °F (1,370 °C) and flexural strengths of SiC as a function of temperature. These materials are at the pilot plant stage.

FIBERS AND COMPOSITES

Within the last year two assessments have been made on selected areas of composites and fibers in Japan. During September 1988, Japan's high performance composite research activities and applications were assessed (Ref 93) and during February 1989 the technology of structural composites was assessed (Ref 94). Since these assessments are to be published in the near future, the present paper will just present some examples of the work being performed on fibers and composites.

As mentioned previously in this paper the focal point for advanced composite work in Japan is the national project on advanced composites under the direction of MITI. Nevertheless, numerous companies and university researchers not directly involved with this project are also conducting studies relevant to fibers and composites. Table 6 indicates some companies that are members of the Japan Research and Development Center for Metals and their efforts involving composite materials. There are 27 companies indicated and most of them are not part of the Advanced Composite Project.

There are a number of companies in Japan producing carbon fibers from either polyacrylonitrile (PAN) oi pitch. Japan produces about 90 percent of the world's supply. These companies as well as the properties of these fibers have been described in a previous article (Ref 95). It is sufficient here to note that PAN carbon fibers have higher strengths (e.g., 6 GPa compared to

3 GPa), whereas pitch fibers have higher moduli (800 GPa compared to 400 GPa). Carbon fibers possess probably the highest strengths of any known material at temperatures in the range between 1,500 and 2,000 °C. The problem is oxidation resistance; to use these properties carbon must be used in vacuum or in inert gases with low partial pressures of oxygen. Uncoated carbon fibers can be used at temperatures up to 700 °C for short times on the order of minutes. Long time exposures cannot exceed temperatures of about 400 °C.

Some of the ceramic fiber manufacturers in Japan are identified in Table 7 along with the approximate fiber compositions and some properties and characteristics. As indicated in Figure 3 the strengths of the ceramic fibers begin to decrease at temperatures in the range between 1,000 and 1,200 °C. Inspection of the compositions presented in Table 7 shows that most of these fibers can react with oxygen, and at high temperatures in environments with low oxygen pressures volatile species (e.g., SiO) can be formed. The ceramic fibers represent a dramatic improvement in oxidation resistance compared to carbon fibers, but at temperatures above 1,000 °C reactions induced because of the environments cannot be considered negligible. This is especially the case when the exposure times are to be long (e.g., ~1,000 hours) and contaminants (e.g., Na, S) may accumulate, even in very small quantities, on the surfaces of these materials.

The fiber-reinforced polymer (FRP) work in Japan is focused on the development of heat-resistant resins, prepregs made from reinforcing materials such as carbon with newly developed resins, and molding techniques. Prepregs with superior heat resistance at high temperatures (~250 °C) have been obtained. An automatic loom for three-dimensional fabrics was developed. Composite materials made by infusing resins into three-dimensional fabrics have been found to possess superior mechanical characteristics. Molding techniques have been established to produce large monolithic structural elements such as aircraft fuselages and wings, negating the need for adhesive bonding or rivet joining. Automatic layup equipment also has been developed for automating the prepreg laminating process instead of using the manual method.

For the development of fiber-reinforced metals (FRMs), carbon fibers and some ceramic fibers (e.g., $Si_{1-x}Ti_xC$+ oxygen) are being used as reinforcing materials. Emphasis has been placed on using aluminum alloys and understanding the reactions that occur between fibers a metals. Techniques have been developed *for continuously producing* wire preform by immersing bundles of surface-treated fibers in molten aluminum. Deposition of chemically vaporized aluminum on fiber surfaces also has been achieved. Waku et al. (Ref 96) have developed an aluminum metal matrix composite with a continuous Si-Ti-C-O fiber by squeeze casting. They found the high temperature flexural strength with an Al-8Ni matrix to be much higher than that for the pure aluminum matrix composite. The flexural strength for the alloy matrix was 1.3 GPa at 300 °C in a longitudinal direction and 1.1 GPa at 400 °C. Ishikawa (Ref 97) describes an aluminum matrix FRM made by using aluminum preform wires. Work on wire preforms in conjunction with press, roll, and hot isostatic press molding has been performed. Optimum molding temperatures, pressures, and times are being evaluated to attempt to achieve higher composite strengths.

Table 6. Some Members of the Japan Research and Development Center for Metals Involved With Composite Materials (as of the end of 1988)

Member Companies	Stage of Development[a] of the Following Composite Materials[b]--											
	FRP 1	FRP 2	FRP 3	FRP 4	FRP 5	FRP 6	FRP 7	FRP 8	MMC	FRC	C/C	Other
Nippon Steel Corp.	R	R			R			R	R	S	R	
NKK Corp.			R		M			R	S			
Kawasaki Steel Corp.	R										R	M
Sumitomo Metal Ind., Ltd.					S					M	M	
Kobe Steel, Ltd.									S	R	M	M
Nisshin Steel Co., Ltd.												M
Daido Steel	S				S							
Nippon Koshuha Steel Co., Ltd.												M
Showa Denko K.K.							R		R		S	M
Mitsubishi Metal Corp.									M			M
Sumitomo Metal Mining Co., Ltd.												M
Nippon Light Metal Co., Ltd.	M								M		M	
Sumitomo Light Metal Ind., Ltd.									S			
Showa Aluminum Corp.												R
Mitsubishi Aluminum Co., Ltd.									S			
Furukawa Electric Co., Ltd.									R			
Sumitomo Electric Ind., Ltd.	M										S	
Fujikura, Ltd.												M
Hitachi Cable, Ltd.												M
Vacuum Metallurgical Co., Ltd.				M		S						
Ishikawajima-Harima Heavy Ind. Co., Ltd.[c]	M	R	R		M	R	R		R	R	R	
NEC Corp.[c]					M							M
Mitsubishi Heavy Ind., Ltd.[c]	M	R	M	M	M				R	R	R	
Nissan Motor Co., Ltd.[c]	M				M						M	M
Toyota Motor Corp.[c]					M				M			
Kawasaki Heavy Ind., Ltd.[c]	M	R	M	M	M	R			R	R	R	
Mitsubishi Electric Corp.[c]	M	M	M		M	M	M	R	R			R
Nippon Telegraph & Telephone Corp.[c]					M							

[a]M - Market/penetration in new materials.
S - Sample shipment.
R - Research stage.
[b]FRP 1 - PAN-type carbon fiber
FRP 2 - Pitch-type carbon fiber
FRP 3 - Aramid fiber
FRP 4 - Boron fiber
FRP 5 - Glass fiber
FRP 6 - Silicon carbide fiber
FRP 7 - Alumina fiber
FRP 8 - Metallic fiber
[c]M - Includes companies that procure new materials and put them into practical use.
R - Research stage, aiming at practical use.

Ceramic whiskers also are being used to strengthen metals such as aluminum. KOBELCO has developed a process to fabricate a SiC whisker-reinforced aluminum alloy. A high pressure casting process is used that is claimed to be cheaper compared to hardware prepared by using powder metallurgical procedures, and mechanical properties such as strength and elasticity are improved.

Table 7. Ceramic Fiber Manufacturers in Japan

Company	Approximate Composition (all % are wt. %)	Diameter (microns)	Density (gm/cm^3)	Elongation Modulus (GPa)	UTS (MPa)
Ube Industries Ltd. (Tyranno fiber)	$Si_{1-x}Ti_xC$+oxygen (typical titanium and oxygen concentrations are 2% and 18%, respectively; Ti can be as high as 7%)	8-10	2.3-2.5	200	2,740
Nippon Carbon Co. Ltd. (Nicalon)	69.6%SiC+20.8%SiO_2+9.6%free oxygen (58.3%Si, 30.4%C, 11.1%O, 0.2%H)	15	2.55	200	2,740
Toa Nenryo Kogyo K.K. (Tonen Si_3N_4)	Si_3N_4+oxygen+carbon	10	2.5	300	2,500
Shimadzu Corp. (glass fiber)	Silicon oxynitride glass+Mg,Ca,Al (up to 7% nitrogen; metal oxide permits more nitrogen to be added with no crystallization)	7-20	3.03	195	4,800
Sumitomo Chemical Co.	Al_2O_3-15%SiO_2	10-15	3.25	210	1,800
Mitsui Mining	99.5%Al_2O_3	10-13	--	342	1,950

Since composite materials possess properties not available in conventional materials, new evaluation criteria and design concepts are being developed. Methods for evaluating the heat resistance of resins, techniques to detect mold defects, methods for evaluating the mechanical characteristics of fracture, and reliability assessment of molds are examples of the areas that have been investigated in order to better define, control, and utilize FRP and FRM composites.

Ceramic matrix composites are being studied in Japan but not as extensively as polymer or metal matrix composites. Nippon Carbon has developed a ceramic fiber (Nicalon)-SiC matrix material called Nicalo-Ceram. It has been proposed that this material may be used for extended periods of time in oxidizing environments at temperatures up to 1,200 °C. It is important to emphasize that while this material has very impressive resistance to oxidation, the oxidation resistance is achieved by the formation of SiO_2 scales. The protectiveness of SiO_2 is affected by impurities. Sources of impurities that will affect the protectiveness of SiO_2 scales are the composite itself and the environment in which the composite is used.

Niihara at the National Defense Academy is studying the toughening of ceramics by incorporating second phases, or structural defects. For example, in the case of Al_2O_3, the fracture toughness and strength were increased by a factor of three by dispersing superfine SiC or stabilized ZrO_2 particles, or SiC whiskers. This approach has also resulted in the improvement of the mechanical properties of both Si_3N_4 and SiC.

Noritake Co., Ltd. has reported a high strength, high toughness composite material based upon Si_3N_4 with carbon fibers.

This composite showed a fracture toughness of 29 MPa at a temperature of 1,200 °C and a flexural strength of 690 MPa at room temperature. This approach has also been applied to mullite; a fracture toughness of 18 MPa with a flexural strength of 610 MPa was obtained at room temperature.

Recent governmental research themes emphasize fiber and composite investigations. For example, oxidation-resistant carbon fibers sheathed in ceramics, high strength SiC fibers, carbon fiber-carbon composite materials with heat resistances of 2,000 °C, and intermetallic compounds reinforced with SiC fibers will receive emphasis.

HIGH TEMPERATURE CORROSION

In describing the technical effort on high temperature materials in Japan, some of the research that is directed specifically at high temperature corrosion processes will be identified. The proceedings from the Materials Research Society meeting in Tokyo in June 1988 on advanced materials, which included a session on corrosion of advanced materials, will be published soon (Ref 98).

A number of investigators are studying the corrosion of ceramics. Yoshimura and coworkers at the Tokyo Institute of Technology are investigating the effects of high temperature, high pressure water on the degradation of materials such as Si_3N_4, SiC, and yttria-stabilized zirconia (Ref 98-100). Takeuchi and coworkers at Kyoto University are investigating the oxidation of Si_3N_4 in oxygen at temperatures up to 1,600 °C (Ref 98). The oxidation of TiN is being examined by Taniguchi at Osaka University. Endo and coworkers at Tohoku University are studying the corrosion of ceramics induced by molten salts (Ref 98). Ceramics corrosion also is being investigated at the Government Industrial Research Institute in Kyushu and at a number of industrial laboratories (Ref 98).

As noted previously, the corrosion of alloys under conditions similar to those developed in gas turbines is being studied by the gas turbine manufacturers (IHI, KHI, and MHI) and NRIM. High temperature corrosion investigations on metallic alloys are being performed at the Tokyo Institute of Technology by Saito and coworkers. They are studying the effects of rare-earth elements on oxide scale adherence (Ref 98,101). Nagai at Osaka University has been studying the effects of rare-earth oxide dispersions on the oxidation of Ni-Cr alloys (Ref 98), and Narita and coworkers at Hokkaido University have been investigating the corrosion of a variety of alloys including austenitic stainless steels in H_2S-H_2 gas mixtures.

CONCLUDING REMARKS

There is a very extensive amount of R&D being performed in Japan on high temperature materials. In the case of superalloys and high temperature coatings much of the work has followed that in the United States. For example, the work that has been performed on directional solidification, single-crystal technology, oxide dispersion strengthening, and low pressure plasma sprayed coatings involves more detailed studies of developments achieved previously in the United States. A very good technology base has been established and some significant contributions have been made, which include the use of regression analyses as an aid to optimizing superalloy elemental compositions and advances to the theory for precipitate aging morphologies.

The work performed by the Japanese with titanium alloys also follows the United States, but in the case of studies on compounds such as TiAl, some innovative concepts have been developed in regards to achieving improved ductility at low temperatures. Furthermore, research on mechanical properties of intermetallics such as Ni_3Al and the influence of elements such as carbon, boron, and beryllium is very significant and represents some concepts that are at the leading edge of such investigations.

The Japanese are placing emphasis on functional gradient materials. Functional thermal barriers were designed and effectively used by the National Aeronautics and Space Administration and by Pratt and Whitney more than 20 years ago. Moreover, much work is being performed in the United States on attempting to develop more effective thermal barrier systems. The Japanese are now taking this concept and attempting to develop a technology based upon it to obtain materials for ultra high temperature applications.

With the interest in Japan on various types of steels, especially specialty steels, and on steels for nuclear applications, the R&D on heat-resisting steels is extensive and at the very leading edge of this technology.

The coatings technology for high temperature applications in regards to diffusion aluminide coatings and MCRALY overlay coatings is behind that of the United States. In the case of various coating techniques to form coatings such as carbides (e.g., SiC) or nitrides (e.g., TiN), however, the technology is highly advanced and some unique coatings as well as coatings procedures have been developed.

An impressive effort is being made in Japan to use ceramics in automotive and industrial gas turbines. The emphasis is on improving the mechanical properties and oxidation resistance of Si_3N_4. Carbon and ceramic fiber technology is also highly advanced with current research emphasizing improved high temperature properties. These technologies are at the leading edge when compared to efforts in all other countries.

As stated at the beginning of this paper, high temperature materials have not been priority items in Japan. Nevertheless, a very significant base in such materials has been developed extending from industrial laboratories and national laboratories to university research. This base consists of very capable researchers working on subjects that have been identified by research in other countries first. There are some exceptions, and in the case of fine ceramics, carbon fibers, and ceramic fibers, Japan is leading the way. Finally, it is worth noting that more basic research is being emphasized in Japan and high temperature materials are receiving more attention. With the technical base that exists in high temperature materials, some significant breakthroughs in high temperature materials technology should be achieved.

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Edward Mark Lenoe is a program manager for international programs at the U.S. Army Materials Technology Laboratory [formerly called the Army Materials and Mechanics Research Center (AMMRC)]. He was a liaison scientist at ONR/AFOSR/ARO-FE from October 1985 to September 1989. Previously Dr. Lenoe managed the AMMRC Reliability Mechanics and Standardization Division, served as operating agent for the International Energy Agency implementing agreements on high temperature ceramics for heat engine applications, and also managed numerous major contracts. His areas of interest include advanced materials and relevant emerging technologies.

Appendix

CURRENT CERAMICS RESEARCH AND DEVELOPMENT (R&D) AT JAPANESE NATIONAL LABORATORIES, INDUSTRIAL LABORATORIES, AND UNIVERSITIES

This appendix includes a current compilation of ceramics research that emphasizes high temperature applications. It includes research that is part of the third phase of the Fine Ceramics Project and some selected papers from a recent meeting of the Japan Ceramics Society. This latter research represents research at universities funded by the Ministry of Education (Monbusho) and industrial companies.

OUTLINE OF R&D IN THE THIRD TERM OF THE HIGH PERFORMANCE CERAMICS PROJECT (1988-1991) BY THEME AND INSTITUTION

Theme	Institution
National Laboratories	
R&D on high temperature fracture; elucidation of fracture mechanism	National Inst. for Research in Inorganic Materials (NIRIM), Tsukuba
Technology for production processes	
Evaluation of process technology; general forming and sintering techniques	Government Industrial Research Inst. (GIRI), Nagoya
Explosion forming and sintering technology	National Chemical Lab for Industry, Tsukuba
Machining technology	Mechanical Engineering Lab (MEL), Tsukuba
Toughening by fiber reinforcement	GIRI, Osaka
Toughening by particle dispersion	GIRI, Nagoya
Surface strengthening technology (by ion implantation, etc.)	GIRI, Nagoya
Evaluation of mechanical properties	
Strength	GIRI, Nagoya
Wear resistance	GIRI, Osaka
Corrosion resistance against high temperature gases	GIRI, Kyushu
Toughness	GIRI, Nagoya

Theme	Institution
Industrial Laboratories	
Investigation of technology related to structural ceramics and consolidation of database	Engineering Research Assoc. (ERA) Project Office
Technology for gas-turbine components	
Model design and evaluation	Ishikawajima-Harima Heavy Ind. (IHI) Co., Ltd.
Material optimization for specific properties	
Silicon nitride	NGK Spark Plug Co., Ltd. Sumitomo Electric Ind., Ltd.
Silicon carbide	Asahi Glass Co., Ltd. Kyocera Central Research Lab
Forming and sintering (for large and complicated products)	
Silicon nitride	Toshiba R&D Center Kobe Steel, Ltd.
Silicon carbide	Asahi Glass Co., Ltd.
Machining	
Silicon nitride	Toyoda Machine Works, Ltd.
Silicon carbide	Inoue Japax Research Inc.
Joining	
Silicon nitride	Sumitomo Electric Ind., Ltd.
Silicon carbide	Kyocera Central Research Lab
Proof-test	IHI
Material technology	
Particle-dispersed high toughness material	
Silicon nitride matrix	Denki Kagaku Kogyo K.K.
Silicon carbide matrix	Showa Denko K.K.
Boron-deposited silicon carbide matrix	Kurosaki Refractories Co., Ltd. Nippon Steel Corp.

Theme	Institution
Industrial Laboratories (continued)	
Fiber-reinforced high toughness material	
Silicon nitride matrix	Toshiba R&D Center
Silicon carbide matrix	IHI
Laminate structure	Sumitomo Electric Ind., Ltd.
Chemical vapor infiltration preforms	Kyocera Central Research Lab
Microstructural optimization for high toughness	Asahi Glass Co., Ltd.
Surface modification technology	Toshiba R&D Center
Surface coating technology	NGK Insulator, Ltd.
Evaluation & application technology	
Nondestructive test	Toshiba R&D Center
Design standards	IHI
Fracture analyses	
Under combined stress with tension	NGK Insulator, Ltd.
Under stress gradients	IHI
Impact fracture	Japan Fine Ceramics Center (JFCC)
Corrosion-fracture mechanisms	Toyota Motor Corp. NGK Spark Plug Co., Ltd.
Thermal fatigue	Shinagawa Refractories Co., Ltd.

SPECIFIC RESEARCH PROGRAMS IN THE THIRD TERM OF THE HIGH PERFORMANCE CERAMICS PROJECT

Title	Investigator	Institution
Synthesis of Silicon Nitride Powders from Silica Reduction	Yoshiyuki Ohnuma	Toshiba R&D Center
Synthesis of High-Quality α-Si_3N_4 Powder by Means of Direct Nitridation Method of Metallic Silicon	Youzou Kuranari Miyuki Nakamura	R&D Div, Omuta Plant, Denki Kagaku Kogyo
Synthesis of High-Quality α-Si_3N_4 Powder by Means of High Temperature Vapor Phase Reaction Between $SiCl_4$ & NH_3	Masaji Ishii Tadasuke Shigi Hiroaki Tanji Masaaki Obata	Central Research Lab, Denki Kagaku Kogyo K.K.
Silicon Carbide Powder Synthesis Technology	Masataka Yamamoto	Showa Denko K.K.
Development of High Strength Silicon Nitride	Katsutoshi Nishida	Toshiba New Materials Engineering Lab (NMEL)
	Yasuhiro Goto	Toshiba R&D Center
	Takeshi Kanda	Kobe Steel Mechanical Engineering Research Lab (MERL)
	Hiroshi Okada	Kobe Steel Material Research Lab (MRL)
Silicon Carbide High Temperature Materials	Takashi Kanno Keiichiro Suzuki Minoru Kawai Nobuhiro Shonohara Hiroyuki Fujita Nobuo Kageyama Shigeru Osaka Hideo Takahashi Hiroshi Abe	Asahi Glass Co., Ltd.
Development of Oxidation Resistant Silicon Nitride Ceramics by Post Sintering Techniques	Toru Shimamori Takehiko Kato Yasushi Matsuo	NGK Spark Plug Co., Ltd.
Research on Wear-Resistant Silicon Nitride Ceramics	Masaaki Honda Masaya Miyake	Sumitomo Electric Ind., Ceramics Project Group
Development of High Wear-Resistant Silicon Carbide	Yasurou Samejima Kazunori Koga Saburou Nagano	Kyocera Central Research Lab

Title	Investigator	Institution
High Strength Ceramic Model	Junsuke Okamura Kooichi Katohno	IHI
	Minoru Matsui Hideyoshi Turuta	NGK Insulators Co., Ltd.
Thermal Shock Testing of Corrosion-Resistant Ceramic Model Parts	Takao Mikami Tadashi Sasa Junsuke Okamura Masakazu Obata Kanji Watanabe	IHI
Test of Ceramics Durability for High Precision and Antiwear Parts	Shinobu Saito Hisao Iwamatsu Takashi Sugita Masaki Horiuchi	IHI
Synthesis of Silicon Nitride Powders from Silica Reduction	Yoshiyuki Ohnuma	Toshiba R&D Center
Forming and Sintering of the First Stage Model of High Strength Silicon Nitride and Results of the Spin Test	Takeshi Kanda Yasuhiko Inoue	Kobe Steel MERL
	Katsutoshi Nishida Yasuhiro Goto	Toshiba NMEL Toshiba R&D Center
	Junsuke Okamura	IHI
Silicon Carbides	Takashi Kanno Keiichiro Suzuki Minoru Kawai Nobuhiro Shonohara Hiroyuki Fujita Nobuo Kageyama Shigeru Osaka Hideo Takahashi Hiroshi Abe	Asahi Glass Research Center
	Junsuke Okamura Takao Mikami	IHI Technical Center
Forming and Sintering Techniques and Results of Model Tests of Corrosion-Resistant Silicon Nitride	Toru Shimamori Takehiko Kato Yasushi Matsuo	NGK Spark Plug Co., Ltd.
	Takao Mikami Junsuke Okamura Tadashi Sasa	IHI

Title	Investigator	Institution
Research on Wear-Resistant Silicon Nitride Ceramics	Masaaki Honda Masaya Miyake Akira Kuibira	Sumitomo Electric Ind.
	Hisayasu Iwamatsu Shinobu Saito Takashi Sugita Masaaki Horiuchi	IHI
Development of High Wear-Resistant Silicon Carbide	Yasurou Samejima Kazunori Koga Saburou Nagano Akira Saitou Masaki Terazono	Kyocera Central Research Lab
	Shinobu Saitou Takashi Sugita Hisayasu Iwamatsu Masaaki Horiuchi	IHI
Influence of Specific Surface Area and Oxygen Content of Starting Powders on Sinterability, Microstructural Development, and Mechanical Properties of Silicon Nitride	Suzuo Kanzaki Takaaki Nagaoka Masayoshi Ohashi Osami Abe	GIRI, Nagoya
	Akio Yoshida Miyuki Nakamura Hideki Hirotsuru Yukihiko Nakajima	Denki Kagaku Kogyo K.K.
Influence of Silicon Nitride Powders Characteristics on the Sintering Behavior and Properties of Sintered Bodies	Yukihiko Nakajima Miyuki Nakamura Akio Yoshida Hideki Hirotsuru	Denki Kagaku Kogyo K.K.
	Yoshiyuki Onuma	Toshiba R&D Center
	Toru Shimamori	NGK Spark Plug Co., Ltd.
	Masaaki Honda	Sumitomo Electric Ind.
	Takeshi Kanda	Kobe Steel MERL
	Suzuo Kanzaki Osami Abe Masayoshi Ohashi Takaaki Nagaoka	GIRI, Nagoya

Title	Investigator	Institution
Influence of Powder Characteristics on Sinterability of Silicon Carbide	Osami Abe	GIRI, Nagoya
	Masataka Yamamoto	Showa Denko K.K.
	Yasuro Samejima	Kyocera Central Research Lab
	Takashi Kanno	Asahi Glass Co., Ltd.
Grinding of Fine Ceramics (Development of Electrolytic In-Process Dressing and Ultrasonically Assisted Drilling)	Keisaku Okano Chisato Tsutsumi Satoshi Itoh	MEL, Tsukuba
Development of High Rigidity Grinding-Laser Processing Machine for Fine Ceramics	Masahiro Okamoto	Toyoda Machine Works
Joining of Silicon Nitride Ceramics	Masaaki Honda Masaya Miyake Osamu Komura Hirohiko Nakata Akira Kuibira	Sumitomo Electric Ind.
Surface Flaw Detection	Izumi Tomeno Hideyuki Ohzu	Toshiba R&D Center
Inspection of Inner Defects	Yoshinori Tanimoto Kiichiro Uyama Masami Tomizawa Masaya Yoshida	Toshiba R&D Center, Fuchu Works
Fracture Behavior of Sintered Silicon Nitride Under Uniaxial and Multiaxial Stresses	Naohito Yamada Masaaki Masuda Takao Soma Minoru Matsui Isao Oda	NGK Insulators Co., Ltd.
Fast Fracture Strength Under Nonuniform Stress State	Jun-ichi Hamanaka Akihiko Suzuki Seijiro Hayashi	IHI
Flexural Fracture Behavior in High Temperature Atmospheres	Takuya Kondo	Toyota Motor Corp.
Fracture of Cylindrical Sample Under Static Thermal Stress	Hiroshi Kubota	Kurosaki Refractories

Title	Investigator	Institution
Static Fatigue Behavior Under Tensile Stress	M. Sasuda T. Soma M. Tatsui I. Oda	NGK Insulators Co., Ltd.
Static Fatigue Under Bending	Akihiko Suzuki	IHI
Microscopic Observation of the Crack Propagation Behavior	Masaki Kitagawa	IHI
Fatigue Behavior Under Tension-Compression Cyclic Stress	M. Masuda T. Soma M. Matsui I. Oda	NGK Insulators Co., Ltd.
Cyclic Fatigue Under Bending	Akihiko Suzuki Shigekatsu Sugiyama	IHI
Thermal Fatigue Behavior	Kenki Ishizawa Nobuo Ayuzawa Hideki Hashi Akira Shiranita	Shinagawa Refractories Co., Ltd.
Proof Testing of Ceramic Components	Jun-ichi Hamanaka Yoshitaka Nakamura Akihiko Suzuki Seijiro Hayashi	IHI
Design Guide for Ceramic Components	Akihiko Suzuki Jun-ichi Hamanaka	IHI
Basic Research on Process Technology - Forming Process	Osami Abe	GIRI, Nagoya
Solid State Sintering of Silicon Nitride Ceramics with the Addition of Beryllium Aluminum Oxide	Hideyo Tabata Shuzo Kanzaki Asami Abe Masayoshi Ohashi	GIRI, Nagoya
High Pressure Sintering of Silicon Nitride Without Additives	Michihide Machida Haruo Yoshida Shoichi Kume	GIRI, Nagoya

Title	Investigator	Institution
Shock Consolidation and Shock-Activated Sintering	Fumikazu Ikazaki Kunio Kamiya Kunio Uchida Mitsutaka Kawamura Katsumi Tanaka Katsutoshi Aoki Shuzo Fujiwara	National Chemical Lab for Industry, Tsukuba
Evaluation Technology for Starting Powder	Yoshitaka Kuwahara Kazuo Suzuki Toshio Ishizuka Yoshinori Uwamino Akira Tsuge	GIRI, Nagoya
Tensile Testing	Tatsuki Ohji Seisuke Sakai Masaru Ito Shoji Ito	GIRI, Nagoya
Fatigue Behavior	Yukihiko Yamauchi Seisuke Sakai Masaru Ito Shoji Ito	GIRI, Nagoya
Fracture Mechanics	Shuji Sakaguchi Norimitsu Murayama Fumihiro Wakai	GIRI, Nagoya
Hot Gas Corrosion Test	Seiki Umebayashi Kazushi Kishi Kenji Miyazaki Akira Takase	GIRI, Kyushu
Tribological Properties of Ceramics and Its Testing Method	Mikio Iwasa Yasuo Toibana Makoto Kinoshita	GIRI, Osaka
High Temperature Creep, Crack Tip Geometry, and Microstructure of SiC and Si_3N_4 Ceramics	Hidehiko Tanaka Yoshio Bando Yoshizo Inomata	NIRIM

SELECTED PAPERS REPRESENTING HIGH TEMPERATURE CERAMICS RESEARCH PRESENTED AT THE ANNUAL MEETING OF THE JAPAN CERAMICS SOCIETY (15-17 MAY 1989)

Paper	Researcher	Institution
Oxides		
Far-Infrared Radiation Property of Oxide-Ceramics	Jouji Matsumoto Noboru Yoshimura Haruo Taguchi Shouichi Iwaya	Ceramic Div., TDK Co.
Effects of Heating Conditions on Properties of Magnesia Compacts (1)	Kenya Hamano Tokuo Nakazawa Shigeru Okada	Kanagawa University
Structure of Green Compacts Made from Al_2O_3-SiO_2 Colloidal Suspension	Takao Yamada Toshio Kimura Takashi Yamaguchi	Keio University
Hot-Extrusion Process of Oxide Ceramics	Takeshi Shiono Toshihiko Nishida Yoshiro Takeda Tomozo Nishikawa	Kyoto Institute of Technology
Dewaxing and Sintering of Injection Molded Al_2O_3 Green Bodies in Natural Gas-Fired Ceramic Kiln	Mitsuru Wakamatsu Satoshi Shimizu Nobuyuki Takeuchi Yoichi Hachitani Minoru Takao	Kyoto Institute of Technology
Synthesis of Spherical TiO_2 Powders by Homogeneous Precipitation Method	Yukitoshi Takeshita Yukiko Katatae Akio Kato	Kyushu University
Densification and Microstructure Development During Hot Isostatic Pressing of Alumina	M. Sekiguchi N. Uchida K. Uematsu K. Saito	Nagaoka University of Technology
	A. Miyamoto	Nippon Kokan K.K.
Effect of Water Vapor on Ionic Conductivity for Porous β/β''-Al_2O_3 Ceramics	Teruo Kushida Masayuki Nagai Tadashi Sakurai Tadashi Nishino	Musashi Institute of Technology
Effect of Grain Size on Fatigue Strength of Sintered Al_2O_3 Under Rotary Bending	H.N. Ko	Nakanihon Automotive College

Paper	Researcher	Institution
	Oxides (continued)	
Impregnation and Firing of Al_2O_3 Compact with CrO_3 Saturated Solution	Hidehiko Kobayashi Tsutomu Suzuki Nobuhiko Hayashi Takashi Mitamura	Saitama University
Preparation of Aluminum Hydroxides Precipitated from Aqueous Solutions of Sulphates of Aluminum by Reaction with Alkali	Taichi Sato Keiichi Sato Hiroaki Otsuki	Shizuoka University, Hamamatsu
Intermediate Stage Sintering Mechanism of Monodispersed TiO_2 Fine Particles	Takashi Ogihara Masaki Ikeda Noboyasu Mizutani Masanori Kato	Tokyo Institute of Technology
Zirconia Toughened Apatite Ceramics Prepared by Post-Sintering	Koji Ioku Shigeyuki Somiya Masahiro Yoshimura	Research Laboratory of Engineering Materials, Tokyo Institute of Technology
Preparation of Mullite Ceramics from Kaolin and Alumina	Kenya Hamano Hiroaki Nakajima Shigeru Okada	Kanagawa University
	Zenbe-e Nakagawa	Research Laboratory of Engineering Materials, Tokyo Institute of Technology
Sintering of Binary Alumina Powder Mixtures (3)	Seiichi Taruta Kiyoshi Okada Nozomu Otsuka	Tokyo Institute of Technology
Property of Mechanochemically Treated Alumina Powder by Heating	Masaki Yasuoka Kiyoshi Okada Nozomu Otsuka	Tokyo Institute of Technology
Injection Molding Process of Oxide Ceramics	Yoshitaka Ohyama Yasunari Kaneko Hiromichi Iwasaki	Ritsumeikan University
	Norio Kasahara	Mitsui Mining and Smelting Co., Ltd.
	Yoshimitsu Kankawa Katsuyoshi Saitoh	Kyoto Municipal Inst. of Industrial Research

Paper	Researcher	Institution
Oxides (continued)		
Sintering and Mechanical Properties of Ce-TZP/Al_2O_3 Composite	Masayuki Ishitsuka Tsugio Sato Tadashi Endo Masahiko Shimada	Tohoku University
Influence of Forming Aids on Sintering of Binary Alumina Powder Mixtures	Seiichi Taruta Kiyoshi Okada Nozomu Otsuka	Tokyo Institute of Technology
Analysis of Fracture Mechanics of Beta-Alumina by Acoustic Emission	Akiyasu Okuno	Engineering Research Center, Tokyo Electric Power Company
	Mitsuharu Shiwa Teruo Kishi	Research Center for Advanced Science and Technology, University of Tokyo
Zirconia		
Preparation of the Cordierite-ZrO_2 Ceramics by the Sol-Gel Process	Masayuki Nogami	Aichi Institute of Technology
	Shin-ichi Ogawa Katsumi Nagasaka	Hoya Co.
Compressive Deformation Properties in Partially Sintered Preform-Zirconia	Kazuo Yamana Yukiko Yamamoto Shizuo Nakamura	Industrial Research Institute, Ishikawa
	Kazuo Kitagawa	Kanazawa University
	Takuji Yoshimura Toshimasa Mano Yoshitomo Shintani	Kanebo Ltd.
Effect of Heating Rate on the Shrinkage of Y-ZrO_2 during Isothermal Sintering	Yasuro Ikuma Masaaki Nakayama	Kanagawa Institute of Technology
Hot Isostatic Pressing of Pre-Sintered Zirconia	Y. Y. Kim Z. Kato N. Uchida K. Uematsu K. Saito	Nagaoka University of Technology

Paper	Researcher	Institution
	Zirconia (continued)	
Chemical Processing of Oxide/ ZrO_2 Composite Ceramics by Colloidal Method	Sin-ichi Hirano Takashi Hayashi Chikage Kato	Nagoya University
Effect of a Small Amount of Metal Oxide Addition on Synthesis of Zircon	Toshiyuki Takano Kenji Kanamitsu Hidehiko Kobayashi Takashi Mitamura	Saitama University
	Toshiyuki Mori	Tosoh Co., Ltd.
Sintering and Mechanical Properties of Y-TZP/Non-Oxide Composites	Shinya Terauchi Tsugio Sato Tadashi Endo Masahiko Shimada	Tohoku University
Superstructure Diffraction of Zirconium Titanate Affected by Heating Time	Toshiyuki Yamada Hiroyuki Ikawa Osamu Fukunaga	Tokyo Institute of Technology
	Kazuyori Urabe	Ryukoku University
Orientation of c-Axis on Ground Surface in Tetragonal Zirconia	Atsushi Saiki Mobuyasu Mizutani Masanori Kato	Tokyo Institute of Technology
High Temperature Deformation in ZrO_2-Base Ceramics	Yu-ichi Yoshizawa Taketo Sakuma	University of Tokyo
Final-Stage Densification and Grain Growth in ZrO_2-Y_2O_3 Alloys	Hideyuki Harada Taketo Sakuma	University of Tokyo
	Nitrides	
Quantitative Analysis of O'-Phase in β'-O' Sialon	K. Yabuta K. Yamada H. Nishino	Nippon Kokan K.K.
	K. Uematsu S. Okamoto	Nagaoka University of Technology
Simulation of Si_3N_4 Grain Boundary Phase and Its Properties	Koji Watari Kozo Ishizaki	Nagaoka University of Technology

Paper	Researcher	Institution
	Nitrides (continued)	
Synthesis of High Purity Si_3N_4 Powder by Using Fluidized Nitridation Technique and Its Properties	Masahiro Yoshida Masahiro Ishii Natsukaze Saito Isao Kimura Noriyasu Hotta	Niigata University
HIP Sintering of β-Sialon Derived from Silicon Diimide	Yu-ichi Fujiwara	Tsubakimoto Chain Co.
	Isao Tanaka Taira Okamoto Shouichi Kume Yoshinari Miyamoto	Osaka University, Institute of Scientific and Industrial Research
Effect of Atmosphere on High Temperature Corrosion Resistance of Si_3N_4	Chyuan Rong Liu	Saitama University
	Toshiyuki Mori	Tosoh Co.
	Hidehiko Kobayashi Takashi Mitamura	Saitama University
Formation Phases of Tantalum Nitrides in the $TaCl_5$-Mg-N_2 Reaction System	Makoto Tokunaga Kazuko Eguchi Hidehiko Kobayashi Takashi Mitamura	Saitama University
Crystallization of Amorphous Si-N Fine Powders Containing Carbon	Tadaaki Amano Toshio Hirai	Institute for Materials Research, Tohoku University
	Kansei Izaki	Mitsubishi Gas Chem. Co.
Preparation of Spherical Non-Oxide Particles of Si/N/C by Spray Pyrolysis	Tian-quan Liu Osamu Sakurai Nobuo Kieda Nobuyasu Mizutani Masanori Kato	Tokyo Institute of Technology
Chemical Processing of Aluminum Nitride Sintered Body	Shin-ichi Hirano Takashi Hayashi Shin Tajima Tamao Eguchi	Nagoya University
Synthesis of Fine AlN Powder from Al Powder and N_2-NH_3 Gas and Its Properties	Masahiro Ishii Noriyasu Hotta Isao Kimura Natsukaze Saito Kenji Ichiya Masahiro Yoshida	Niigata University

Paper	Researcher	Institution
	Nitrides (continued)	
Plasma Sintering of AlN (II)	Shigeru Akimoto	Murata Mfg. Co., Ltd.
	Kazunori Kijima Toru Uetsuki Kaichiro Tanaka	Kyoto Institute of Technology
Properties of Aluminum Nitride Synthesized by the Reduced Pressure CVD Technique	Kiyoshi Itatani Kenya Sano Akira Kishioka Makio Kinoshita	Sophia University
Migration of Grain Boundary Phases in AlN Ceramics During Heating in Reduced Atmosphere	Takeshi Yagi Kazuo Shinozaki Nobuyasu Mizutani Masanori Kato	Tokyo Institute of Technology
	Yutaka Sawada	Tokyo Inst. Polytech.
Nitriding of Aluminum Powders Treated by Yttrium Nitrate	Shigeru Ito Masashi Sugiyama Noboru Yoneda	Science University of Tokyo
	Yukio Sato	Toyo Aluminum Co., Ltd.
	Carbides	
High-Temperature Active Oxidation of CVD-SiC in CO/CO	Takashi Goto Takayuki Narushima Toshio Hirai Yasutaka Iguchi	Institute for Materials Research, Tohoku University
Effect of Vacuum-Heating on the Fracture Strength of Reaction-Sintered SiC	Chang-Bin Lim Takayoshi Iseki	Tokyo Institute of Technology
Effect of HIP Treatment on the Fracture Strength of Reaction-Sintered SiC	Takayoshi Iseki Chang-Bin Lim	Tokyo Institute of Technology
Theoretical Calculation of Atomic and Electronic Structure of a Grain Boundary in SiC	Masanori Kohyama Ryoichi Yamamoto Yoshihiro Ebata Makoto Kinoshita	University of Tokyo
Fast Thermal Response in SiC-Fiber Thermistor	Norio Muto Masaru Miyayama Hiroaki Yanagida	Research Center for Advanced Science and Technology, University of Tokyo

Paper	Researcher	Institution
	Mullites	
Mechanical Properties of HIP Sintered Mullite	Toyohiro Hamasaki	Nagaoka University of Technology
	Yasuo Manabe	Kobe Steel, Ltd.
	Kozo Ishizaki	Nagaoka University of Technology
High-Temperature Properties of Needle-Like Mullite Obtained from New Zealand Kaolin	Hiroaki Katsuki Akihiko Kawahara Hiromichi Ichinose Sachiko Furuta Shuji Yoshida	Ceramics Research Institute of Saga Pref.
	Makoto Egashita	Nagasaki University
Microstructure and Mechanical Properties of Excess Silica Mullite Ceramics	Teruhiko Kinoshita Yoshinari Sawabe Yutaka Ohya Zenbe-e Nakagawa	Tokyo Institute of Technology
	Kenya Hamano	Kanagawa University
Compressive Creep Behavior of Mullite Ceramics	Hiroyuki Ohira Hiroshi Shige M.G.M.U. Ismail Zenjiro Nakai Tokuji Akiba	Chichibu Cement Co., Ltd.
	Eiichi Yasuda	Tokyo Institute of Technology
Diffusional Creep of Polycrystalline Mullite	Yasunori Okamoto Hidetaka Fukudome Kunio Hayashi Momozo Nishikawa	Kyoto Institute of Technology
	Jun Yano	Hitachi Zosen
Creep of Mullite Ceramics Containing Zirconia	Masahiro Ashizuka Tsutomu Okuno Emiko Fukuda Takeshi Honda	Kyushu Institute of Technology
	Yoshitaka Kubota	Tosho Mfg. Co., Ltd.

Paper	Researcher	Institution
	Mullites (continued)	
Static Fatigue of Mullite Ceramics at 1200 °C	Masahiro Ashizuka Tsutomu Okuno Takeshi Honda Emiko Fukuda	Kyushu Institute of Technology
	Yoshitaka Kubota	Tosho Mfg. Co., Ltd.
Corrosion Behavior of Mullite Ceramics Under Hydrothermal Conditions	Tetsuo Yoshio Atsunori Kohno	Okayama University
	Kohei Oda	Yonago NCT
Effect of Metallic Salt Additives on the Properties of a Mullite Sintered Body	Noboru Ishibashi Ken-ichi Tahara Hidehiko Kobayashi Takashi Mitamura	Saitama University
	Tokuji Akiba	Chichibu Cement Co. Ltd.
Evaluation of Fracture Origin of Mullite by Acoustic Emission Technique	Yoshiaki Yamade Yutaka Ariake Yoshiaki Kawaguchi	Sumitomo Metal Industry
	Mitsuharu Shiwa Teruo Kishi	University of Tokyo
	Thin Films/Coatings	
Preparation of Full Stabilized Zirconia Thin Film by Metal Alkoxides - DEA System	Yoshio Matsuda Toshihisa Nonaka Tatsuhiko Suzuki	Toray Industries, Inc.
	Keisuke Kobayashi Yasutaka Takahashi	Gifu University
Synthesis of Boron Nitride Thin Films by CVD Method	Izumi Tamatani Kazunori Kijima Toru Uetsuki Kaichiro Tanaka	Kyoto Institute of Technology
Fabrication of Yttria-Stabilized ZrO_2 Film for Solid Oxide Fuel Cell by Slip Casting	Hiromichi Takabe Naoki Yoshihara Kenji Morinaga	Kyushu University

Paper	Researcher	Institution
Thin Films/Coatings (continued)		
Preparation and Characterization of Stabilized Zirconia Films by Magnetron Sputtering	Yoshimori Kawaguchi Norio Saito Noriyuki Hayashi Kiichiro Kamata Isao Tanabe	Nagaoka University of Technology
Preparation and Characterization of Si-B-N Films by Plasma CVD I	Kunifumi Sameshima Koji Suzuki Noriyuki Hayashi Kiichiro Kamata Isao Tanabe	Nagaoka University of Technology
Thermo-Chemical Etching Effect on the CVD Deposited Diamond Film in O_2 Atmosphere	Hideki Ohokoshi Tsutomu Kurita Zenji Kato Nozomu Uchida Keizou Uematsu Katsuichi Saito	Nagaoka University of Technology
Synthesis of cBN Films by CVD with Various Solids	Hidetoshi Saitoh Yukio Ichinose	Nagaoka University of Technology
Nitridation of Ti Metal by the Combustion Synthesis Method	Kimiaki Tanihata Yoshinari Miyamoto	Osaka University, Institute of Scientific and Industrial Research
	Mitsue Koizumi	Ryukoku University
Annealing Behavior of Low Pressure Plasma Sprayed Y_2O_3 Stabilized ZrO_2 Film	Jiro Harada	Mitsubishi Mining & Cement Co., Ltd.
	Yoshinari Miyamoto	Osaka University, Institute of Scientific and Industrial Research
	Mitsue Koizumi	Ryukoku University
Special Projects		
Proof Test for Assuring the Strength of Brittle Materials Containing Small Flaws	Ichiro Takahashi	Kanagawa Institute of Technology
A Simulation of CIP Densification Processes of Particles with Size Distributions	Yasuhiro Konakawa Yoshiaki Hamada Kozo Ishizaki	Nagaoka University of Technology

Paper	Researcher	Institution
Special Projects (continued)		
Development of Reference Sintered Materials for Grinding	Hiroshi Okuda Jun-ichiro Tsubaki Isao Sugiura Heizaburo Nakagawa	JFCC Tottori University
Research on Mold Rubber Pressing of Ceramics	Shigeki Ichikawa Hiroshi Ona	Takushoku University
Numerical and Experimental Studies of Chemically Reacting Powder Mixtures Under Shock Compression	Hiroshi Kunishige Yasuyuki Horie Akira Sawaoka	Tokyo Institute of Technology
Ceramic Matrix Composites/Reinforcement		
Shape Effect of SiC Whisker on Al_2O_3-SiC Whisker Composites	Hidemi Watanabe	Ashikaga Institute of Technology
	Atsushi Nakahira Takeshi Hirao Koichi Niihara	National Defense Academy
Properties of SiC Whisker-SiO_2 Glass Composites Prepared by the Sol-Gel Method	Hidero Unuma	Government Industrial Development Laboratory (GIDL), Hokkaido
	Satoshi Ogata	Hokkaido Inst. for Tech.
	Yoshikazu Suzuki Katsuyoshi Shimokawa	GIDL, Hokkaido
Preparation of Beta-Alumina Fibers by Sol-Gel Method	Toshio Waki Sumio Sakka	Institute for Chemical Research, Kyoto University
Fracture Behavior of Al_2O_3-ZrO_2-C Composite Refractory	Toshihiko Nishida Takeshi Shiono Masayasu Narimatsu Tomozo Nishikawa	Kyoto Institute of of Technology
Colloidal Processing of Ceramic Composites in the System of Alumina Powder-Silicon Nitride Whisker	Yoshihiro Hirata Shinichi Matsushita Yoshimi Ishihara	Kagoshima University
	Saburo Hori	Kureha Chemical Ind.

Paper	Researcher	Institution
Ceramic Matrix Composites/Reinforcement (continued)		
Synthesis of Fiber-Reinforced AlN Ceramics by Chemical Vapor Infiltration	Isao Kimura Masahiro Ishii Noriyasu Hotta Natsukaze Saito	Niigata University
Particle Dispersion Reinforced B_4C Ceramic Composite	Kazuo Ueno Satoshi Sodeoka	GIRI, Osaka
	Takehiro Futami	Osaka Electronics and Communication University
High-Temperature Corrosion of TiC/SiC Multilayer Prepared by CVD on SUS304 in Br_2-O_2	Cheng-Yan Guo Takashi Goto Toshio Hirai	Institute for Materials Research, Tohoku University
Microstructure of CVD-SiC-C Composites	Yucong Wang Makoto Sasaki Toshio Hirai	Institute for Materials Research, Tohoku University
Fracture Toughness and Thermal Stress in SiC Whisker/Glass Composite	Eiichi Yasuda Shin Matsuura Takashi Akatsu Yasuhiro Tanabe Yotaro Matsuo	Tokyo Institute of Technology
Effect of the Additives on Formation of Fibrous Potassium Titanate by the Hydrothermal Method	Hajime Saito Hideo Nagashima Seiichi Fukuoka	STK Ceramics Lab Co. Toshiba Ceramics Co. Toyota Technical Inst.
Preparation of YTZ-Mullite Whisker Composites and Their Fracture Toughness	Kiyoshi Okada Nozumu Otsuka Richard Brook Tony Moulson	Tokyo Institute of Technology Max-Planck-Inst. Leeds University
Fracture Toughness of Si_3N_4 Based Composite Fabricated by HIP - Effects of Whisker Dispersion	Giuseppe Pezzotti Isao Tanaka	Osaka University, Institute of Scientific and Industrial Research
	Taira Okamoto Mitsue Koizumi	Ryukoku University
	Yoshinari Miyamoto	Osaka University, Institute of Scientific and Industrial Research
Synthesis and Observation of TiN Whiskers	Mitsuharu Tabuchi Yasunari Kaneko Hiromichi Iwasaki	Ritsumeikan University

SHOCK-WAVE SCIENCE AND TECHNOLOGY IN JAPAN

William J. Nellis

Shock-wave science and technology in Japan is reviewed by examining the papers presented at the Second Workshop on Industrial Application Feasibility of Dynamic Compaction Technology and by visiting the two-stage, light-gas gun facilities at the Tokyo Institute of Technology and Tohoku University. The workshop and the laboratory visits showed that shock-compression research in Japan is structured virtually in its entirety such that work in universities and national laboratories supports development programs in industry. The Japanese are doing interesting and creative materials research and product development with shock-wave technology developed to a large extent at U.S. Department of Energy (DOE) defense laboratories: gas guns for investigating research-size specimens, fast shock-wave diagnostics, large computers and hydrodynamic codes for guiding the recovery process and its scaling, and explosive firing chambers and remote sites for scaling from laboratory to industrial products. No comparable program exists in the United States, including the DOE defense laboratories, where the technology the Japanese are using has resided for 20 years. The probability is high that the Japanese dynamic compaction program will make significant scientific and technological advances because of (1) their focussed program involving industry, universities, and national laboratories; (2) their systematic use of all available shock-wave technology; (3) their quality graduate education program in shock-wave materials science; (4) their program of visiting foreign scientists; and (5) their long-term commitment.

WORKSHOP REVIEW

The Second Workshop on Industrial Application Feasibility of Dynamic Compaction Technology was held in Tokyo from 1-2 December 1988. The program was concerned with shock compaction and shock synthesis of high-temperature superconductors and hard ceramics. These materials are relevant to programs of the Department of Energy (DOE) and other Federal agencies. Since the Japanese conduct a high quality research and industrial program in these areas, the workshop offered an opportunity to learn of recent developments in these topics.

The workshop with its 101 participants was organized by the Tokyo Institute of Technology and held at the Tokyo campus. A. Sawaoka was the workshop chairman. Twenty-one papers were presented: 11 from Japan, 9 from the United States, and 1 from West Germany. The Japanese participants came from industry (37), universities (32), national laboratories (14), and the National Defense Academy (6). The workshop left me with the strong impression that shock-compression research in Japan is structured virtually in its entirety such that work in the universities and national laboratories supports development programs in industry.

A. Sawaoka presented a general review of shock compaction methods and the Japanese plan for industrialization. The goals are twofold: (1) to produce small-size, high-value compacts, such as cubic BN and diamond and (2) to scale up the process and reduce costs for large compacts of high-temperature ceramics (e.g., SiC) and oxide superconductors. With respect to large compacts, Sawaoka said he is seeking collaborations in the United States and Canada so that explosive charges could be fired that are larger than the 100-pound weight limit in Japan. In his own research he is using a 6-anvil, 100-ton press to sinter shocked ceramics and he is shock-compacting SiC powders by using an adjacent mixture of Ti and C powders. The mixture reacts chemically by a shock-induced exothermic reaction; the additional heat renders the SiC more compactible.

Y. Syono, a ceramist at Tohoku University, has concentrated the last few years on synthesizing and characterizing high-temperature oxide superconductors by conventional (nonshock) methods. He reviewed the current status of this work. He has done few shock experiments on these materials with his two-stage gun. However, he showed interesting results for a Bi compound that indicated that shock-induced (7.8 GPa) defects enhance the sintering process to produce a single phase with a sharp superconducting transition. He also showed results for shocked solid disks 10 mm in diameter and 1 mm thick of single-crystal pure La_2CuO_4. Shock processing at 50 GPa induced an appreciable volume fraction of superconducting material ($T_c \simeq 40$ K), apparently by introducing holes associated with shock-induced defects. A 70-GPa shock caused chemical decomposition, as indicated by a lowering of T_c and broadening of the transition.

K. Takashima of Kumamoto University with coworkers at Mitsubishi Metal Corp. discussed the preparation of oxide superconducting coils with high current density using explosives. $YBa_2Cu_3O_{7-x}$ powder of 1.8 μm average particle size was placed in a 6-mm-diameter Ag tube, cold-drawn down in diameter by a factor of ~4, and then molded into a ~10 turn coil with a diameter of ~12 mm. This coil was embedded in SiC powder and shock-compacted by a cylindrical explosive system. Coils sintered at 925 °C after shock showed critical current densities ranging from a few 100 A/cm^2 to more than 13,000 A/cm^2 in various segments along the Ag-sheathed coil length. The process without shock produced 1,000 A/cm^2 critical current density. The 10-fold enhancement in current density showed shock compaction to have a high potential to produce useful superconductors.

M. Yoshimoto of A. Sawaoka's group described results of shock synthesis experiments. Powders of $Bi_2Sr_2Ca_2Cu_3O_x$ (2223) were shocked at 20 GPa. The product was platelike cracked crystallites of $Bi_2Sr_2Ca_1Cu_2O_x$ (2212) with T_c increased to 93 K from 85 K, but the volume fraction of superconducting material decreased. The shock compaction of a mixture of Tl_2O_3, $BaCuO_2$, and Ca_2CuO_3 at 20 GPa produced a small amount of a superconducting phase with an onset $T_c = 76$ K.

Y. Gotoh of the National Chemical Laboratory for Industry described the shock synthesis of superconducting chevrel-phase compounds. These are low-T_c (10 to 15 K) ceramic materials with high critical magnetic fields that have not been synthesized with high critical current densities; that is, they are low-T_c analogues of high-T_c oxides. By mixing stoichiometric amounts of elemental powders and shocking to 20 GPa, single-phase fine-grained $Cu_2Mo_6S_8$ was synthesized with a sharp superconducting transition. $PbMo_6S_8$ was also synthesized, but only as a minority phase thus far.

T. Akashi of Toshiba Tungaloy Company, with A. Sawaoka as coauthor, reported on the dynamic compaction of ceramic powders using an exothermic chemical reaction for postshock heating. The method uses SiC powder at 60 percent of crystal density with a layer of Ti+C powders on either side. The reaction of Ti+C induced by the incident shock is exothermic and heats the compact after pressure release. The method greatly reduces microcracks and increases Vickers hardness by 50 percent. The high hardness was said to be caused by recrystallization of the amorphous material formed by heterogeneous shock heating in the intergranular region.

M. Yoshida of the National Chemical Laboratory for Industry described a cylindrical implosion system for generating Mbar pressures and specimen recovery. This laboratory has obtained a CRAY computer and one- and two-dimensional hydrodynamic computer codes for designing and scaling shock recovery fixtures. The cylindrical implosion system was designed using one-dimensional hydrodynamic computer calculations. The system involves a tube of explosives in which three tubes of steel are placed, spaced by two tubes of plexiglass, which spread the converging shock wave into several reverberations rather than one large shock. The explosive is initiated by a multipoint system.

Two-dimensional hydrodynamic calculations are being performed and experiments conducted on a system in which a layer of nitromethane was placed adjacent to the central steel recovery capsule. The explosive acts as a tamper to the capsule and worked successfully for a peak pressure of 80 GPa in the capsule. At 200 GPa the capsule was broken axially into several pieces because the explosive was overdriven and because of axial tensile waves. Two-dimensional design calculations are being performed to minimize axial tensile stresses in order to recover the capsule intact at multi-Mbars.

T. Sato discussed the synthesis of rhombohedral BN and its transformation into cubic BN by a diffusionless process.

T. Sekine of the National Institute for Research in Inorganic Materials reported results on the shock synthesis of carbon phases from hydrocarbons. This work was motivated by theoretical calculations by F. Ree of Lawrence Livermore National Laboratory (LLNL) that match shock compression curves under the assumption that shocked hydrocarbons decompose into a mixture of carbon in a diamondlike phase and molecular hydrogen. Specimens were mixed with large amounts of Cu powder with 30μm or less particle size. The slurries were shocked in the range of 15 to 35 GPa using a propellant gun. Shocked adamantane yielded amorphous carbon, graphite, hexagonal diamond, and carbon-IX. Naphthalene yielded amorphous or very fine-grained graphite and hexagonal diamond. Pyrene formed graphite, amorphous carbon, and complex phases. Diamond production is very small for all three hydrocarbons. If diamond is formed as predicted, the recovery system must be greatly improved, he said.

T. Tobisawa of the National Defense Academy described multitudinous crystallite patterns of recrystallized shocked ZnO that have a curious resemblance to snowflake forms.

M. Araki of Nippon Oil and Fats Company described the design and construction of a quiet industrial explosion chamber used in a populated area.

SITE VISITS

Tohoku University

I visited Prof. Y. Syono of the Institute of Materials Research. The name of this institute was recently changed from the Research Institute for Iron, Steel, and Other Metals. Prof. Syono's group studies ceramics primarily. His experimental facilities include a 20-mm-bore, 7-meter-long, two-stage light-gas gun (1.5 to 4.5 km/s); a 25-mm-bore, 2-meter-long, single-stage propellant gun (to 2.4 km/s); and a diamond anvil cell. The diamond cell is used to search for high-pressure phases in oxide systems by x-ray diffraction at various pressures. The gas guns are then used for shock recovery experiments to synthesize large specimens of high-pressure phases for characterization of the physical and structural properties of the quenched metastable materials. A high-pressure and high-temperature press is also used for synthesizing and quenching new phases.

A second group at this university is initiating a gas-gun program. Prof. K. Takayama is installing two 7-meter-long, two-stage light-gas guns for the study of high-speed mechanics. Thus, Tohoku University is about to have three two-stage gas guns for materials research.

The campus also has high-quality facilities that complement nicely the high-pressure work, including a well-equipped electron microscopy laboratory and an impressive, large high-magnetic-field laboratory where materials are studied in static fields up to 30 T, the current world-best.

Tokyo Institute of Technology

A tour of the shock-wave laboratory of Prof. A. Sawaoka was held after the workshop. The facility includes a 20-mm-bore, 7-meter-long two-stage gun (up to 5 km/s); an 8-mm-bore, 3.5-meter-long two-stage gun; a 40-mm-bore powder gun (up to 2 km/s); and a new plasma accelerator. The latter is for accelerating sub-mg particles to 10 km/s for micro-meteorite experiments (Prof. Sawaoka is also in charge of a substantial portion of the Japanese space program). The 20-mm two-stage gun also has a powder breech for the launch tube, which permits the gun to be operated in single-stage mode. The experiments at all the guns are primarily shock recovery. Experimental setup and gun cleanup are performed by students. An engineer fires the guns.

Also included in this shock group are visiting researchers from industry, who return to their companies to work on or manage scaled-up processes using explosives. The group also works closely with other faculty, who measure superconducting properties of oxide superconductors, for example.

Prof. Sawaoka said that his rail gun project was restarted recently. The goal is to achieve high velocity in a disposable design.

CONCLUSIONS

The Japanese have assembled an interesting, cohesive, and focussed program in shock-wave science and technology. The science deals with the synthesis and characterization of ceramics having high potential commercial value. The scientific research is performed at excellent, well-equipped universities and at national laboratories. The technology is developed by industry and at national laboratories. The commitment to this plan is long term and growing.

This system is driven by industrial end products, which are chosen to be as valuable as possible. For example, groups in Japan are working on improving the shock synthesis of diamond because the DuPont patent is going to expire soon. However, whereas DuPont sells shock-synthesized diamond powder as an abrasive, several groups in Japan are working to perfect the dynamic compaction of diamond powder into compacts for cutting tools, etc.

The Japanese are doing this materials and product development program with shock-wave technology developed to a large extent at U.S. DOE defense laboratories: gas guns for investigating research-size specimens, fast shock-wave diagnostics, large computers and hydrodynamic codes for guiding the recovery process and its scaling, and explosive firing chambers for scaling from laboratory to industrial products. No comparable program exists in the United States. This statement includes DOE defense laboratories, where all this technology has resided for 20 years but has never been used in total nor with continuity for these purposes.

The light-gas guns at the two Japanese universities comprise first-rate shock-wave facilities for materials research. The Japanese 7-meter-long two-stage guns are small compared to ones used at the U.S. national laboratories. They are used to perform many experiments in an inexpensive and efficient manner. Tohoku University is about to have three such guns; Tokyo Institute of Technology has two two-stage guns. The two-stage guns at LLNL, LANL, and SNLA are 19 meters long. Many applications require this size. However, these large guns are slower to turn around and require substantial technical support to fire and maintain. One smaller 7-meter, two-stage gun is being completed at LLNL, motivated by the economies of scale of the smaller size Japanese guns. A similar gun is in operation at SNLA for fragmentation studies.

In Japan the gun facilities are at universities and are used to train sizeable groups of shock-wave scientists for industry and national laboratories. The DOE shock-wave facilities are in classified areas, which effectively eliminates access to graduate students. As a result an excellent opportunity is lost to educate people in a field in which U.S. universities do not train sufficient numbers of shock-wave scientists and engineers to meet the needs of DOE, the Department of Defense, and industrial laboratories.

The Japanese are doing interesting and creative work in dynamic compaction. With their quality graduate education program in shock-wave materials science, their program of visiting scientists, their focussed program involving universities, national laboratories, and industries, their unique systematic use of all available shock-wave technology, and their long-term commitment to the program, the probability is quite high that they will make significant scientific and technological advances.

William J. Nellis, head of the Shock Compression Group at Lawrence Livermore National Laboratory (LLNL) since 1978, has also been head of the High Pressure Research Center of the University of California Institute of Geophysics and Planetary Physics at LLNL since 1984. He received a Ph.D. degree in solid state physics from Iowa State University in 1968. He was a postdoctoral researcher in the Materials Science Division of Argonne National Laboratory (1968-70) and an assistant professor of physics at Monmouth (Illinois) College (1970-73). Dr. Nellis joined LLNL in 1973 as a computational physicist and moved to the Shock Compression Group in 1976. Dr. Nellis is a Fellow of the American Physical Society and was 1987 chairman of the APS Topical Group on the Shock Compression of Condensed Matter. He is chairman of the 1990 Gordon Research Conference on Research at High Pressure. Dr. Nellis is currently visiting professor of physics at the University of California, San Diego. His research interests include the properties of materials at high shock pressures, the shock compaction and synthesis of high-T_c superconductors and other ceramics, and the nature of materials at high pressures and temperatures inside the giant planets.

FOURTH INTERNATIONAL CONFERENCE ON LANGMUIR-BLODGETT FILMS

Geoffrey A. Lindsay

The Fourth International Conference on Langmuir-Blodgett (LB) Films was quite successful with about 370 scientists in attendance. New LB trough designs are available to build up hetero-multilayered films, to anneal and irradiate films, and to continuously deposit films (e.g., lubricating layers for magnetic tapes). Use of polymers, such as polyimides, conductive polymers, and polypeptides, in LB films is gaining importance, especially in the pursuit of device applications, such as molecular recognition sensors, electron beam resists, optical switches, solar energy converters, and thermal imaging. The understanding of LB film structure as a function of processing conditions was advanced; however, no reports on electron tunneling/atomic force microscopy were given. Japan, West Germany, the U.K., and France dominate research in the LB field. Commercial application of LB films has been slow in developing. The author believes that specialty uses will be announced within the next few years; however, complex molecular electronic/photonic devices will need a longer evolutionary time.

INTRODUCTION

About 370 people attended the Fourth International Conference on Langmuir-Blodgett (LB) Films held in Tsukuba, Japan, from 24-29 April 1989. The three previous LB conferences were: in 1983, Durham, U.K. (G. Roberts, organizer); in 1985, Schenectady, NY (G. Gaines of GE, organizer); and in 1987, Goettingen, FRG (D. Mobius, organizer). Refereed papers from these conferences are published in special editions of *Thin Solid Films*. The 1991 conference will be held in France (Bordeaux or Paris in September). This is the author's first attendance at an LB conference.

There were 250 papers presented and 11 invited speakers. Sixteen countries were represented. Prof. K. Fukuda of Saitama University was the organizer and Dr. M. Sugi of the Electrotechnical Laboratory in Tsukuba was the program chairman. Forty-one Japanese companies and 14 Japanese professional societies provided financial support.

The Japanese appear to have the largest effort on LB film technology, followed by West Germany and the U.K. Prof. Fukuda said there are over 100 research groups in Japan working on LB thin film processing. The head of Nima (an LB trough manufacturer) estimated there are about 400 troughs in Japan. I counted about 140 Japanese papers. About 100 papers were from 25 different Japanese universities, including 24 from Tsukuba University and National Laboratories, 17 from the Tokyo Institute of Technology (TIT), 13 from Kyushu University, and 11 from Saitama University; about 40 papers were presented by Japanese companies (6 each from Matsushita Electric and Mitsubishi Electric, several from Toshiba, Canon, and Hitachi Chemical). Japanese contributions to the field are numerous and innovative (for example, Kyoto University's Shimidzu's molecular engineering). Japan will likely create the first commercial devices from LB technology. LB technology requires great attention to purity of materials, and the Japanese have excelled at this in the integrated circuit (IC) industry. They are placing more emphasis on LB films derived from polymers, which yield robust films, more free from pin holes.

The West Germans have a large coordinated effort on LB technology that includes the big three chemical companies and German academia. The contingent from Mainz was particularly vocal in the discussion periods following the presentations. In my opinion, some of the best efforts in this field continue to be in: Germany--the University of Mainz (Ringsdorf's and Mohwald's groups), the Max Planck Institute at Mainz (G. Wegner's group), and the Max Planck Institute at Goettingen (D. Mobius's group gave six papers); France--Andre Barraud's group (they are emphasizing molecular recognition sensors); and England--Garreth Roberts' group, which is focused on pyroelectric LB films for thermal imaging. The organizers couldn't invite everyone, but noticeably missing were Tredgold and Hodge from Lancester University (U.K.), who continue to publish on creative polymeric LB films for electronic applications.

Some European experts were bothered at the Japanese reinvention, and renaming, of certain phenomena that have been reported years ago in western literature. Lack of fluency in English is probably the single greatest impediment to the Japanese ability to assert the quality of their contributions (to the English speaking countries, including Europe). However, what they lack in quality of presentation is more than compensated for in quantity and enthusiasm.

What could have been a great U.S. LB center by now, Case Western Reserve University (CWRU), is getting a slow start because Cliff Fung and Scott Rickert both left for industrial jobs. The little pockets of effort in the United States seem totally uncoordinated. IBM, Exxon, and Kodak were the only large U.S. companies represented, and their papers gave no indication of device applications orientation.

BACKGROUND

Brief Tutorial

The Langmuir-Blodgett trough provides a means for depositing ultra thin layers of organic materials, typically 20 Å in thickness per layer, onto solid substrates (even onto curved surfaces). The thickness of each layer is very uniform.

Water is the most common "subphase" on which an organic-soluble material is injected. The solvent evaporates, leaving a monolayer floating on the water surface. The organic molecule must be insoluble in the subphase, yet must wet the subphase. A movable "dam" compresses the floating layer, squeezing out holes and aligning the molecules. The surface pressure (tension) is measured and controlled to insure that the film is sufficiently compact yet not buckled or collapsed. A solid substrate is "dipped" into and/or out of the water, transferring monolayer from the water to the substrate.

A half-dozen companies sell computer-controlled LB troughs. Many research laboratories have built troughs of their own design. Quite a lot of the research on LB monolayers has involved fatty acids, which yield films that are polycrystalline (full of grain boundaries and pin holes). Polymers tnat are specially designed for LB processing are becoming the preferred material for device applications because of their ruggedness and lack of defects. Polymer backbones tend to become aligned by the dipping process, and methods to control (or take advantage of) this phenomenon are now under investigation.

Historical Perspective

George Gaines of GE wrote the modern bible of LB science and technology (published in 1966). GE forced his departure from this scientific area for several years; he, however, attended this conference and said he has recently reentered this field to develop nonlinear optical LB films. He showed a very special historical movie (1939) of Irving Langmuir, the first U.S. industrial Nobel Prize winner, and Katherine Blodgett demonstrating their findings. Blodgett was the first to coat substrates with monolayers. She demonstrated antireflection coatings. Zisman of the Naval Research Laboratory (NRL) was also a pioneer in LB technology in the 1940s and 1950s. Hans Kuhn of the University of Goettingen, FRG, did much to revive interest in the LB field in the 1960s and 1970s by incorporating dye molecules in the monolayers and studying energy transfer mechanisms.

Future Directions

Hans Kuhn gave an excellent preface and current review of LB advances in his plenary lecture. He has devoted his long life to this field, has given much inspiration, and continues to give insight on where this technology can find fruition in devices. He suggested these areas as most promising for future utility of LB processing: optical data storage, optical switches, membrane catalysts, microsensors, semipermeable membranes, solar energy conversion membranes, and lubricating layers. Garreth Roberts (University of Oxford, U.K.) presented a similar list: thermal imaging (pyroelectric films), electron beam resists, lubricants, insulators for field effect transistors, biosensors, and optoelectronics.

Kuhn points out that we are just beginning to approach biological systems in complexity. Our LB strategies are leading to "supramolecular" machines. He gave many recent examples of clever molecular designs for photonics (e.g., second harmonic generation (SHG), photoelectron pumps, and molecular recognition membranes, some of which were reported at this meeting).

I believe that the coupling of the scanning electron microscope or atomic force microscope to LB films will yield not only more structural insight but also new devices, for example, random access memory on a molecular scale.

Biologically derived polymers (proteins, polysaccharides, etc.) are monodispersed, well-characterized materials that should be given more consideration as monolayer building blocks. There is a wide range of structures and properties available, and they can be further chemically modified, as was reported in several papers at this conference.

SCIENCE AND ENGINEERING ISSUES

Field Maturity

LB technology has been around long enough to become a mature field. However, the processing complexity leading to poor film homogeneity (which, until recently, we did not have the analytical tools to measure) has thus far held back LB's successful commercial application. Processing innovations continue to advance the state of the art, such as the alternating trough for making noncentrosymmetric multilayers, and the "zone treating" process, offered by the Nippon Laser and Electronics Laboratory (NLE) of Nagoya, which melts and recrystallizes the compressed monolayer to give larger, more perfect single crystals.

The deposition of **polymeric** monolayers is only now being emphasized (and mainly in industrial labs) because new purification and controlled synthetic techniques are making synthetic polymers "respectable" to the chemical research community. Polymers offer more robust films and may obviate grain boundary problems in the case of amorphous polymers and polymers with groups that can be crosslinked. We have only begun to explore the potential of polymers in LB films.

New Science

Film Structural Characterization. Still not enough people are paying attention to fully characterizing the microstructure in their films, for example, by polarized Fourier transform infrared spectroscopy (FTIR) and low angle x-ray scattering. But this is starting to be remedied.

A paper from Exeter University and GEC (U.K.) described the measurement of the contact angle between the LB film and the solid substrate being dipped through the water. This appears to be an important, underexplored technique for quality control of the films. They found unexpected and unexplained long range surface energy effects (10 to 15 layers away).

Jones from the University of Wales pointed out the fugitive nature of stearic acid (it sublimes in vacuum at room temperature), which points out to me again the importance of emphasizing **polymeric** films.

A paper from Bayer AG by H. Ohst described polyurethanes and polyesters, containing fatty side chains, which easily formed Y-type multilayers by conventional LB deposition. The side chains melted at 45 °C, but the multilayer structure remained intact to about 200 °C (after many temperature cycles) because the polymer backbone layer (about 10 Å thick) "melted" above 200 °C, indicating the existence of phase-separated main chain and side chains (i.e., the polyester and polyurethane backbone layers and the liquid hydrocarbon pendent groups).

More attention is now being paid to alignment of materials in the LB films caused by viscoelastic flow during dipping. About 20 papers addressed this issue, which is especially important with polymeric films. This can be controlled or eliminated, but one must be aware of it.

Mobius's report on measurements of local charge distribution and surface potential is leading to better understanding on how to control the structure and properties of LB films.

Laschevsky of Ringsdorf's group in Mainz gave a very nice lecture on side chain versus main chain control of multilayer structure. They have shown that hydrophilic spacer comonomers improve the order of the fatty side chain comonomers. The spacer they find most beneficial is hydroxyethylmethacrylate, which also affords one the opportunity to crosslink the monolayer, further adding to its mechanical integrity! They have found that the multilayer structure of side chain polymers retains its layer integrity above the melting point of the side chains. (Ohst found the same.) I proposed that this may be due to the thermodynamic phase separation of the main chain from the side chain, affording a stability to the multilayered structure until one reaches the temperature at which thermodynamics prefers one phase (e.g., one goes above the upper critical solution temperature).

A fascinating paper by Mitsubishi Electric disclosed the formation of highly aligned microfibrillar LB films derived from 7,8-dimethyl-3,10-dinonylisoalloxazine (DIN), a flavin. Although the structure was probably enhanced by epitaxy on their graphite substrate, this unexpected structure points out to me science's inability to predict crystalline or secondary structure (in a hierarchical progression). We should be able to do better with the advent of supercomputers.

Self-Assembled Films. Zisman of NRL in 1946 is credited with publishing the first report of depositing monomolecular films by self-assembly of an organic solute by dipping a solid substrate into the solution. Three major efforts in this area are headed by Sagiv (Weizmann Institute, Israel), Uhlman (Kodak), and Sagawa (Matsushita). It seems appealing because no expensive equipment is needed. However, there is no way to laterally squeeze the film to help perfect the order. Another problem is that epitaxy is more important than for the case of LB processing; hence, defects will be propagated from layer to layer. To overcome this problem, one might design molecules to be covalently linked in the lateral dimension (i.e., polymers).

Sagiv reviewed his attempts to build three-dimensionally crosslinked multilayers by chemically converting the top of one layer to a reactive group for the bottom of the next layer. The only proof he gives that he is building up quality layers is from FTIR. It is a very tedious procedure in that he extracts each layer with boiling toluene before adding the next. In principle, it could be a viable way to make noncentrosymmetric films. He is now collaborating with researchers at Stanford to measure molecular perfection by atomic force microscopy (AFM).

Lando of CWRU reported on structural characterization of microtubules (technology from Schnur's group at NRL) and their efforts to make LB monolayers of tubules. These tubules form by self-assembly of fatty diacetylene-substituted glycero-3-phosphocholine.

New LB Trough Designs. B.R. Malcom of Edinburgh University (U.K.) showed that LB films undergo heterogeneous compression on the trough (some troughs are much worse than others), which leads to built-in strains and which can be visualized by depositing a grid of sulfur on the surface before compression. This nonuniformity means that the surface pressure near the film balance is probably different than the pressure near the dipping substrate. Hence bath design leaves a lot of room for improvement.

Nitsch from the Technical University of Munich showed a channel-flow design similar to what Molecular Electronics Inc. (Torrance, CA) has built that offers continuous coating and potentially more uniform films.

Nakayama of Toshiba reported on a very attractive dipping innovation involving a tilted solid substrate (slightly off horizontal) to allow the water to be squeezed out as one deposits polymers, some of which are too viscous for vertical depositions. This type of trough is not commercially available and, I believe, could give Toshiba a large competitive advantage.

Kato of Utsunomiya University (Japan) reported on a trough for measuring thermal expansion (area-temperature isobars) of insoluble monolayer films. This is also a useful technique to confirm the absence of leakage of the film around the dam. They *advocated isobaric thermal treatment of the* films to densify and perfect the structure of the films.

Ultrathin Film Technology, Ltd., of Mountain Lakes, NJ, offers a microscope-mountable LB trough that allows one to observe microstructures by fluorescent labels and measure lateral diffusion coefficients by photobleaching technology.

Papers described elipsometry, polarized FTIR, and x-ray scattering measurements right at the air-water interface.

Many people regard the expensive ($90K) KSV (Findland) trough as the best in terms of no leakage or crosscontamination, which is important in heterolayer designs.

Many regard NLE's Miyata trough as giving the best uniformity of deposition in terms of lack of shear on the monolayer as it is compressed as a result of their "moving wall" dam. However, their dual compartment, heterolayer trough is very large and sells for about $170K.

Nima and Joyce-Loebl (JL) offer good heterolayer troughs for about $40K to $50K. The JL trough requires more water. The Nima trough has a smaller reservoir of film (has to be refilled more often if you are making thick films.) Laude does not yet offer a heterolayer trough.

Chemical Processing. Barraud reported ways to interleave group VIII sulfides with fatty acid monolayers to give ultra thin photoactive materials, such as HgS. The Russians commented that they are also active with this approach.

A number of photopolymerizations of diacetylene amphiphiles in LB films were reported to form high molecular weight polymers. Vinyl unsaturation in hydrophobic portions of amphiphiles yielded crosslinked films when exposed to electron beam and ultraviolet (UV) irradiation. Several papers *described reversible photochromic reactions* (e.g., cis/trans isomerizations).

Electrochemical reactions were carried out in LB films deposited on electrodes, e.g., reduction of CO_2, electrochromic reactions, switching on enzyme activity.

Fukuda of Saitama showed that L-aminoacids containing fatty side groups easily undergo polycondensation in LB films at 40 °C.

Molecular Recognition. Quite a number of papers addressed schemes for molecular recognition based upon enzyme-mimicking LB membranes. A fair representation from the biochemistry community was present. I saw no papers from the United States in this important area, which has potential applications for toxic gas sensors and in vivo blood analysis monitors.

Aizawa from TIT reviewed work on biosensors, one of which was composed of an enzyme/poly(pyrrole)/electrode. The catalytic activity of the enzyme (glucose oxidation) could be turned on and off by varying the potential on the electrode.

Kunitake's group at Kyushu University fabricated LB calixarene films and found that the tetramer has selectivity for sodium and the hexamer for potassium ions; resorcinol-dodecane cyclic oligomer LB films formed complexes with ribose (although I judged this to be a very tentative conclusion).

Electrical Properties. There is quite a lot of activity in synthesizing electrically conductive monolayers from conductive polymers. Conductive films may find applications in electrochromic displays, light shutters, solid state batteries, and microsensors. (The Office of Naval Research Chemistry Division has sponsored a fair amount of research on conductive polymers.) Rubner (MIT) and Nishikata (TIT) presented papers on this topic. Several papers described films that were photoconductive (TIT and Kyushu University).

The charge transfer complexes and radical ion salts, so far, have the record for electrical conductivity in LB films (about 30 S/cm); however, they are quite unstable in the atmosphere and at elevated temperatures. Reports on these materials came from Bordeaux and Saclay, Tsukuba, and Moscow.

Several reports on Schottky barrier work indicate that pin-hole-free thin films between noble metal electrodes cannot be fabricated from fatty acids (this lesson should have been learned years ago!). Amorphous glassy polymers are the way to go. Shigehara from Tsukuba reported that monolayer films (1 nm thick) of poly(fumarates) sandwiched between aluminum and indium tin oxide electrodes gave the first ever observed electron tunneling on Al without any extra Al_2O_3 insulator layer. A paper from Mitsui Toatsu Chemical also demonstrated the benefits of interleaving electroactive molecules with amorphous polymers rather than the conventional fatty acids.

A paper from Canon, Inc. reported a very promising way to make electrical memory switches by interleaving amorphous poly(isobutyl methacrylate) and a squarylium dye between gold electrodes. The amorphous polymer provides pin-hole-free insulation of controlled thickness (80 nm in this case). Switching time was about 10 ns. They are in the process of making a scanning tunneling microscope-type probe over this polymer/dye film in order to make random access memory (one can imagine that the memory pixels could be on the order of 100 nm apart).

A nice innovation was reported by Wegmann from Ciba Geigy. He dipped an electrode into the trough (near a stationary counter electrode) and doped (oxidized) 5,6,11,12-tetrathiotetracene (TTT), as it was deposited, to form an electrochromic film right on the indium/tin oxide electrode. This film could be cycled only about 300 times due to diffusion of the TTT back into solution. But when he switched to a proprietary polymer donor, he obtained thousands of cycles.

Optical Properties. Noncentrosymmetric films offer new materials for pyroelectric, piezoelectric, and second-order nonlinear optical applications. Taylor of the University of Wales told of stable Z-type multilayers built up from chiral fatty acids that melt at about 75 °C (no SHG measurements yet). It was apparent from his lecture that surface potential measurements will be of utmost importance in characterizing the degree of polarity of these films.

Blinov (Moscow) gave an excellent invited paper on using an asymmetric probe molecule in LB films to measure the local field effects on SHG. This technique will be very useful in understanding and designing better polarized films.

A paper from the University of Essex (U.K.) on rare earth bisphthalocyanines concluded that there is no advantage to placing these compounds in LB films for electrochromic applications. However, these interesting chromophores are related to work at China Lake and NRL. China Lake is pursuing rare earth plastic lasers, and NRL is pursuing these compounds for their third-order nonlinear optical properties.

A paper from Kyushu University by Nagamura reported on conversion of 4,4'-bipyridinium/tetrakis-(3,5-bis(trifluorometyl)phenyl)borate salt (colored pale yellow) to a blue-colored radical cation by irradiation in the yellow region of the spectrum. The conversion was fast and reversible. Therefore, this salt may have utility in eye protection against lasers.

Ledoux of CNET (Bagneux, France) gave a very nice paper related to our second-order nonlinear optical (NLO) work. They investigated the SHG from LB multilayers of amphiphilic dyes upon illumination with polarized light from 0.8 to 1.34 microns; they found a splitting (or reduction) of the SHG signal near the absorption peak in a single LB layer but no splitting in noncentrosymmetric multilayers. This points out once again the importance of the substrate on the structure and vibronic states of the neighboring dye layers.

Device Applications. Prof. Garreth Roberts said that room temperature thermal imaging will be the first major use of LB films taking advantage of pyroelectric properties. The only serious contenders are ceramics, but they cannot be made thin enough, their thermal capacity is too high, their grain boundaries are a problem, and processing costs are high. He predicts the U.K. effort will have a working prototype in 2 years based on LB technology (pixels, 50 square microns each, on silicon). The optimum thickness of the pyroelectric films is about 75 nm, or 30 LB layers. He cautions that the LB layers must not be piezoelectric.

I believe that polyimide-based photoresists may be the first substantial commercial use of LB processing. NEC, Sony, and Kanegafuchi Chemical gave papers on this subject. Its first disclosure was at an ACS meeting in Denver in 1986; hence, there has been enough time for it to undergo substantial applications development. NEC boasted a negative polyimide (PI) resist layer 4 Å thick after chemical imidization and cross-linking with octadecenyl pyridine. Iwamoto from TIT put about 30 layers (100 nm) of PI between superconductors to make a microwave detector. The dielectric breakdown was 10 million V/cm.

Ikeno of TIT reviewed work on fabrication and performance of a ferroelectric liquid crystal display (FLCD) in which a polyimide LB layer on the electrode was shown to give almost perfect bistability. This was attributed to the thinness, orientation, and partial conductivity of the PI layer.

FUTURE OUTLOOK

Impediments to Progress and Approaches to Overcome Them

One of the major disadvantages of LB processing continues to be the time required to build up complicated multilayered films (days per film in some cases). Hence, LB processing will be expensive. There are continuous processes under development. Molecular Electronics of Torrance, CA, will coat materials from their continuous trough and just recently offered to build continuous troughs for a fee. Another main issue is the difficulty in controlling or eliminating pin holes and microdomain defects/boundaries. The incorporation of polymers into LB films will help this situation. However, polymers, being more viscous, require different dipping conditions (slower or totally new dipping schemes, e.g., tilted versus vertical or horizontal dipping). New trough equipment to anneal films, crosslink films, and control gas and liquid phases offers solutions to these problems.

Future Challenges

Of the 14 papers given on the first day, only 2 were from the United States, one of which was disappointing in its lack of breadth and quality of slides in view of the fact that it was one of the few invited papers. In addition to the lack of participation from the United States, noticeably missing were any applied research papers. The United States funds a few basic structural studies, whereas Japan and the U.K. emphasize attempts to make useful devices. Granted one needs the fundamental understanding to build reliable devices, but there should be a more balanced and coordinated effort in the United States.

Geoffrey Lindsay, head of the Polymer Science Branch, Naval Weapons Center, China Lake, CA, has a combined B.S./M.S. in chemical engineering from Ohio State University and a Ph.D. in polymer science from the University of Akron. He worked 15 years for BF Goodrich in polymer-related new product development and research and development management positions at Brecksville, Ohio, then came to the Navy 3 years ago. Dr. Lindsay currently coordinates research teams involved in the synthesis and characterization of new polymers for electro-optical applications, structural composites, and binding solid and gelled rocket propellants. Dr. Lindsay has had a passive interest in LB processing for molecular electronics for about 10 years. In 1987 his group began working on optically nonlinear polymer films in collaboration with UC Davis and presented a poster paper, coauthored with researchers from UC Davis, at this conference.

PROFESSOR KUNIO KUWAHARA'S UNIQUE INSTITUTE OF COMPUTATIONAL FLUID DYNAMICS

Hideo Yoshihara

The Institute of Computational Fluid Dynamics is a private company operated by Professor Kunio Kuwahara that leases four supercomputers with computer power exceeding that of the National Aeronautical and Space Administration's National Aerodynamic Simulator in the United States. The key personnel, supercomputer facilities, and research undertaken are described.

INTRODUCTION

Professor Kunio Kuwahara is an associate professor in the Research Division for Space Systems Engineering of the Institute of Space and Astronautical Science (ISAS). More importantly, he is the mainstay of his private computational fluid dynamics (CFD) research firm, the Institute of CFD (abbreviated iCFD by the company), which operates four supercomputers. The computers are the Fujitsu VP-200 and VP-400E, Hitachi S-820/80, and the NEC SX-2. In Figure 1 Professor Kuwahara stands next to his latest and most powerful supercomputer, the Hitachi S-820/80. The total computer power represented by these supercomputers exceeds, for example, that of the National Aerodynamic Simulator at the National Aeronautical and Space Administration's Ames Research Center.

For those unfamiliar with metropolitan Tokyo, it is the result of many separate small villages that have expanded outward to form the present-day sprawl. Haramachi, the location of iCFD, is one of the small villages located approximately 30 minutes by train south of the Office of Naval Research in Roppongi. The four supercomputers are housed in two inconspicuous buildings abutting Professor Kuwahara's residence, which is located in the crowded original section of Haramachi. Here the streets are barely wide enough for the one-way passage of cars. The sole hint to the presence of such massive computing power is the thick power lines that enter the buildings. The monthly electric power bill incidentally is ¥10 million per month or approximately $80,000.

Professor Kuwahara's original motivation in establishing iCFD was to have access to a supercomputer, unavailable to him at the time, to carry out fundamental flow studies. To support this activity, outside contracts were acquired and surplus computer time sold, with the primary customers being the principal automobile manufacturers in Japan. The relative occupancy of the computers is approximately as follows: outside research contracts 20 percent, sale of computer time 10 percent, and inhouse research 50 percent. The balance of 20 percent is donated to research for students, not only from Japan, but from foreign countries, presently Korea and India. All of the computers and terminals are leased at the customary large discounts. It is clear that monetary gain is not the driver of iCFD.

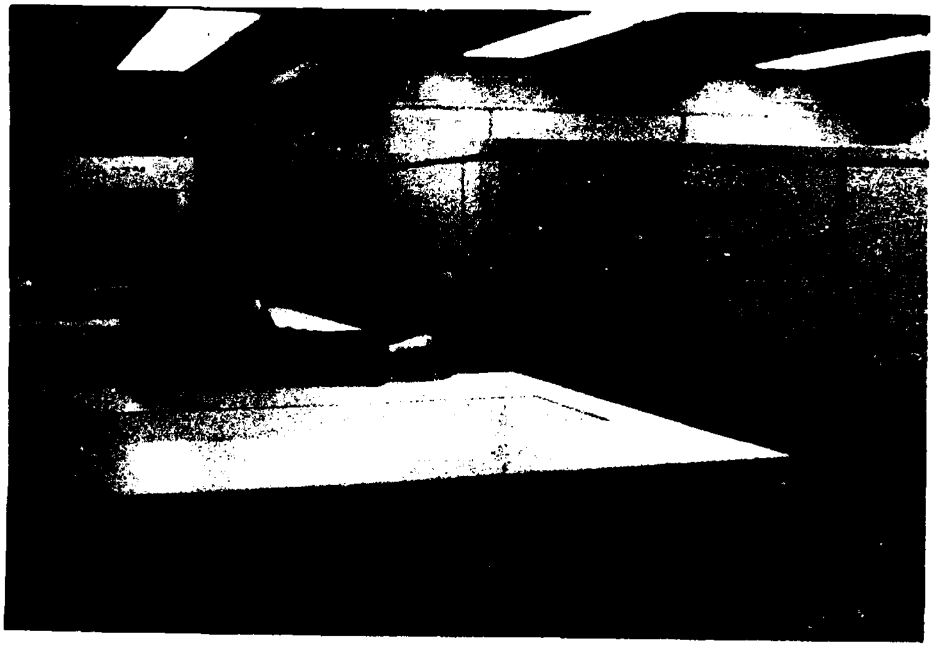

Figure 1. Professor Kuwahara and the Hitachi S-820/80.

The present organization of iCFD consists of about 15 CFD engineers with 10 supporting administrative personnel. With space for personnel understandably at a premium in the computer buildings, Professor Kuwahara uses his large living room as his conference room as well as the development area for his new video visualization system, which will be shortly marketed.

In the following the backgrounds of two of the key personnel are described, followed in turn by a description of the principal computer facilities and the fluid dynamics problems being researched.

KEY PERSONNEL AT iCFD

Professor Kunio Kuwahara (in his 40s) has a Doctor of Science degree from the Physics Department of the University of Tokyo. He was a student of Professor Isao Imai, who is an internationally known theoretical fluid dynamicist. Professor Kuwahara was perhaps the earliest researcher of CFD in Japan. He represented Japan in the session devoted to international reviews of CFD activities at the AIAA Meeting in Honolulu in 1987. His color-video presentations of complex unsteady Navier/Stokes flows have impressed world-wide audiences including a packed audience in Kharborovsk during the Joint Japan/U.S.S.R. CFD meeting in 1988 that I attended as an observer.

The technical director at iCFD is Dr. Katsuya Ishii, also a graduate of the Imai Laboratory of the University of Tokyo Physics Department. Dr. Ishii was a student of Professor Hidenori Hashimoto, who succeeded Professor Imai. Dr. Ishii directs the day-to-day computational activities at iCFD.

COMPUTATIONAL FACILITIES

The four supercomputers at iCFD are on-line around the clock and nominally operated 365 days a year. The CPU speed and memory size of these computers are:

Computer	CPU Speed (GFLOPS)	Memory (MB)
Fujitsu VP-200	0.533	256
VP-400E	1.7	512
Hitachi S-820/80	3.0	512
NEC SX-2	1.3	256
Total	6.5	1,536

With the total peak speed and memory of the 8-CPU Cray Y-MP/832 being 2.5 GFLOPS and 256 MB, it follows that the iCFD computers are approximately equivalent to 2.6 Y-MPs on the basis of CPU speed and to 6 Y-MPs in terms of memory size.

In addition to the custom work stations hooked to each of the supercomputers, powerful UNIX-based Titan (Ardent) and Stellar graphics work stations have also been installed. With each custom work station having a different operating system, users at iCFD must experience considerable inconvenience.

RESEARCH AT iCFD

Research at iCFD is centered about the calculation of complex unsteady incompressible turbulent flows over bluff bodies such as automobile configurations. The nature of the calculated flows can be seen in the recent published papers of iCFD given in the annotated bibliography. The physics of the treated flows is reasonably well understood. In particular, there is an energy cascading process in which turbulent energy contained in the large scale eddies of the turbulence is cascaded down to the small scale via the intermediate scales. Energy is ultimately dissipated by the small eddy (Kolmogorov) flow. The large eddy flow will accordingly depend on the small scale flow through the rate of turbulent energy dissipation.

In the iCFD research the direct simulation method is employed where turbulent flow is represented as a highly unsteady laminar flow. In such an approach, it is essential that a suitably refined mesh and a sufficiently small marching (time) step be used in a finite difference method to properly simulate the small eddy energy dissipation process. For high Reynolds numbers the estimated computing time required would far exceed the capability of existing computers. To moderate this requirement, the large eddy simulation (LES) approach was devised where the small scale flow was filtered (averaged) out with its effect replaced by a subgrid diffusivity. The difficulty to date has been the inability to model adequately the subgrid diffusivity.

In many practical applications, the large scale features of the flow are of primary interest. In view of the inadequate state of LES modeling, the approach taken by iCFD was to assume that the large scale motion was only negligibly influenced by the small scale motion. Accordingly the mesh was coarsened and the time step increased to a point where the computing time, though still large, became affordable. The difficulty with this approach is that a numerical (truncation error) diffusivity arises due to the inadequate mesh refinement and time step that does not model the unresolved small scale effects. Since little validation of the solutions was provided, there was understandably criticism of the iCFD results.

In response to these criticisms, efforts are presently underway to establish the plausibility of the results in two ways. First is to systematically reduce the time step and increase the mesh refinement to gauge the dependency of the large scale motion on the discretization. Here it would be necessary to show, for example, that the (unsteady) surface pressures and the large eddy pattern have attained a reasonably stationary state. The second approach, and clearly a very necessary one in view of the difficulty in assessing the solutions, is to carry out controlled/well-diagnosed wind tunnel tests to compare with the calculations. Such experiments, moreover, would provide an inflow boundary condition containing the free stream turbulence that may be needed in the calculations. For this purpose, a low-speed research wind tunnel, to be described in the next section, was just completed at iCFD and is presently undergoing calibration.

An aspect of the iCFD accomplishments receiving international attention has been the outstanding graphics display of the results using color video showing simultaneously, for example, particle path lines, instantaneous streamlines, and pressure levels. Perhaps the iCFD video presentations are presently among the best in the world. In this connection iCFD has developed a scientific video visualization system for producing high resolution video movies that costs a fraction of existing graphics stations. The low cost is made possible by using PCs and standard video equipment. During a recent visit to iCFD, Professor Kuwahara demonstrated the system starting with the calculation of five time-steps in a Navier/Stokes calculation over a cylinder and then showing the results on the video screen. This system is presently being marketed and should help ease the cash flow problems that usually plague private companies.

LOW-SPEED RESEARCH WIND TUNNEL AT iCFD

The iCFD wind tunnel is a nonreturn type with a test section 50 by 50 cm and a length of 2 meters. For a test section velocity of 10 m/s, the Reynolds number based on a 2-cm-diameter cylinder is between 10^4 and 10^5. The turbulence level is designed to be less than 0.1 percent. The primary diagnostic tool will be a hot wire anemometer, but techniques to measure (unsteady) surface pressures for the small models and for flow visualization must also be developed. Professor Hiroshi Sato, formerly of the University of Tokyo, served as a consultant in the design of the facility. Dr. Toshio Otaguro, a former student of Professor Sato, is the manager of the facility.

CONCLUDING REMARKS

Professor Kuwahara is an experienced, knowledgeable, computational fluid dynamicist. Over the years he has produced many highly complex turbulent flow solutions and made them highly visible through imaginative video graphics. It is clear, however, that these solutions are in need of validation. He and iCFD are in the process of doing this, both computationally and through experiments. Sufficient computer power, experienced experimentalists, and resources reside at iCFD for this purpose, but satisfactorily validating the solutions will be an extremely difficult task..

There is a continuing plan at iCFD to install the latest supercomputers as they become available. It was suggested that the recently announced 4-CPU NEC SX-3 would be installed at iCFD. Though the reason for organizing iCFD originally is clear, reasons for the subsequent massive addition of supercomputer power, however, are more obscure.

ANNOTATED BIBLIOGRAPHY

Hashiguchi, M., T. Ohta, and K. Kuwahara, "Computational study of aerodynamic behavior of a car configuration," AIAA Paper 87-1386 (June 1987).

The planar flow over the symmetry section of the new Mazda RX-7 car was calculated using the same procedure as in Tamura et al. (above). Meaningful results for design considerations, however, must await the three-dimensional extension.

Obayashi, S., and K. Kuwahara, "Navier-Stokes simulation of sidewall effects of two-dimensional transonic wind tunnel," AIAA Paper 87-0037 (January 1987).

This is an interesting paper where the three-dimensional transonic flow over an unswept wing mounted between the sidewalls of the wind tunnel was calculated. Instead of the coarse direct simulation method of the previous two papers, an LU/ADI difference procedure was used to solve the compressible Reynolds-averaged Navier/Stokes equations with the Baldwin/Lomax turbulence model. For the wing/sidewall junction boundary layer a special definition of the mixing length due to Hung was used. With the use of 1.5 million grid points, considerable detail of the three-dimensional sidewall effects was obtained. Test/theory match of the pressure distributions was reasonable, but differences in the shock location persisted, reflecting the well-known shortcoming of the equilibrium Baldwin/Lomax turbulence model for shock/boundary layer interactions. Computations took 25 hours on the VP-200 computer for one case.

Tamura, T., K. Tsuboi, and K. Kuwahara, "Numerical simulation of unsteady flow patterns around a vibrating cylinder," AIAA Paper 88-00128 (January 1988).

The "coarsened" direct simulation approach described earlier was employed yielding impressively detailed results. An implicit marching scheme was used to solve the incompressible Navier/Stokes equations where third order upwind differences were employed for the convection derivatives. An SLOR procedure was used for the Poisson equation for the pressure. A more complete set of test/theory comparisons to validate the solutions would be highly desirable.

THE 1989 U.S.-INDO WORKSHOP ON ELECTRONIC CERAMICS AND MATERIALS

M. Kahn

The 1989 U.S.-Indo Workshop on Electronic Ceramics and Materials provided a comprehensive view of the present Indian research in this area. Thirty-five Indian contributions are summarized as well as a smaller number of Japanese and U.S. presentations. The latter highlight the state of electronic ceramics research in these countries. A short summary of a panel session, an overall review, and reports on site visits in the Pune area also are included.

INTRODUCTION

The 1989 U.S.-Indo Workshop on Electronic Ceramics and Materials, which was held from 14-16 January 1989 in Pune, India, was conducted mostly in the auditorium of the National Chemical Laboratory (NCL). The local arrangements were organized by Dr. Subbarao from the Tata Research and Development Center (TRDC). Oral technical contributions were made by nearly 20 Indian, 15 U.S., and 9 Japanese participants. In addition there were more than 15 posters, mostly by Indian contributors. Following is a summary of many of the contributions. They are organized by country of origin and ordered in their sequence of presentation. Full papers will be published in *Ferroelectrics*.

INDIAN ORAL PRESENTATIONS

C.N.R. Rao (Indian Institute of Science (IISc), Bangalore) reviewed a "periodic table" of mostly perovskite compositions, with particular emphasis on superconductive materials. He did not go into their properties in depth but noted that $SrRuO_3$ is ferromagnetic and $LaCoO_3$ is metallic at high temperature. La_2CoO_4 is an antiferromagnetic insulator having the K_2NiF_4 structure. He discussed three-dimensional perovskites (said to be ferromagnetic) and two-dimensional perovskites, which are not ferromagnetic. In present superconductors the copper was reported to interact in the A-B plane only, since the O_2 separations parallel to the c-axis are larger than those in the A-B plane. He characterized the BISSCO superconducting compounds as two dimensional. Three oxygen layers (N=3) were said to give highest T_c with only negligible improvements with N=4. The same applies to the thallium compounds. Lack of control over the actual number of CuO layers that are formed was noted. He mentioned the formation of superconducting glasses from superconducting compositions to which the polarizability of CuO clusters provides a high dielectric constant. In conjunction with a relatively high conductivity they were reported to absorb electromagnetic waves.

He mentioned a number of thallium-based superconducting compositions, i.e., TlCaSrCuO, $TlCa_{1-x}Ln_xSr_2Cu_2O_4$, and $Pb_2Sr_2Ca_{1-x}Ln_xCu_3O_n$. He also discussed the stability of the copper and of the oxygen valence states, insofar as a Cu^{2+} was said to be paired with an O^{-2} and a Cu^{3+} with an O^{-1}. He characterized all these superconducting compositions as "two-dimensional" oxides.

$BaKBiO_3$ with a T_c at 30 K was mentioned as the lone three-dimensional oxide superconductor known. He felt that three-dimensional oxides will also exhibit high T_c including $BaBBiO_3$ and that the versatility of the perovskite structure comes from its capability of accepting a large range of cations. Anion substitution was said not to be advantageous for superconductivity, i.e., fluorine is too ionic.

Ramji Lal (Naval Chemical and Metallurgical Laboratory (NCML), Bombay) described the effects of iron and lanthanum doping on the piezoelectric and the dielectric properties of lead zirconium titanate (PZT) prepared from spray-dried nitride precursors. This is significant in light of the fact that there are at least two Indian organizations in which a range of different hardness PZT materials, closely patterned after U.S. types, are being made. He found Fe substitutions to lower piezoelectric properties and raise the Q whereas La additions to PZT had the opposite effect. La and Sr additions yielded uniform grain size, which was attributed to grain growth inhibition by vacancies. He reported smaller unit cell sizes, lower Curie temperatures, and increased "poling efficiencies" with La substituents. There was a loss of density after more extended sintering, at least in part probably due to inadequate control over the partial lead vapor pressure. Not much new here, but the Indians think it worthwhile to have their own data on this. They are also investigating PZT composites and the preparation of ceramics with (ordered) voids.

D. Chakravorty (Indian Association for Cultivation of Science (IACS), Calcutta) discussed glass-metal "nanocomposites" made by quenching melted oxides, introducing nucleation centers by ultraviolet (UV) or x-ray irradiation, and then precipitating ultrafine metal grains at about 500 °C. The use of $AgSO_4$ gave precipitation of silver and Bi_2O_3 gave chainlike aggregates of bismuth particles. Fine aluminum powder in the initial mix gave a dispersion of aluminum nanoparticles in a silicate glass matrix. Chakravorty's group studied both optical absorption and conductivity. The conductivity that was observed with bismuth concentrations that formed a distinct, dilute, and not connected phase has been ascribed to electron tunneling. Electron activation energies of 10^{2} to 10^{3} eV have been observed. Some of these "nanocomposites" based on vanadium phosphate glasses exhibited (Ovshinsky) switching effects. For these Chakravorty advanced a model of particle heating and elongation in the direction of the field. Descriptions of this general technology are also found elsewhere.

IACS has contributed to the technology of the preparation of "nanocomposites" by using sol gel and metalorganic precursors, specifically preparing silica-based glasses containing Fe, Co, Ni, and Mn. The optical absorption spectra of these materials showed less clustering than those of materials prepared by other techniques.

In a third approach to the preparation of "nanocomposites" Chakravorty's group has ion exchanged a sodium-containing glass in a bath of silver nitrate or copper chloride. The rate of exchange can be enhanced by the application of an electric field. A subsequent reduction of the ion-exchanged surface has recently been shown to provide 2- to 4-mm silver particles with a relatively very high large-signal conductivity. In the case of "dual phase" glasses, the field-assisted ion exchange process, using silver or lithium, has led to materials with a 1- to 2-V/cm threshold switching capability. Quenching with a field was said to maintain the conductivity at negligible fields. This paper summarizing more than 10 years of activity in this area is available (Ref 1).

M. Multani (Tata Institute of Technology (TIT), Bombay) and V.R. Palkar, a chemist, have applied both the sol gel process as well as spray drying of nitrates to prepare a range of materials in nanosize powder form. Instrumental analysis was then used to study their behavior. They found that the oxygen concentration, the b/a ratio, and the T_c of YBC material decrease significantly with equivalent spherical particle sizes below 130 nm. The lattice parameters of BISSCO material behave similarly, but they project a maximum for its T_c when it has a 120-nm equivalent spherical particle size.

They found electron energy loss peaks (for narrow frequency ranges) in nanometer particles of PZT. This was said to indicate the presence of "domains" within such particles, since disturbances in antiferroelectric-ferroelectric ordering are thought to be a prerequisite for the occurrence of energy loss peaks. The occurrence of ferroelectricity in submicron size material makes such a conclusion plausible. Submicron particles of YIG (Ref 2) and of $YFeO_3$ were also made and nonlinear and nonsaturating behavior was observed (Ref 3).

Fine Fe_2O_3 particles were formed by a microemulsion technique. Dispersed particles are precipitated by intense agitation from a water-2 ethyl hexanol-surfactant emulsion, in which $Fe(NO_3)_3$ was dissolved. An increase in unit cell dimensions of the <200 nm particles is claimed. The measurements are derived from x-ray diffraction data, but this conclusion has to be examined for its dependence upon strain and domain size induced x-ray pattern distortion (Ref 4). Other items they have reported on include an early (pre-1979) preparation of PZT that started to crystallize at 600 °C from sol gel precursors (Ref 5) and dielectric peaks ascribed to an amorphous "ferroelectric" phase in PZT (Ref 6). They are also looking at Yamamoto's "partial chemical" preparation of PZT ceramic (see below).

D.N. Bose (Indian Institute of Technology (IIT), Kharagpur) investigated agents and films for their suitability to passivate and provide dielectric layers on indium phosphide substrates. Using resistivity and C-V measurements he established that etching and subsequent application of sulfides reduce the interface charge and density of states. In addition a thin film dielectric of BaF_2-SrF_2 was applied to the semiconductor and studied for electrical properties.

V. Saraswati (Defense Metallurgical Research Laboratory (DMRL), Kanchanbagh) prepared Al_2O_3 from a gel. It exhibited a "hard" smooth surface with internal porosity. The addition of SiC whiskers raised the hardness even more.

A.R. Kulkarni (IIT, Bombay) found a relatively high ionic conductivity in $PbF_2MnF_2Pb(PO_3)_2$ at 200 °C, 10^{-4} Ω-cm^{-1}. He feels that the conductivity is particularly affected by the Pb^{2+}/Mn^{2+} ratio, being maximum when this ratio is 0.5.

P.S.V. Subbarao (Andhra University, Waltair) investigated $(BaNa)NbO_3$ doped with dysprosium and found tetragonal tungsten bronze symmetry, grain growth inhibition, and a downshift of the Curie temperature with the Dy addition. A positive temperature coefficient of resistance (PTCR) effect has been observed in the material.

V.C.S. Prasad (Bharat Electronics) developed a $BaTiO_3$-based PTCR formulation that contains about 5 percent of an Al_2O_3-SiO_2-TiO_2 glass plus the conventional antimony and manganese dopants. This may compensate for the impurity levels in the Indian raw materials used. Relatively low firing temperatures (1,260 °C) with a 10^6 increase in resistivity was observed. There was no mention of the large signal response.

H.S. Maiti (Central Indian Glass and Ceramic Research Institute) applied ac circuit analysis in conjunction with Cole-Cole plots to the characterization of PTCR devices and grain boundary capacitors. He used the barium vacancy model to explain his cooling rate effects and calculated a low temperature grain boundary resistance of more than six times that of the bulk resistance. This may be due to the excess titania used as a sintering aid.

A. Mansingh (University of Delhi) provided a review of rf sputtering parameters as applied to $BaTiO_3$, PZT, and ZnO films (Ref 7). One item of interest was the observation that when barium titanate is sputtered from a target having $BaTiO_3$ composition, the nature of the target, i.e., precursor oxide, calcined powder, or a fired compact, had a very significant effect upon the deposited film. The latter gave the best results, unless it was reduced by prolonged use as a target. For the case of sputtered PZT, crystallization temperatures below 500 °C were observed.

Sputtered ZnO showed a good preferential orientation unless the substrate was below 350 °C and oxygen was present in the atmosphere. Surface acoustic wave (SAW) velocities were measured for a variety of film materials as deposited on silicon, as a function of film thickness: for thin film they have the velocity of the underlying silicon (4,770 m/s). The velocities go towards that of the bulk value of the film material when the normalized thickness of the film exceeds 0.5. These are all significantly lower than that of silicon, except for that of AlN films, that consequently allow narrower spacings for SAW electrode arrays. The coupling coefficients for PZT, $LiNbO_3$, and $PbTiO_3$ films are all significantly higher than those for ZnO, but only for normalized film thicknesses above 0.15. Because of low sputtering rates, the thinner ZnO films nevertheless find more application than the perovskites noted.

A. Bhanumathi (Andhra University, Waltair) reviewed his group's investigations of a range of tungsten bronze ceramics. They have made doped strontium barium niobate with relaxor characteristics and dielectric constants in excess of 1000 and Curie temperatures between 200 and 350 °C. Lanthanum-doped lead potassium niobate had an orthorhombic structure and (when hot pressed) a K_t of 0.4.

D. Dube (Physics Dept., IIT, Delhi) is measuring the dielectric properties of 90-10 and 70-30 lead magnesium niobate-lead titanate (PMN-PT) relaxor compositions (made at Penn State) in the 10 GHz range, using a home-built microwave transmission attenuation setup. They minimize reflections from the ceramic disc under test by using thin Teflon matching plates. Only the 10-percent lead titanate (PT) composition behaves like a relaxor, indicating a (temperature dependent) morphological phase transformation when the PT concentration is between 10 and 30 percent. The PT addition was shown to enhance domain growth and raise the transition temperature as well as the peak dielectric constant. Varistor as well as superconducting film work is also conducted at IIT in Delhi.

Rastogi of the IIT film lab has an array of (largely self-built) evaporation and sputtering equipment. He is evaporating thin molybdenum films onto silicon substrates, trying to react this with molybdenum silicate. His group found that a thin layer of nickel or cobalt permits diffusion of silicon from the substrate into the molybdenum film. Without this the amorphous SiO_2 film that inevitably forms on the silicon is thought to constitute a barrier to such diffusion.

R.N.P. Choudhary (IIT, Kharagpur) discussed his work with samarium, gadolinium, and dysprosium molybdenates. Quenching causes these materials to show transitions when examined with a differential scanning calorimeter. Ferroelectric behavior is then verified with dielectric measurements.

S.K. Sundaram (TRDC, Pune) discussed his work with conventional Y-doped $BaTiO_3$ surface barrier capacitors. ac analysis and Cole-Cole plots were used to analyze the material. The high dielectric constants obtained were associated with significant losses.

P.O. Godbole (NCL, Pune) discussed his preparation of high purity $BaTiO_3$ powder by hydrolyzing butyl titanate in a solution of barium nitrate, drying the nitrate mixture, and calcining at 650 °C. $BaTiO_3$ film preparation is also under investigation.

E.C. Subbarao (TRDC, Pune) discussed ZrO_2 electrolyte oxygen sensors and proposed the use of electrodes made from conductive ceramic. He also discussed the improved accuracy that can be obtained in a sensor by combining it with ZrO_2 operating as an oxygen pump, so as to provide a cavity with a very low oxygen pressure.

P. Mukhopadhyay (IIT, Bombay) together with Multani and Guptasarma from TIT in Bombay grew and tested 0.2- to 2-mm single YBC crystals in a platinum crucible, using a copper chloride flux after holding the melt at 1,050 °C for 2 hours. They observe an electron spin resonance (ESR) signal in these crystals, particularly at low temperatures, that appears only when these crystals are fully oxidized. These crystals are then heavily twinned. Nonsuperconducting (low oxygen content) YBC material, material in which yttrium is substituted with europium, and BISSCO superconductors do not show appreciable twinning and do not exhibit ESR signals. They concluded that domain boundaries are essential for the occurrence of an ESR signal.

INDIAN POSTER PRESENTATIONS

S.N. Murthy (Andhra University) investigated $(Na_{1/2}K_{1/2})NbO_3$ with substitution of 5 to 15 percent of praseodymium for potassium. Grain growth inhibition, slightly lower Curie temperatures, reduced dielectric constants, and a K_p of 0.18 with "good" Q, were observed. Murthy also modified strontium barium titanate ceramics with Mg, Ca, Li, Fe, and Ni. He obtained tetragonal tungsten bronze structures. He saw a reduction of Curie temperature with Ca additions and increases in resistivity at 25 °C. Together with A. Bhanumati he investigated the effects of the lead addition in $Dy_{0.35}Ba_{0.65}Pb_{0.1}Cu_{0.9}O_3$ and found the transition temperature to decrease from the lead free value (92 K). The density was increased by the lead.

S.B. Ogale (University of Pune) reported on using a pulsed laser to evaporate a range of ferrites and deposit ferrite films, controlling the oxygen pressure to obtain the right stoichiometry.

B. Reddy (S.V. University, Tirupati) used optical absorption to determine the presence of iron in talc and the presence of a six-line ESR spectrum to determine if Mn^{2+} was present in the material.

K.S. Sundram (IIT, Kharagpur) made internal boundary layer strontium titanate capacitors. Properties were investigated as a function of depth into the ceramic by grinding off surface layers and remeasuring the bulk.

P. Sureshkumar (Anna University, Madras) grew single crystals of YBC material in a 2.3:1 mixture of BaOCuO and YBC. Heating was in a platinum crucible to 1,050 °C for >10 hours with subsequent cooling to 850 °C at 5 °C/h and at 10 times this cooling rate to 25 °C. Vickers hardness was measured on millimeter size crystals and found to be 7.2 GPa. A toughness of 1.5 MPa $m^{1/2}$ was determined, duplicating closely previous results (Ref 8).

P.R. Gandi (Nagpur University) investigated results from quenching LiO_2:B_2O_3 glasses. Fast (copper drum) quenching extended glass formation to 70 percent lithium oxide with a conductivity at 1.39 x 10^{-3} Ω^{-1} cm^{-1}. Glasses with 42.5 percent Li_2O also exhibited a high conductivity.

C.C. Desai (Sardar Patel University) grew transparent single crystals of lead nitrate phosphate to a size of 6 by 4 by 2 mm at room temperature in a silica gel. Conduction processes characterized to be both extrinsic and intrinsic and higher than those observed in a ceramic were observed.

M. Thirumavalan (Solid State Physics Lab, Delhi) reported to have grown 2-inch-diameter, 1.3-kg $LiNbO_3$ single crystals of "good" optical quality.

S.H. Chavan (Shivaji University) doped lithium vanadate with Fe_2O_3. This lowered the Curie temperature and increased the pyroelectric current.

V.N. Bindal (National Physical Laboratory) substituted Ba for some of the Pb in lead metal niobate. He evolved an unspecified formulation that is said to have high intrinsic damping and said to be comparable to commercial $PbNb_2O_6$ formulations.

U.S. PRESENTATIONS

R.E. Newnham (Penn State) discussed his concept of "smart" composites, which in essence are integral combinations of a sensor and a transmitter. They are connected by a gain element and a feedback loop. The transmitter can then be made to cancel or reinforce the input signal, depending upon the phase shift in the loop. On a macroscale, very hard or very soft surfaces can then be simulated. Composites containing a gain and signal conditioning element together with a feedback loop may exist today only in certain biological systems, but the application of this concept could have some notable possibilities as, for instance, on an invisible submersible system.

Newnham characterized as a "very smart" composite a system in which the response (transfer function) is nonlinear and is adjustable in accordance with environmental stimuli. A PTCR in which the pulse response changes with ambient temperature would be an example of this. He then mentioned a number of uniquely behaving materials that may conceivable be applicable to smart composites: (1) 0.9 PMN + 0.1 PT that when based with a 3-kV/mm field has an electrostrictive d_{33} of 1,500 pC/N; (2) the hydrostatic behavior of moonies (a macro version of an individual void section of a ceramic-air composite); and (3) ferrite-filled plastic composites that can be tailored to have (at least over a limited temperature range) a temperature-independent piezoresistivity of a significant magnitude. He discussed at length the behavior of penterythritol $[C(CH_2OH)_4]$ that has a high latent heat which can be applied towards limiting the temperature increase of components subjected to power spikes.

R.Y. Ting [Underwater Sound Reference Detachment (USRD)] reviewed various hydrostatic materials. He discussed some of the shortcomings of PVF_2 and described the performance (-195 dB) of Plessey 1-3 rod composites. The rods have a 3:1 to 6:1 aspect ratio. Due to the polymer phase the composite has significant pressure and temperature sensitivities. He also discussed 0-3 composites, the high loading ratios (up to 70 percent) required to make them polable, and the advantage of lead titanate in this application: its low K, which improves the polability, overrides the effects of its lower d_{33} value.

A. Bhalla (Penn State) reviewed pyroelectric detector materials and pointed out that high voltage gains calculated for low dielectric constant material sensors are useful only for large area detectors: point contact detectors require high K materials so as to have enough capacitance to obtain an adequate signal-to-noise ratio. He discussed PZN-PT and PZN-PZ materials, composed to operate near the morphotropic grain boundary, which have sensitivities at least an order of magnitude higher than arsenic-doped triglycine sulphate (TGS). He felt that at cryogenic temperatures, ferroelectric or relaxor type ceramics could have sensitivities as high as quantum detectors.

M. Kahn (Naval Research Laboratory, Washington) described the polarization response of PZT to a uniaxial force, applied at an arbitrary angle. He also demonstrated a determination of the piezoelectric shear coefficient of PZT ceramic through the application of a uniaxial force to the circumference of a PZT disc that was poled uniformly at 90° to its thickness. Fitting the data to a response curve obtained from a rotation of the d_{ijk} tensor then provided the d_{15} parameter of the material.

R. Vest (Purdue University) discussed his work with metalorganic films, which are metal soaps or partially substituted carboxylates. The range of materials that are available in metalorganic form with a useful metal content is still quite limited. Rheology is adjusted to deposit 1.5-μm-thick wet films that shrink in the z direction during pyrolysis to a 0.3-μm thickness (thicker films are made by multiple processing). During pyrolysis it is first necessary to drive off the solvent and then to decompose the metalorganic, without evaporating it off first. This sometimes requires high heating rates, but it is necessary to do this in the presence of enough oxygen at the film surface so that carbon is not formed. At the same time it is necessary to prevent the reaction to proceed to (an often destructive) autocatalytic stage. Close attention to the pyrolysis conditions is necessary to obtain good films reproducibly and more work on this is indicated. In general the metalorganic process proceeds at very significantly lower temperatures than solid state materials preparation.

PbO is formed at 350 °C, $PbTiO_3$ in amorphous form appears at 430 °C, and crystalline diffraction peaks appear at 475 °C. $BaTiO_3$ with 12-μm grain size and a nonferroelectric dielectric constant of 200 is formed at 780 °C and subsequent annealing was said to give preferential gain orientation. When films were treated to have a 200-μm grain size, conventional $BaTiO_3$ properties were observed. $KPbTiO_3$ films with dielectric constants of 100 and breakdown strengths of >100 kV/cm were also reported.

D. Payne (University of Illinois) described a "sol gel" technique of making 1,000-Å to 1-μm thin films. He spin casts and polymerizes alkoxide solutions that gel at about 250 °C and crystallize just above 400 °C. This can be done on Si or GaAs integrated circuit substrates. The application of $LiNbO_3$ or of $PbTiO_3$ then provides films having piezoelectric, electro-optic, or memory effects. Payne observed 1,000-Å grains with 400-Å domains, and the 1-μm-thick films were said to have a coercive voltage of 3 V, suitable for direct transistor drive.

Lead titanate crystals were shown to have an appreciable volume change at 450 °C, requiring processing of such films below that temperature, even though their coefficient of thermal expansion matches that of silicon very closely.

E. Cross (Penn State) gave a review of recent trends in electronic ceramics and composites:

- Ceramic processing and applications are getting "colder."

- Polymers are operating at higher temperatures.

- Integration with semiconducting circuits will become more extensive.

- Epitaxially deposited ceramics with very small crystallites will find optical use.

- Relaxor composites will become very sophisticated (the temperature dependence of the morphotropic grain boundary in the PZN-PT system is the present focus of attention).

- "Self-assembling" nanocomposites will appear and will find application at short electromagnetic and visible light frequencies.

- We have to learn much from nature. Handedness as applied in Chiral structures will become an important parameter, used for instance in acoustic absorbers.

- Diamond technology will see more development and impact. Plasma-assisted or low pressure applications give hard, biologically inert, human tissue compatible, low dielectric constant, high thermal conductance (1,000-W/M K) films.

- The Japanese multilayer capacitor industry, i.e., Murata, Kyocera, Tayo Yuden, presently makes 5 x 10^9 devices, just with base metal electrodes. The most recent dielectric for these is PMN+Ca+Ti+NiW, which gave high K, donor doping, a good temperature behavior, and presumably lower firing temperatures, respectively. This is a rather sophisticated formulation which is said to provide compatibility with copper electrodes.

- Another issue in the multilayer capacitor area is the attainment of thinner dielectrics that usually have higher breakdown strengths. Antiferroelectric materials can be used for these, since they have no hysteresis and permit higher ac field strengths.

- On the topic of circuit packaging, IBM modules dissipate as much as 3 kW each, but at the same time commonly used alumina has too high a dielectric constant, a firing shrinkage that makes close tolerances difficult, and a compatible (Mo-Ta) internal electrode that has too high a resistance. There are no good coaxial interconnects for these and the trend is to put more and more circuitry onto larger silicon chips. The wider utilization of glass-bonded alumina with photoetched conductors is one response to this trend.

- He showed a schematic drawing of a piezoelectric motor which uses a torsional element as well as a distending member that brings the torsional device into positive contact with the load. The torsional member has to be assembled from separately poled pieces, but high performance (torque, speed, and positional accuracy) is combined with very effective braking.

- He mentioned experiments in making ferroelectric fibers (for 1-3 composites), materials with complex d coefficients with values up to 2,000 pC/N, composites with 0.5 percent dilation, and agile, distributed sensor-transducer structures in which the amplitude and phase of electrostrictively induced alternating motion is controlled by an applied dc bias. The possibilities of surfaces with active compliance parameters, which would have only minimal sound reflectivity, were also described.

- He also mentioned his ultra dilatometer and its application to measure distentional and shear responses of actuator materials.

I. Burn (DuPont) discussed some dielectric formulations used for thin layer capacitors and precursors. DuPont uses 0.55-μm particle size $BaTiO_3$ powder (0.3-μm minimum particle size) obtained from noncontaminating milling and (for low firing temperatures) a fluorine-free, zinc-aluminum borate glass additive. Upon grain growth much of the glass component goes into the lattice and stoichiometry is calculated accordingly. The grain growth is controlled by using both n and p dopants. Grain sizes of 3 to 5 μm give a K of 10,000 (with Z5U behavior) and 5- to 10-μm grain sizes give a K of 20,000 (Y5V characteristics). The material was said to exhibit transgranular fracture, while temperature-stable but multiphase $MgTiO_3$ was said to exhibit intergranular fracture.

R. Neurgaonkar (Rockwell) reviewed his group's work on tungsten bronzes. He also discussed the feasibility of making oriented and single-crystal films suitable for optical computer applications using $LiNbO_3$ and $LiTaO_3$. He indicated that they were able to prepare oriented superconductive films on MgO substrates.

T.K. Gupta (Alcoa) discussed his work with Al_2O_3 doping of ZnO varistors. Small amounts of Al apparently substitute in the Al_2O_3 lattice as a donor whereas larger amounts go interstitial resulting in a p-doped material. At a critical concentration level (near 400 ppm) improved varistor performance is attained.

Mehrotra from Wright State University discussed some of the effects of sulphur in automobile exhaust on ceramic electrolyte oxygen sensors. It tends to raise the electronic current, most so in 13 percent Ca-stabilized ZrO_2, less in Y-stabilized material. The latter was also found to be more stable in high temperature storage. TiO_2-based sensors, operating at lower temperatures, are thought to be less sensitive to sulphur.

D. Smyth (Lehigh University) discussed measurements of equilibrium oxygen content and the determination of the high temperature conductivity in YBC material. The data indicated a gradually increasing p conductivity as the oxygen content of $YBa_2Cu_3O_{6+y}$ is raised from y=0 to y=1. A minimum of conductance was observed at 850 °C with an O_2 pressure of 10^{-3} atm, under which condition y=0. No abrupt change in enthalpy is observed as the oxygen content is gradually increased. He feels that y=0 gives the stoichiometric composition that gradually attains a fully orthorhombic structure, as more oxygen is diffused into the material.

A.M. Glass (AT&T) discussed the possibilities of electro-optic systems that can handle as much as 10^8 bits in parallel and therefore allow a high volume of information transfer even at only millisecond switching rates. He mentions the need for improving the quality of $LiNbO_3$ crystals that are presently made in >4-inch-diameter slices and pointed out that cadmium telluride has the highest available ratio of electro-optic coefficient to dielectric constant. He feels that optical quality thin films will have a significant cost advantage and that electro-optic materials in which the refractive index can be modulated will find considerable use.

JAPANESE PRESENTATIONS

T. Shiozaki (Kyoto University) discussed properties and applications of electronic crystals and of oriented and single-crystal films. $Li_2B_4O_3$ single crystals have a large piezoelectric coupling coefficient with a zero temperature coefficient. Their behavior is tolerant to cutting angle error and they can be grown from a congruent melt, but they grow only at 2.5 mm/h. They are soluble in acid (not in basic solvents). In thin film form they are used for high power surface acoustic wave applications. Electrode problems are prevented under these conditions by a 0.7-percent Ti additive into the aluminum electrodes. $LiNbO_3$ films have found much application in cellular telephones and he discussed film orientations that can be adjusted to minimize the penetration of the surface wave onto the bulk.

Epitaxial ZnO films (on sapphire) also have a very high coupling coefficient with a low T_c and are used in the SAW mode to frequencies up to 1.8 GHz. ZnO films on glass are made in rather large quantities (2.5 x 10^6/month). The technology of these materials is very advanced and they find application also in optical devices and in Bragg deflectors. He indicated that frequency control circuits comprise about 60 percent of the ZnO film applications. He mentioned $Li_2B_4O_7$ bulk applications in both the VHF and UHF bands, Ta_2O_5 piezoelectric and dielectric films, as well as $PbTiO_3$ and $PbLaTiO_3$ film sensing arrays. He finally mentioned nonlinearities in piezoelectric phenomena, in particular in PZT material used in (high drive) motors.

A. Nagai (Nippon Soda Co.) discussed his group's preparation of very high K multilayer capacitors that have a high volume efficiency. They apply a $0.2Pb(Mg_{1/3}Nb_{1/3})O_3 + 0.6Pb(Ni_{1/3}Nb_{2/3})O_3 + 0.2PbTiO_3$ formulation using powder prepared via the alkoxide process. They attributed the properties attained to improved powder homogeneity (as compared to conventionally prepared oxide powder). They felt that heterogeneities in oxide-based powder mandate higher firing temperatures and that these contribute to the formation of the undesirable pyroclor phase.

Y. Kubota (Tosoh Corporation) reported on the preparation of lead zinc niobate (that is very difficult to prepare by itself) in a composition with lead zirconate titanate and lead titanate. His group combined coprecipitation with solid state reaction and showed perovskite structures with d_{33} coefficients near 250 pC/N.

K. Uchino (Sophia University) discussed three types of actuators:

(1) A digital displacement device made of PZT containing 6 percent of TiO_2. An electric field induces in this composition an antiferroelectric-to-ferroelectric transition that when completed induces a strain in the material that is independent upon further field increases. The exact concentration of TiO_2 in the composition is critical; with 6 percent TiO_2 elimination of the field will reintroduce the antiferroelectric phase and eliminate the strain, as one would want in a micropositioner. When the TiO_2 content is raised to 6.5 percent, the material will exhibit shape memory until a reverse field or a temperature increase is applied. This, for instance, could be used in a nonvolatile memory relay.

(2) A monomorph actuator uses a semiconductive ceramic with an $N\text{-}N^+$ surface barrier on its major surfaces. An applied voltage biases one barrier in the forward direction and the second in the reverse direction, where then a significant voltage gradient develops. The piezoelectric interaction then causes a voltage dependent strain. As much as $200 \mu m$ has been observed on a 30-mm-long plate with 300 V across a total plate thickness of 0.5 mm.

(3) A photostrictive actuator is based on the photovoltaic effect in PZT (or in $BaTiO_3$) where shortwave light causes the generation of a high voltage that then causes a piezoelectric strain. Moving a light beam from one such element to another can then be caused to provide a snap action movement.

These items were discussed by K. Uchino before and are now documented in a detailed article (Ref 9).

In a related paper Matsumoto and Uchino presented the application of a low hysteresis actuator for moving the probing point of a field emission microscope to get precision surface scanning. Niobium-doped PZT, containing as much as a 27 percent Ba for lead substitution and a 3:1 Zr/Ti ratio, was said to have a particularly low hysteresis, giving greatly improved scanning resolution (Ref 10).

H. Yanagida (University of Tokyo) discussed humidity and gas sensors that have heterogeneous p-n junctions that are open to the atmosphere. Examples are NiO-ZnO or CuO-ZnO that serve as humidity sensors or $SrCl_2$-Al_2O_3 in which conduction is affected by moisture even at enclosed interfaces. He stated that some of these heterogeneous junctions were derived from crystal-chemistry considerations but that also serendipity played a major role in arriving at materials for multiphase interactions that exhibit nonlinear behavior.

N. Ichinose (Waseda University) described the preparation of thick BISSCO films on Y-stabilized ZrO_2, MgO, Al_2O_3, and glass substrates. Powders having 1112 and 4334 compositions were milled for up to 120 hours with 2-mm ZrO_2 media in ethyl alcohol, some with 20 to 30 percent lead for bismuth substitution and some with 0.4 percent potassium added (to raise the valence of the copper). Firing was above 865 °C for up to 50 hours. Short firing cycles gave a superconducting upper layer only, presumably due to inadequate oxygen diffusion. On MgO substrates they obtained films with a preferential c-axis orientation, a T_c above 92 K, but only relatively low current densities.

T. Takenaka (Science University, Tokyo) discussed some results from hot forging of YBC and PBISSCO prefired compacts. A room temperature resistivity anisotropy of as much as 10:1 was observed and x-ray diffraction showed evidence of grain orientation. A 6-μm powder particle size and a high compact density contributed to the alignments attained. The measured current densities went up in YBC from 74 to 110 A/cm^2 and in PBISSCO from 40 to 180 A/cm^2.

Dr. Okazaki presented some highlights of electronic ceramic processing technology at a seminar at the Tata Institute of Technology in Bombay. In his introduction he claimed that the Japanese picked up the first "high K" ceramics (TiO_2) from Germany as early as 1935 and that both Murata and KCK have been in this field since. At this time they are making voltage stable relaxor dielectrics, using PMN + PT + MgO and its derivations in as many as 16 ternary compositions. This, of course, attests to the width of the experimental effort that is underway there. He discussed Yamamoto's "partial chemical" method for preparing superconductors. He uses $BaCO_3$ and Y_2O_3 suspended in a dilute oxalic acid and drips into it $Cu(NO_3)_2$ that then precipitates onto the suspended powders. Drying and sintering at 780 °C for 6 hours gave a superconductor with a sharp transition at 104 °C. This is compatible with observations by others (Ref 11) that lower temperature annealing of YBC gives a higher T_c phase than higher temperature oxidation. Powder made this way was used in a superconductor-metal composite that had a current density of 133 A/cm^2.

Lead oxalate was coated in a similar manner onto PZT (or onto hydrothermally prepared $ZrTiO_3$) particles. Sintering temperatures were then also lowered and dense ceramics with grain sizes controlled by adjusting the sintering temperature were obtained. He mentioned that Hitachi has stopped making their BeO-SiC substrate material. He also discussed some of the work on the intensive milling of powders that is presently done in Japan. They are working with fine (millimeter size) ZrO_2 beads in a plastic-coated attrition mill. The finer media are said to give finer particles with a more uniform particle size distribution. Milling to a particle size below 0.1 μm is presently not being practiced, largely due to dispersion and powder packing difficulties.

The hydrothermal preparation of powders, i.e., $BaTiO_3$, gives almost ideally round fine particles that are nearly nonagglomerating. This has also been looked at in the United States, but steps to prepare such powders in quantity and in particular at an economical cost are at least in the United States still in their infancy. Some of this information has also been presented by T. Yamamoto and was further included in Dr. Okazaki's Fulrath award (Ref 12) paper.

COMMENTS FROM CONCLUDING PANEL SESSION

(1) There are presently in India 300 active, U.S.-sponsored research projects.

(2) Research projects in India have long gestation periods and have long lead times (M. Multani).

(3) Market forces are not what drives research in India (C.N.R. Rao).

(4) Workshops are drivers.

REVIEW

The Indian presentations revealed a large variety of electronic materials research activities. This has to be viewed, though, against the background of them having hundreds of laboratories, with nearly 50 of them attached to their defense department, 50 to their commerce department, and others established with the cooperation of foreign countries. The timeliness of their data ranges all the way from the most topical, i.e., the ESR response of YBC single crystals, to efforts at establishing Indian base lines in materials systems ($BaTiO_3$ surface barrier capacitors for instance) that have been investigated and commercially exploited in the United States, Japan, and Europe for more than 30 years.

The variety of presentations makes it difficult to generalize. Some of the senior academic people displayed an extensive knowledge of the art whereas some of the more esoteric materials were reported on by younger researchers, with fewer relevant references.

From a more personal point of view, the presentation by Chakravorty on precipitated and on field-enhanced ion exchanged superfine metals in glasses (now called nanocomposites) has motivated me to review further the literature on this. In the PZT materials and transducer area they are doing significantly more than what I was shown last year, but the work still has a way to go before they are at par with what we are familiar with. I am not sure though that we saw a full cross section of Indian electronic ceramic technology. The competence that seems to exist at the Armament Research and Development Establishment laboratories in the preparation and process of piezoelectric materials and devices (see below) and the work in dielectric ceramics at some of the Indian capacitor manufacturers were not well represented at the meeting.

Some Indian organizations seem to have a variety of very up-to-date equipment; I also saw a lot of homemade setups. In many other Indian laboratories a shortage of equipment was claimed, but just the scope of the materials research effort in India practically assures them a spot in the sun. Their climate, on the other hand, combined with a dearth of air-conditioned facilities, tends to slow their rate of progress.

It appears that involvement in research activities in electronic ceramics in India will bring to U.S. researchers at the present time a limited return that over the next few years could be expected to increase significantly. As noted many Indian workers had a very thorough knowledge of the literature and it appears that they were trying to apply this information. Considering the amount of brain power available in India and the number of their research laboratories, they invariably will become a factor in the research in this field. On the other hand, it is questionable whether their progress will match that of mainland China, for instance.

Upon reviewing U.S. presentations, one finds R. Newnham thinking of practical implementations of his "smart composite" concept and A. Bhalla quoting ferroelectric pyroelectric detectors having at cryogenic temperatures sensitivities as high as quantum detectors.

R. Vest is now emphasizing the pyrolysis process aspects of organometallic materials and E. Cross was noting "self-assembling nanocomposites." Particularly interesting were D. Smyth's measurements on the high temperature conductance of YBC. That indicated to him that at least from a bulk point of view, the tetragonal to orthorhombic phase change in this material is gradual, a somewhat controversial point of view.

Of the Japanese presentations, N. Ichinose's discussion of the successful preparation of BISSCO thick films as well as discussions of the results of Dr. Yamamoto's partial chemical processing of YBC and PZT were of interest. K. Uchino's low hysteresis actuator for a field emission microscope was a new application. Also new and detailed (English) documentation of actuator devices and materials was provided. H. Yamagida's comment on the success of his "serendipity" in devising gas sensing heterojunctions should not really come as a surprise, considering the way development is conducted in Japan.

The attribution of imperfect ceramics to powder nonhomogeneities is not new, but A. Nagay reported now to have seen such imperfections with energy-dispersive spectroscopy in oxide-based powders.

SITE VISITS

Bharat Electronics, Pune

The manager, M. Srinivasan, demonstrated and discussed their product line:

(1) An extended storage time battery is made from an aluminum-doped magnesium tube (closed at one end) that has an oxide film, lined with porous paper, and filled with a $MgClO_4$ electrolyte. The cathode is carbon. Closing an external circuit causes the oxide layer to be punctured and the battery to be activated. A battery of slightly less volume than a "C" cell can provide 7 A-h at 2 V.

(2) They are making image intensifier tubes using a technology that is similar to that at the U.S. Night Vision Laboratory at Fort Belvoir. The glass target is about 1 inch in diameter. A few hundred angstrom of silver are evaporated on it. This is then oxidized. Cerium is evaporated from cerium chromate sealed into the tube. It reacts with the oxidized silver to form an alloy that has good photoemissivity. The nickel metal structure has 16 kV applied, is self-focusing, and provides a 0.75 size image with a 150X light amplification. A P3 phosphorous screen and halogen free Corning 7056 glass are used in the envelope. The device is used in tanks.

Armament Research and Development Establishment, Pune

This is a very substantial and well maintained facility that employs about 1,500 persons. The ceramic facility was established nearly 15 years ago to provide an alternate spark generator to a hollow charge impact explosive device that they were making under license and that initially contained a barium titanate transducer. Their present pilot plant contains an array of modern process and process control equipment including a vibratory mill, an attritor, a sedograph particle size analyzer, a BET surface analyzer, a hydrostatic press, a hot press, and x-ray equipment. They have access to a scanning electron microscope in the neighboring National Chemical Laboratory. Their efforts were apparently successful, insofar as they said to have developed equivalents to PZT 5A, PZT 5H, PZT 4, and PZT 8 using Indian raw materials. With these they have developed processing procedures for a range of PZT devices, some of rather substantial size; 300,000 of these have been made at C.E.T., a manufacturing plant in Delhi. They are very well informed about U.S. materials, transducers, and arrays and have lately made pilot runs of spherical hydrophones. Their devices seem quite sophisticated in performance; Qs of 1,000 with densities above 7.8 g/cm^3 were quoted for transducers made from their PZT 8 material.

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Manfred Kahn received a BSEE degree from the University of Wisconsin, an MSEE degree from Rensselaer Polytechnic Institute, and a Ph.D. in ceramic science from Pennsylvania State University. Dr. Kahn worked for 20 years at Sprague Electric Company and for 8 years at AVX Ceramics in the electronic ceramics area. For 1 year he taught electrical engineering. Since 1983 he has been in charge of the Electronic Section in the Ceramics Branch of the Material Science and Technology Division of the Naval Research Laboratory in Washington, DC. Dr. Kahn is a Fellow of the American Ceramics Society. His current research interests include the design as well as the processing of composites made from electronic ceramics.

SOVIET RESEARCH ON EXPLOSIVELY COMPACTED SOLIDS AND HIGH-TEMPERATURE, HIGH-PRESSURE PROCESSING OF MATERIALS

William J. Nellis

About 35 papers were presented at the International Seminar on the High Energy Working of Rapidly Solidified Materials in Novosibirsk, U.S.S.R. These papers dealt principally with the processing and resulting properties of explosively compacted, initially porous metallic glasses, high-T_c superconductors, and other materials; the dynamic high-pressure and high-temperature processing of bulk surface layers with quench rates as high as 10^6 to 10^8 K/s; and the modeling of relevant macroscopic and microscopic dynamic processes. Site visits were made to a shock-wave and a pulsed laser-heating laboratory at the Institute for High Temperatures; diamond-anvil-cell, crystal-growing, and high-T_c superconductivity laboratories at the Institute of Crystallography; and diamond-anvil-cell, diamond-indentor, and superconductivity laboratories at the Institute of High Pressure Physics.

INTRODUCTION

The scientific program of the International Seminar on the High Energy Working of Rapidly Solidified Materials consisted of five areas: (1) explosive and dynamic compaction of powders of rapidly solidified materials; (2) explosive welding of metallic glasses; (3) modification of the physical and mechanical properties of amorphous alloys due to dynamic- and static-pressure processing and plastic deformation; (4) effects of high-energy-rate loading and subsequent thermal treatment of rapidly solidified materials on their structure, phase composition, and properties; and (5) high-energy-rate fabrication of metastable materials and high-temperature superconducting ceramics. These topics are relevant for producing novel materials with improved properties with potential far-reaching applications to programs of the Department of Energy and other Federal agencies. Since the Soviet Union conducts a large, high-quality research and industrial program in these areas, the seminar offered an opportunity to learn of recent developments in these topics. The visits to the institutes provided an opportunity to learn of recent developments in shock compression and static high-pressure science and technology, areas of ongoing interest at the Lawrence Livermore National Laboratory.

INSTITUTE OF HIGH TEMPERATURES (IHT)

This institute deals with thermophysical properties of materials in high-temperature devices, shock waves at extreme conditions, physical gas dynamics for space and rocket applications, superconducting energy storage systems, and magnetohydrodynamic (MHD) plants. The new director is

V. Batinin, who has recently succeeded A.E. Scheindlin as director. The institute employs a total of 4,500 people. A 0.6-GW commercial MHD plant has recently been built at Rezan for electromagnetic probes of the Earth and earthquake prediction. Relativistic MeV electron beams with 10^{3}-s pulses are studied with respect to the propagation of energy and the properties of matter at extreme conditions. An explosive firing tank 14 m in diameter with a limit of 500 kg of explosive is being installed. A 10-μm wavelength laser is used for inducing amorphous layers on steel cylinders. An MFE tokomak 1.5 m in diameter is used to study the first-wall problem and how to inject fissile fuel into the central 20-cm working region by gas gun or railgun. Superconducting engineering applications are developed, including a large-scale NbTi wiremaking process in collaboration with a Finnish company. A 10^{8}-J superconducting inductive storage device is being built to smooth usage in an electric power distribution system.

V.E. Fortov, my host, is head of the Scientific Center of the Thermophysics of Intense Action. This center studies the response of matter to the deposition of intense amounts of energy by laser, charged-particle beams, high explosives, impact, etc. Experiments, computations, and physical property measurements are studied. The center has 100 people in 10 groups including the shock-wave spallation group of G.I. Kanel, the theory group of S.I. Anisimov, the railgun group of E.F. Lebedev, and the plasma physics group of V.E. Fortov. This center will be housed in 265,000 ft^2 in new buildings nearing completion and partially in operation.

The railgun project has achieved about 6 km/s with a 1-g lexan cubic projectile using a 0.8-MJ capacitor bank and currents up to 500 to 600 kA.

The shock-wave laboratory I visited had two 50-mm-bore single-stage powder guns about 4 m long to study mechanical properties and phase transitions. Diagnostics included a VISAR velocimeter and a flash x-ray diffraction setup. X-rays from Mo, Fe, and Cu targets irradiated graphite specimens transversely to the shock direction; diffracted spectra are measured with a light-intensified recording system.

Laser intensities of 10^{15} W/cm^2 are being used by B. Ageev to achieve up to 100 Mbar pressures. He is using second harmonic Nd-glass laser light in 2.5-ns, 100-J pulses. Stepped targets 50 μm thick are used that consist of two 25-μm-thick foils. Laser focus is 10 to 100 μm in diameter. Shock transit time across the 25-μm step is measured by fiber optically coupling light emitted from the two-stepped free surfaces to a streak camera. The ablation pressure in targets is calculated by $I^{2/3}$ intensity scaling and by calculating the crater size observed in recovered targets. Results for the two methods are in good agreement. Because of high quench rates, the recovered specimens are also investigated for new phases.

On my second day at IHT I visited the laboratory of M. Scheindlin, which is located in another part of Moscow near a large technical university specializing in energy issues. This group of 25 studies thermophysical properties of matter at high temperatures and pressures achieved by laser heating. Maximum conditions are about 6,000 K and 2 kbar. The material of greatest interest is melted carbon-graphite. Both the melt curve and the liquid state are studied. The liquid-vapor phase line has also been measured up to 1 kbar and 7,000 K. High temperatures are generated by a 1-kW, 1.06-μm laser. Surface temperature is measured on millisecond timescales by a pyrometer with up to nanosecond time resolution and by a high-speed multichannel spectrometer. Static pressure in the specimen chamber is measured with a He manometer. Specimens include industrial and pyrolytic types and a highly oriented pyrolytic graphite prepared by heating graphite whiskers in a CH_4 atmosphere. This method produces rods with the basal plane oriented along the rod axis. These rods are metallic in the basal plane. The optical reflectivity is 0.3 to 0.4 and it increases linearly with temperature. Conductivity in the basal plane is similar to that of W and Mo and 1,000 times less along the c-axis. Because of the large anisotropy of thermal conductivity, the rods are effectively thermally insulated radially. Craters of liquid carbon are produced on axis. The measured emissivity of the liquid is 0.65, comparable to that of liquid metals. Scheindlin said that this is the first measurement of the emissivity of liquid carbon. This emissivity is similar to the c-axis value of solid graphite and the conductivity of the liquid is similar to that along the a-axis; i.e., metallic. X-ray diffraction of resolidified carbon shows sharp x-ray lines and randomly oriented crystallites.

The enthalpy and specific heat of W has also been measured in the liquid state up to 1,000 K above the melting temperature. The accuracy in enthalpy was said to be 1.5 percent, comparable to the best caloric data.

Vaporization of graphite is studied by heating a specimen in vacuum with a CO_2 laser at 1 to 2 x 10^7 W/cm^2. The velocity distribution of the ejected plume is measured by laser-Doppler anemometry. Temperature is measured to 5,000 K with 50-ns time resolution using fiber optically coupled photodiodes with RCA optical filters. Emissivities of 0.3 are obtained by measuring the reflectivity of a laser beam.

Surface heating is also done at 10^4 W/cm^2 in a 1-bar gaseous atmosphere using a 1-kW solid state laser. The emitted spectrum becomes blackbody when a crater forms in the surface of the target. Reflectivities are measured using a He-Ne laser.

I requested to meet with V.N. Zharkov of the Institute of the Physics of the Earth to discuss his high-pressure/high-temperature models of the interiors of the giant planets. Time did not permit me to visit his institute but Dr. Zharkov came to IHT, where we had ample time to discuss scientific topics. He is the head of a 12-person planetary theory group and leader of the Soviet effort to interpret Mars data.

INSTITUTE OF CRYSTALLOGRAPHY

I visited the laboratories of S.M. Stishov. These include both a high-pressure laboratory, where diamond anvil cells are the technique of greatest current interest, and crystal growing facilities by the hydrothermal method. The main physics interests currently are the properties of high-T_c superconductors, mostly at ambient pressure. Techniques developed for studying small specimens in diamond cells are being used to investigate the properties of small (0.1 by 0.1 by 1 mm^3) single crystals of high-T_c oxides grown from the melt. Measurements include electrical resistance, Raman spectroscopy, and x-ray diffraction. The specimens are prepared with a wide range of chemical compositions.

INSTITUTE OF HIGH-PRESSURE PHYSICS

This is a large institute that performs a wide variety of research and development using static high pressures. Yu. S. Konyaev was still acting director. The Academy of Sciences has since chosen academician A.A. Abrikosov, a well-known condensed-matter theorist, as the new permanent director. I visited the diamond-indentor-cell laboratory where recent results were shown to me by E.N. Yakovlev, the former acting director. This cell uses a natural diamond anvil and a rounded carbonado diamond indentor. Transitions to superconducting phases were being studied in PbTl, PbSe, and PbS at pressures up to 560 kbar. The pressure distribution with radius is measured at 4.2 and 300 K using ruby fluorescence. Plateaus in the pressure distribution are interpreted as phase transitions. The large pressure gradient under the diamond indentor is thus used to scan a wide range of pressure in a single cell. Yu. A. Timofeev, the group leader, showed me a databook with 1-hour-old entries and gave me photocopies of plots of measured pressure distributions, a good example of the scientific openness I encountered on my trip.

In the laboratory of A. Shapotchenko and S. Budko the pressure dependences up to 20 kbar of superconducting critical magnetic fields were being measured inductively for $YBa_2Cu_3O_7$ and La_2CuO_4.

In the laboratory of E.S. Itskevich, M.I. Yeremets was measuring the pressure dependence in a diamond anvil cell of the optical properties of semiconductors. Also Raman vibrational spectra of $YBa_2Cu_3O_7$ have been measured versus pressure in a diamond anvil cell.

I spoke with V.V. Evdokimova about her high-pressure and high-temperature processing of molybdenum-sulfide superconductors to increase critical current densities. Work on new high-T_c oxides is in progress and results are not yet available.

I visited with S.V. Popova, V.V. Braschkin, and G. G. Skrotskaya, whose group is quenching materials from high temperatures at static pressures in the 50 to 100 kbar range. Maximum thermal quench rates are 10^3 K/s. They are synthesizing new phases and mixed phases in a wide range of materials. A condensed-matter theory group of R.G. Arkhipov and coworkers performs band theory and other calculations addressing phase stability and synthesis in parallel with the experimental work.

CONFERENCE IN NOVOSIBIRSK

The presentations included 28 Soviet speakers addressing diverse topics many of which were quite interesting and novel. In many cases the work presented was the result of collaborations between a shock processing group and a materials institute and/or an industrial organization. Many projects appeared focused on getting processes into industrial production.

Dynamic Compaction of Metallic Glasses and Crystalline Materials

A consensus seemed to be expressed by several Soviet researchers that compacts produced by the dynamic compaction of powders made from rapidly solidified materials were not industrially viable, compared to products made by other methods. The main reason was the cost of powdering and the heat treatment of powders.

A paper by O.I. Vorotnikova, working with the group of V.F. Nesterenko in Novosibirsk, described the explosive compaction of a soft magnetic transformer by winding ribbons of a Co-based alloy around the core of a cylindrical explosive system. To minimize eddy-current-heating losses, an insulating layer was placed between the ribbon windings by placing a layer of MgO in alcohol on the ribbon and letting the alcohol evaporate. Cores could be cut from such compacts and polished to produce coercive forces of <1 A/m.

A.N. Lazaridi, working with the group of V.F. Nesterenko in Novosibirsk, described $Nd_2Fe_{14}B$ bulk compacts produced by shock compaction. Good magnetic properties have not yet been obtained. S.A. Pershin discussed the shock compaction of alternate ribbons of metallic glass and foils of copper.

Surface Processing

A.A. Shtertser of Novosibirsk described the explosive compaction of powder layers on the surfaces of metal plates and tubes to produce 2-mm-thick coatings. V.M. Bukin of Volgagrad described experiments to explosively shock melt powder layers on the surface of a metal substrate. Substrates were steel and Cu up to 1 m long. Surface layers produced were 50- to 200-μm-thick Ni/Al and Ni_3Al, steel/Ni, and Cr/C. N.I. Pak of Krasnoyarsk discussed rapidly solidified surface melts produced by explosive plasma sources. The purpose is to produce surfaces with corrosion resistance, wear resistance, and hardness. Steel plates 1.5 m long were rapidly heated by a two-wave thermal pulse caused by an air shock at ~10,000 K followed by the explosive reaction products at 2,000 to 3,000 K. Maximum pressure on the working piece is about 10 kbar caused by the explosive products. With this technique surface layers a few micrometers thick are melted and quenched at 10^6 to 10^8 K/s. Layers 20 to 100 μm thick are saturated by nitrogen and detonation product gases. The gas dynamics, heat transfer, and gas saturation were modeled computationally.

Coatings From Exploding Metals

Dr. Motorin of Novosibirsk described a process using exploding wires to produce rapidly solidified coatings on substrates. Layers 1 μm thick of W, Mo, Ni, Ti, Al, and Cu were coated on thin, brittle substrates of arbitrary shapes made of Si, ceramics, sapphire, and metals. Good adhesion was obtained. L.B. Zuev described a process using exploding foils to produce a 100-μs beam at 10 km/s to coat a vaporized foil or material pushed by the exploding foil onto ceramics and glasses. These two methods used electrical discharges through metal specimens.

Dynamic Compaction of High-T_c Superconductors

Results for $YBa_2Cu_3O_{7-x}$ were reported by two Soviet groups. V.F. Nesterenko of Novosibirsk reported results on explosive-compaction work done in collaboration with the Institute of Inorganic Chemistry. His group is working in several areas: (1) the explosive compaction of high-T_c powders; (2) the shock treatment of solid high-T_c compacts; (3) the shock synthesis of oxide superconductors from constituent chemical powders; (4) the shock fabrication of metal-oxide composites (including preheating to as much as 1,000 °C just prior to shock); (5) shock-induced oxygenation of high-T_c oxides in various O_2 environments; and (6) shock processing powders prior to conventional sintering.

Densities greater than 98 percent of theoretical have been obtained in explosively compacted high-T_c oxide powders. Shock pressures were in the vicinity of 60 kbar. Magnetic susceptibility data showed that superconductivity is maintained in bulk. However, thus far a superconducting (SC) transition has not been observed by electrical transport in the as-shocked state. Annealing in air or O_2 at 950 °C produced a SC transition by transport. Anneals at 500 °C in an oxygen atmosphere also produce a SC transition in the electrical transport data, but with very small critical current densities. The shock treatment of solid high-T_c compacts at pressures of 300 to 400 kbar induces semiconducting behavior above T_c, an onset T_c equal to that of the unshocked specimen, and an extremely broad transition that does not go to zero resistance because of the shock synthesis of second-phase material. Low-temperature anneals at 460 °C in O_2 and at 600 °C in He induce a gradual recovery to the SC transition of the unshocked specimen.

Shock synthesis of superconducting Y-Ba-Cu-O materials was performed by compacting powders of Y_2O_3, CuO, and $BaCO_3$ in proportions to achieve relative compositions 1:2:3 for Y, Ba, and Cu, respectively, followed by anneals in air. Explosively compacted high-T_c oxide-metal composites were fabricated which included high-T_c rods in metallic shells and high-T_c annular shapes with central metallic rods, tubes, or a hole. Copper connections were shock-bonded to high-T_c oxide shapes. Shock-processed powders, when sintered, produced a T_c that is 1 K larger and a width 1.5 K smaller than for unshocked sintered powders. Thus, shock-induced defects affect the sintering process of high-T_c oxides.

Yu. D. Shishkin of Novosibirsk reported the results of experiments performed with A.M. Staver at the University in Krasnoyarsk. High-T_c oxide powders were explosively compacted in planar geometry in initial O_2 pressures of 1 to 100 atm. The estimated shock pressure was 10 kbar and the estimated shock temperature in the gas was 5,000 K. The purpose of the experiments was to saturate the ceramic with oxygen. Initial 123 powder densities were 2.3 g/cm³. The quality of the resulting compacts decreased rather quickly with initial O_2 pressure. Small increases in both the onset T_c and the transition width (~4 K) were observed in the magnetic susceptibility data. When shock pressures of 165 kbar were used, the SC properties did not persist due to loss of oxygen. When shock pressures of 65 kbar were used, the SC properties essentially persisted after shock.

Scientists from many other Soviet groups said that they were working on various aspects of the explosive compaction of high-T_c superconducting powders.

Ceramics

E.S. Chagelishvili of Tblisi said that he is shock-synthesizing single-crystal transparent diamonds of 0.4 to 0.6 mm dimensions. G.A. Shvetsov of Novosibirsk said that he is fabricating railgun launchers by the explosive compaction of ceramic and metal powders. The compacted ceramic forms the rail spacers and the compacted metal forms the rails.

CONCLUSIONS

The Soviet Union has a substantial high-quality and ongoing program in materials research at high dynamic and static pressures. The primary purposes are to develop new materials for applications and to understand the properties of materials at extreme conditions for computational simulations.

The Soviet Union has an educational system that produces the large number of young scientists and engineers required to conduct their ambitious program in shock-wave and static high-pressure research. The success of their educational system for high-pressure research is based on the fact that graduate education is performed in institutes of the Academy of Sciences; that is, graduate students are trained by experts in the Soviet equivalent of U.S. national and government laboratories.

OPPORTUNITIES FOR RESEARCH IN JAPAN

A number of opportunities are available for research visits to Japan. They are detailed in the following brochures published by the National Science Foundation (NSF):

- Fact Sheet: Support for Research Visits to Japan through the National Science Foundation, NSF 88-51
- Japan Initiative FACT SHEET, NSF 88-39
- Japan Society for the Promotion of Science (JSPS); Postdoctoral Awards for United States Researchers, NSF 88-98
- NSF-AIST Program Announcement, NSF-89-16
- Science and Technology Agency of Japan; Postdoctoral Awards for United States Researchers, NSF-88-52

* * *

At the request of the Science and Technology Agency (STA) of Japan, the *Scientific Information Bulletin* is highlighting their Fellowship Program.

STA Fellowships of Japan

Japan currently enjoys an extremely large trading surplus, and its national power as well as its scientific and technological capabilities have rapidly increased. In conjunction with this there have been many calls from Europe and the United States for "Japan to make appropriate contributions in scientific and information exchanges." This issue is becoming a point of major importance in relations between Japan and the United States. It is a matter of urgency for the Japanese to take measures to respond to this matter as soon as possible. As a concrete measure towards this end, the STA Fellowship Program was established in 1988, and efforts are being made to expand this program.

This system provides promising overseas researchers in fields such as the life sciences, space, and nuclear power with the opportunity to carry out research work in Japan, in places such as national laboratories and research institutes. In 1989 it is planned to accept 130 researchers from overseas (budget of ¥950 million). A brief outline of the system is provided below.

In order to provide living assistance to researchers from overseas residing in Japan, the Japan International Science and Technology Exchange Center (JISTEC), on commission from the STA, provides fellowship payments, services such as Japanese language training, Japanese culture study, consultations concerning problems encountered in everyday life, and help in finding housing. The center has an office near Tsukuba Science City, where many Japanese research organizations are located. The consultation service it provides for everyday living has gained a particularly good reputation. For Japanese language training, an allowance is paid separately so that foreign researchers can attend local Japanese language schools. JISTEC also provides health insurance.

NSF serves as the contact point in the United States for researchers interested in this system, so please feel free to make enquiries.

Outline of STA Fellowship

QUALIFICATIONS FOR STA FELLOWSHIP

To qualify, an applicant must satisfy the following conditions:

- Possession of doctoral degree in a scientific or engineering field, or equivalent qualification.

- Age under 35, in principle.

TENURE AND FIELD OF RESEARCH

Tenure is between 6 months and 2 years, to be decided through negotiation between the candidate and the host institute. (The agreed tenure may be reduced by JISTEC for budgetary reasons.)

The field of research is decided between the candidate and the host institute. Publication of research will be subject to the regulations of the host institute.

HOST INSTITUTES

These include national laboratories (excluding universities and laboratories affiliated with university), public (semi-government) corporations, and some nonprofit organizations.

FELLOWSHIP AWARDS

Fellowships include round-trip air tickets (economy class) and the following tax-free allowances:

- Living allowance - ¥270,000 a month

- Family allowance - ¥50,000 a month

- Housing allowance - up to ¥100,000 a month. Recent exchange rates have been in the range of 120-140 ¥/$. Normally, apartments will be provided to awardees. The floor area of apartments is 40 m^2 for awardees unaccompanied by their family and 60 m^2 for awardees with family (in metropolitan areas other than Tokyo). Any shortfall is to be borne by the awardee.

- International Relocation allowance: ¥200,000

- Travel allowance (within Japan): ¥100,000 a year

- Japanese language lesson courses are provided free of charge to the STA Fellowship awardees and their family members in the Tsukuba area. Those who live in places other than the Tsukuba area will be entitled to reimbursement of Japanese language school tuition up to a specified amount.

- Excursions or local trips will be held to help make the Fellowship awardees and their family members in the Tokyo/Tsukuba areas familiar with Japan's culture, tradition, and history.

In addition, ¥1,480,000 per year will be paid to the host institute to cover research costs. Medical insurance for researchers will be paid by JISTEC during their stay in Japan.

In the U.S. contact:

NATIONAL SCIENCE FOUNDATION
Senior Program Manager
U.S.-Japan, Australia, and New Zealand Programs
Division of International Programs
Washington, DC 20550
Tel: 202-357-9558

In Japan contact:

Japan International Science and Technology Exchange Center (JISTEC)
Port One Building 6F, 1-7-6, Mita-machi
Tsuchiura City, Ibaraki Pref. 300
Japan
Tel: 0298-24-3355
Facsimile: 0298-21-3214

INTERNATIONAL MEETINGS IN THE FAR EAST
1989-1994

Compiled by Yuko Ushino

The Japan Convention Bureau, the Science Council of Japan, and journals of professional societies are the primary sources for this list. Readers are asked to notify us of any upcoming international meetings and exhibitions in the Far East which have not yet been included in this report.

1989

Date	Title/Attendance*	Site	Contact for Information
September 17-22	International Conference on the Science and Technology of DEFECT CONTROL IN SEMICONDUCTORS-Yokohama 21st Century Forum	Yokohama, Japan	IC-STDCS c/o Lab. Physics of Crystal Defects Institute for Materials Research Tohoku University 2-1-1 Katahira, Sendai 980
September 17-22	The 40th Meeting of International Society of Electrochemistry 42-F200-J540	Kyoto, Japan	Secretariat 40th Meeting of International Society of Electrochemistry c/o Kyoto International Conference Hall Takaragaike, Sakyo-ku, Kyoto 606
September 18-20	Advanced Materials	Pakistan	Dr. Nazeer Ahmad Khan Research Laboratories Kahuta, P.O. Box 502 Rawalpindi, Pakistan
September 18-22	Asian-Pacific Corrosion Control Conference	Singapore	National Association of Corrosion Engineers P.O. Box 218340 Houston, TX 77218
September 22-25	The 3rd International Symposium on Defect Recognition and Image Processing for Research and Development of Semiconductors (DRIP III)	Tokyo, Japan	Professor Tomoya Ogawa Department of Physics Gakushuin University Mejiro, Tokyo 171
September 23-27	Asian Physics Education Network "Conference/Workshop Teaching of Optics"	Melbourne, Australia	Professor Geoffrey I. Opat School of Physics University of Melbourne Parkville, Victoria 3052
September 24-28	The 6th International Symposium on Passivity - Passivation of Metals and Semiconductors	Sapporo, Japan	Dr. Norio Satoh Faculty of Engineering Hokkaido University Nishi 8-chome, Kita 13-jo Sapporo-shi 060

*Note: Data format was taken from the Japan International Congress Calendar published by the Japan Convention Bureau.

No. of participating countries
F: No. of overseas participants
J: No. of Japanese participants

1989			
Date	**Title/Attendance**	**Site**	**Contact for Information**
October 3-5	The 10th Meeting of World Society for Stereotactic and Functional Neurosurgery 20-F200-J300	Maebashi, Japan	Department of Neurosurgery Gumma University, School of Medicine 3-39 Showa-machi Maebashi 371
October 4-6	International Meeting on Advanced Processing and Characterization Technology (APCT '89)	Tokyo, Japan	Professor Kunio Tada Department of Electronic Engineering University of Tokyo 7-3-1 Hongo Bunkyo-ku, Tokyo 113
October 4-6	The 20th International Symposium on Industrial Robots	Tokyo, Japan	Japanese Society of Industrial Robots 3-5-8 Shibakoen Minato-ku, Tokyo 105
October 7-13	The 40th International Congress	Beijing, People's Republic of China	International Astronautical Federation 3-5 Rue Mario-Nikis 75015 Paris, France
October 9-12	TUBE '89 International Congress and Exhibition	Singapore	International Tube Association P.O. Box 84 Leamington Spa, Warwickshire CV32 5FX, UK
October 10-12	The 4th International Colloquium on Stability of Metal Structures (Asian Session)	Beijing, People's Republic of China	Mr. Wang Shan Secretariat: ICSSAS '89 Dept. of Civil Engineering Tsinghua University Beijing, 100084
October 10-19	International Training Course on Biomembranes	Beijing, People's Republic of China	Professor F.Y. Yang Department of Biomembranes Institute of Biophysics Academia Sinica Beijing, 10080 China
October 11-17	ACHEMASIA'89: International Conference on Chemical Engineering	Beijing, People's Republic of China	James J. Doheny 3625 McCormick Ave. Brookfield, IL 60513
October 11-17	The 1st Asian Congress on Chemical Engineering and Biotechnology	Beijing, People's Republic of China	c/o DECHEMA Theodor-Heuss-Allee 25 P.O. Box 97 01 46 D-6000 Frankfurt-Main 97, FRG
October 12-14	The 1st International Conference on Higher Nervous Functions	Osaka, Japan	Behavioral Physiology Faculty of Human Sciences Osaka University 1-2 Yamadaoka Fukita-shi, Osaka 565
October 15-18	The 9th International Display Research Conference - Japan Display '89 27-F200-J500	Kyoto, Japan	Secretariat of Japan Display '89 c/o Japan Convention Services, Inc. 4F, Nippon Press Center Bldg 2-2-1 Uchisaiwai-cho Chiyoda-ku, Tokyo 100
October 17-19	The 1st International Conference on Music Perception and Cognition	Kyoto, Japan	ICMPC Secretariat Department of Music Kyoto City University of Arts Kutsukake, Ohe Nishikyo-ku, Kyoto 610-11

1989			
Date	**Title/Attendance**	**Site**	**Contact for Information**
October 17-22	CIS '89 Tokyo/International Symposium on Chromatography	Tokyo, Japan	Professor Tadao Hoshino, Secretary General of CIS '89 Division of Chemotherapy Pharmaceutical Institute, School of Medicine Keio University 35 Shinanomachi Shinjuku-ku, Tokyo 160
October 18-21	The 1st ANAIC International Conference on Silicon and Tin	Kuala Lumpur, Malaysia	Professor V.G. Kumar Das Department of Chemistry University of Malaya 59100 Kuala Lumpur
October 22-26	International Conference on Semiconductor and Integrated Circuit Technology	Beijing, People's Republic of China	Continuing Education in Engineering University Extension University of California 2223 Fulton Street Berkeley, CA 94720
October 22-27	The 14th World Congress of Neurology	New Delhi, India	Dr. J.S. Chopra, Organizing Secretary 1033 Sector 24B Chandigarh 160 023 India
October 22-28	1989 Joint International Waste Management Conference	Kyoto, Japan	ASME Account No. 1665 Accounting Service Center 22 Law Drive P.O. Box 2900 Fairfield, NJ 07007-2900
October 23-25	The 10th International Conference on Assembly Automation	Kanazawa, Japan	Conference Manager (ICAA-10) IFS Conferences 35-39 High Street, Kempston Bedford MK42 7BT England
October 23-25	The 2nd International Waste Management Conference	Kyoto, Japan	Mr. R. Kohout Ontario Hydro 700 University Ave. Toronto, Ontario M5G 1X6 Canada
October 23-26	International Conference on System Simulation and Scientific Computing	Beijing, People's Republic of China	
October 23-27	International Conference on Coal Science	Tokyo, Japan	Secretariat for ICCS Coal Conversion Department New Energy Development Organization (NEDO) Sunshine 60 Building 3-1-1 Higashi-Ikebukuro Toshima-ku, Tokyo 170
October 23-28	The 2nd World Congress on Non-Metallic Minerals	Beijing, People's Republic of China	Before 31 August 1989: WCNMM 1989 Wuhan University of Technology Wuhan, Hubei, China After 31 August 1989: WCNMM 1989 Chinese Silicate Society Bai Wan Zhuang Beijing, China
October 24-25	The 2nd International Symposium on New Chemistry	Tokyo, Japan	The Association for the Progress of New Chemistry Izumiya No. 2 Bldg. 3-5-1 Kojimachi Chiyoda-ku, Tokyo 102

1989			
Date	Title/Attendance	Site	Contact for Information
October 24-26	Electric Energy Conference 1989	Sydney, Australia	Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, ACT 2600
October 25-27	IFAC/IFORS/IAEE International Symposium on Energy Systems, Management and Economics (ESME 89)	Tokyo, Japan	Dr. Kenji Yamaji Central Research Institute of Electric Power Industry 1-6-1 Ohtemachi Chiyoda-ku, Tokyo 100
October 25-27	The International Conference on Advanced Materials & Technology (Hi-Tech Polymer '89 Hyogo)	Kobe, Japan	Hi-Tech Polymer '89 Hyogo Secretariat c/o Inter Group Corp. Shohaku Bldg., 6-23 Chayamachi Kita-ku, Osaka 530
October 25-28	International Sheet Metal Working and Forming Exhibition	Hong Kong	Mack-Brooks Exhibitions Ltd. Forum Place Hatfield, Hert AL10 0RN, UK
October 26-28	ACEAN Polymer Symposium 10-F30-J30	Osaka, Japan	Institute of Scientific and Industrial Research, Osaka University 8-1 Mihogaoka Ibaraki-City, Osaka 567
October 26-28	Radioactive Waste Management for Nuclear Power Reactors and Other Facilities	Kyoto, Japan	Dr. A. Alan Moghissi President Institute for Regulatory Science P.O. Box 7166 Alexandria, VA 22307
October 27-28	'89 Korean Automatic Control Conference	Seoul, Korea	Dr. Chang-Koo Yun '89 KACC Secretariat Cheongryang P.O. Box 131 Seoul, Korea 136-791
October 29-November 2	International Symposium on Polymers for Microelectronics (PCPI '89)	Tokyo, Japan	Professor Sei-ichi Tagawa Research Center for Nuclear Science and Technology University of Tokyo Tokai, Ibaraki 319-11
October 30-November 2	IFAC (International Federation of Automatic Control) Workshop on Production Control in Process Industry	Osaka, Japan	PCPI '89 Secretary Dr. H. Nishitani Department of Information and Computer Sciences Osaka University 1-1 Machikaneyama Toyonaka, Osaka 560
November 1-5	International Symposium/Exhibition on Flame Retardants (IFRESEX '89)	Beijing, People's Republic of China	Mr. Niu Qingzhu Director of the Academic Exchange Dept. China Ordnance Society China
November 5-9	The 7th International Conference on Solid State Ionics	Hakone, Japan	
November 5-10	The 5th International Pacific Conference on Automotive Engineering	Beijing, People's Republic of China	IPC-5 Organizing Committee c/o Society of Automotive Engineers of China 16 Fuzingmenwai Street Beijing 100860

1989

Date	Title/Attendance	Site	Contact for Information
November 5-11	The 7th International Conference on Solid State Ionics (SSI-7)	Hakone, Japan	Dr. T. Atake, Executive Secretary SSI-7 Secretariat Research Laboratory of Engineering Materials Tokyo Institute of Technology 4259 Nagatsuta-cho Midori-ku, Yokohama 227
November 6-10	Aluminum and Magnesium	Zhengzhou, People's Republic of China	Conference Office, IMM 44 Portland Place London W1N 4BR, UK
November 6-11	IFHP/CIB/WMO International Conference on Urban Climate, Planning, and Building	Kyoto, Japan	IFHP/CIB/WMO International Conference on Urban Climate, Planning, and Building c/o Associate Professor Yasuto Nakamura Dept. of Architecture Kyoto University Sakyo-ku, Kyoto 606
November 7-10	International Conference on Electronic Components and Materials (ICECM '89)	Beijing, People's Republic of China	Secretariat of ICECM '89 c/o Professor Zhou Zhigang Department of Chemical Engineering Tsinghua University Beijing 100084
November 7-10	The 2nd International Symposium on the Physical and Failure Analysis of Integrated Circuits	Singapore	Secretariat IPFA Symposium Communication International Associate Pte Ltd. 450 Alexandra Road #10-00 Inchcape House, Singapore 0511
November 8-11	1989 International Symposium on Carbene-Type Reactive Intermediates	Kyoto, Japan	Professor Akira Oku Dept. of Chemistry Kyoto Institute of Technology Matsugasaki, Sakyo-ku, Kyoto 606
November 13-14	International Superconductivity Symposium: Superconductivity and Ionic Character in Layered Compounds	Tokyo, Japan	Dr. Tesuro Nakamura Research Laboratory of Engineering Materials Tokyo Institute of Technology 4259 Nagatsuta-cho Midori-ku, Yokohama 227
November 13-14	SSI-7 Post Conference in Solid Oxide Fuel Cells '89 Nagoya	Nagoya, Japan	Dr. M. Dokiya National Chemical Laboratory for Industry Tsukuba, Ibaraki 305
November 13-16	WELDCON '89 "Technology for Profit"	Sydney, Australia	WELDCON '89 Conference Secretariat Muriel Walton Marketing Pty Ltd. Ground Floor, Park House 187 Macquarie Street Sydney NSW 2000 Australia
November 14-16	International Symposium on Photoinduced Solid Surface Reactions	Kyoto, Japan	Professor Hiroshi Haneda Industrial Chemistry Dept. Faculty of Engineering Kyoto University Yoshida Honmachi Sakyo-ku, Kyoto 606
November 14-16	The 1989 International Symposium on Noise and Clutter Rejection in Radar and Imaging Sensors (ISNCR-89)	Kyoto, Japan	Professor Tsutomu Suzuki Department of Electronics University of Electro-Communications Chofu-shi, Tokyo 182

1989			
Date	**Title/Attendance**	**Site**	**Contact for Information**
November 14-16	International Symposium on Exploitation and Utilization of Titaniferrous Vanadio-Magnetite	Panzhihua, People's Republic of China	STiVM Secretariat Chinese Society of Metals 46 Dongsixi Dajie Beijing 100711
November 14-17	The 2nd International Symposium on Superconductivity (ISS '89)	Tsukuba, Japan	ISS '89 Secretariat International Superconductivity Technology Center Eishin Kaihatsu Building 5-34-3 Shimbashi Minato-ku, Tokyo 105
November 16-17	International Conference on Biotechnology, Biological Frontiers and Biochemistry	New Delhi, India	Dr. Vijay M. Bhatnagar Alena Enterprises of Canada POB 1779 Cornwall, Ontario K6H 5V7 Canada
November 16-17	International Conference on New Approaches in Chromatography and Spectroscopy	New Delhi, India	Dr. Vijay M. Bhatnagar Alena Enterprises of Canada POB 1779 Cornwall, Ontario K6H 5V7 Canada
November 16-17	International Conference on Air/Water & Environmental Pollution & Hazardous Wastes	New Delhi, India	Dr. Vijay M. Bhatnagar Alena Enterprises of Canada POB 1779 Cornwall, Ontario K6H 5V7 Canada
November 20-23	International Conference Evaluation of Materials Performance in Severe Environments-Evaluation and Development of Materials in Civil and Marine Uses 20-F80-J120	Kobe, Japan	International Conference Secretariat Conference and Editorial Department Iron and Steel Institute of Japan 1-9-4 Otemachi Chiyoda-ku, Tokyo 100
November 20-December 1	The 1st International Symposium and Exhibition of SAMPE JAPAN CHAPTER	Makuhari, Japan	SAMPE P.O. Box 2459 Covina, CA 91722
November 21-23	Symposium on Instrumentation in Asia-Pacific Region	Guangzhou, People's Republic of China	Liao Chuxiong Dept. of Chemistry Zhongshan University Guangzhou, Guangdong, China
November 22-24	Tencon 89	Bombay, India	Kirit J. Sheth, Chairman IEEE Bombay Section c/o Hakotoronics Pvt. Ltd. Dadoji Konddeo Cross Marg Bombay 400 027, India
November 22-28	International Conference on Plasma Physics 1989	New Delhi, India	P.K. Kaw, Director Institute for Plasma Physics Bhat, Gandhinagar Gujarat 382 424 India
November 27-28	Asia Vibration Conference '89	Shen Zhen, People's Republic of China	Professor Takuzo Iwatsubo Mechanical Engineering Faculty of Engineering Kobe University 1-1 Rokkodai-cho, Nada-ku Kobe-shi, Hyogo 657
November 28-December 1	1st Japan International SAMPE Symposium & Exhibition: New Materials and Processes for the Future	Chiba, Japan	1st Japan International SAMPE Symposium & Exhibition c/o The Nikkan Kogyo Shinbun, Ltd. 1-8-10 Kudan Kita Chiyoda-ku, Tokyo 102

1989			
Date	**Title/Attendance**	**Site**	**Contact for Information**
December 4-6	The 1st International Conference on Deductive and Object-Oriented Databases	Kyoto, Japan	Professor Kiyoshi Agusa ASTEM RI, 9F Asahi Building Oike Yanaginobanba Nakagyo, Kyoto 604
December 4-8	The 4th International Conference on Fusion Reactor Materials	Kyoto, Japan	Professor S. Ishino General Chairman, ICFRM-4 Department of Nuclear Engineering University of Tokyo Bunkyo-ku, Tokyo 113
December 5-7	Symposium on the Application of Mechatronics	Hong Kong	Mr. T.P. Leung Secretariat for Symposium on the Application of Mechatronics c/o Dept. of Mechanical & Marine Engineering Hong Kong Polytechnic Hung Hom, Kowloon, Hong Kong
December 11-13	The 3rd International Workshop on Petri Nets and Performance Models (PNPM 89)	Kyoto, Japan	Dr. Shojiro Nishio Department of Applied Mathematics and Physics Faculty of Engineering Kyoto University Kyoto 606
December 11-15	The 10th Australasian Fluid Mechanics Conference	Melbourne, Australia	10AFMC c/o Professor A.E. Perry Department of Mechanical Engineering The University of Melbourne Parkville, Victoria 3052
December 11-21	The 5th International Symposium on World Trends in Science and Technology Education	Manila, Philippines	Dr. Adracion D. Ambrosio IOSTE Symposium Chairman Philippine Science High School Diliman, Quezon City 1104

1990			
Date	**Title/Attendance**	**Site**	**Contact for Information**
January 22-26	International Conference on Recrystallization in Metallic Meterials	Wollongong, Australia	Metallurgical Society of AIME Conference Department 420 Commonwealth Drive Warrendale, PA 15086
February 4-7	The 18th Australian Polymer Symposium	Bendigo, Australia	Dr. J.D. Wells Chemistry Department Bendigo CAE P.O. Box 1199 Bendigo 3550, Victoria
February 4-9	The 17th International Symposium on the Chemistry of Natural Products (IUPAC)	New Delhi, India	Professor Sukh Dev Multi-Chem. Research Centre Nandesari, Baroda-39340
February 5-9	International Workshop on Polarized Ion Source 10-F40-J20	Tsukuba, Japan	National Laboratory for High Energy Physics 1-1 Oho Tsukuba, Ibaraki-ken 305
March 1	Workshop on Advanced Motion Control	Yokohama, Japan	Professor Kohei Ohnishi Department of Electric Engineering Keio University 3-14-1 Hiyoshi Kohoku, Yokohama 223

1990			
Date	**Title/Attendance**	**Site**	**Contact for Information**
March 12-16	International Conference on Supercomputing in Nuclear Applications	Mito, Japan	Kiyoshi Asai Conference Secretariat Computing Center, JAERI Tokai-mura, Naka-gun Ibaraki 319-11
March 29-31	IEEE Industrial Electronics Society	Tokyo, Japan	Ohnishi Faculty of Science and Technology Keio University 3-14-1 Hiyoshi, Minato Kita-ku Yokohama-shi, Kanagawa 223
April 1-6	The 1990 National Engineering Conference of the Institution of Engineers Australia	Canberra, Australia	The Conference Manager 1990 National Engineers Conference The Institution of Engineers 11 National Circuit Barton, ACT 2600
April 4-6	The 2nd International Symposium on Power Semiconductor Devices & JCs (ISPSD '90)	Tokyo, Japan	Yoshiyuki Uchida Fuji Electric Co., Ltd. Matsumoto Factory 2666 Tsukama, Matsumoto Nagano 390
April 8-12	1990 International Topical Meeting on Optical Computing	Kobe, Japan	OC'90 Secretariat Business Center for Academic Societies Japan (BCASJ) 3-23-1 Hongo Bunkyo-ku, Tokyo 113
April 17-19	The 5th International Symposium on "Advanced Technology in Welding and Materials Processing and Evaluation"	Tokyo, Japan	Japan Welding Society 1-11 Kanda Sakuma-cho Chiyoda-ku, Tokyo 101
April 23-25	The 3rd Japan-China Joint Conference on Fluid Machinery	Osaka, Japan	Professor Yutaka Miyake Department of Mechanical Engineering Faculty of Engineering Osaka University 2-1 Yamada-Oka Suita, Osaka 565
April 23-27	Nankai Conference: International Conference on Physics Education Through Experiments	Tianjin, People's Republic of China	Professor Zhao Jing-yuan Department of Physics Nankai University Jianjin
May (tentative)	Recent Developments and Applications of Hot Cold Rolled and Coated Products	Kaohsiung, Taiwan	South East Asia Iron and Steel Institute P.O. Box 7759 Airmail Distribution Center NAIA, Pasay City 1300, Philippines
May 2-4	1st World Congress on Biosensors	Hong Kong	Penny Moon, Conference Manager Elsevier Seminars Mayfield House 256 Banbury Rd. Oxford OX2 7DH, U.K.
May 14-18	The 14th World Mining Congress and Exhibition	Beijing, People's Republic of China	14th World Mining Congress 54 Sanlihe Road Beijing

1990			
Date	Title/Attendance	Site	Contact for Information
May 19-26	The 27th International Navigation Congress 62-F500-J500	Osaka, Japan	Japan Organizing Committee for 27th International Navigation Congress of PIANC c/o Port and Harbor Bureau City of Osaka 2-8-24 Chikko Minato-ku, Osaka 552
May 21-22	Conference and Exhibition: Foundry Asia '90	Hong Kong	FMJ International Publications
May 21-23	4th Symposium on Our Environment	Singapore	Wong Ming Keong Dept. of Chemistry National University of Singapore Singapore 0511
May 29- June 1	The International Conference on Manufacturing Systems and Environment - Looking Forward to the 21st Century	Tokyo, Japan	T. Nakajima The Japan Society of Mechanical Engineers Sanshin Hokusei Building 2-4-9 Yoyogi Shibuya-ku, Tokyo 151
June (tentative)	The 10th International Conference on Vacuum Metallurgy	Beijing, People's Republic of China	The Chinese Society of Metals 46 Dongsixi Dajie, Beijing 100711
June 11-15	1990 International Conference: Metallurgical Coatings	Beijing, People's Republic of China	Chinese Society of Metals 46 Dongsixi Dajie, Beijing 100711
June 11-15	1990 International Conference: Special Melting	Beijing, People's Republic of China	Chinese Society of Metals 46 Dongsixi Dajie, Beijing 100711
June 15-20	The 2nd International Conference: Aluminum Alloys - Physical and Mechanical Properties	Beijing, People's Republic of China	Beijing University of Aeronautics and Astronautics
June 22-26	International Conference on Dynamics, Vibration, and Control	Beijing, People's Republic of China	Professor Wei Jinduo Chinese Society of Theoretical and Applied Mechanics No. 15 Zhong Guancun Street Beijing
June 26-30	International Symposium on High Temperature Corrosion and Protection	Shenyang, People's Republic of China	Professor Man Yongfa Institute of Metal Research Academia Sinica 2-6 Wenhua Road Shenyang, Liaoning Province China
July 1-6	The 3rd International Conference on Technology of Plasticity (3rd ICTP)	Kyoto, Japan	The Organizing Committee 3rd ICTP c/o The Japan Society for Technology of Plasticity Torikatsu Building 5-2-5 Roppongi Minato-ku, Tokyo 106

1990			
Date	**Title/Attendance**	**Site**	**Contact for Information**
July 6-7	The 1st KSME-JSME Fracture and Strength Conference (Fracture and Strength '90)	Seoul, Korea	Professor Hideaki Takahashi Research Institute for Strength and Fracture of Materials Tohoku University Aoba Tsurumaki Aza Sendai 980
July 9-11	Japan-U.S.A. Symposium on Flexible Automation - A Pacific Rim Conference	Kyoto, Japan	Professor Toshihiro Tsumura c/o Institute of Systems, Control at Engineers 14 Yoshida-Kawahara-cho Sakyo-ku, Kyoto 606
July 15-21	The 10th International Congress of Nephrology 10-F1,000-J4,000	Tokyo, Japan	Japanese Society of Nephrology c/o 2nd Department of Internal Medicine School of Medicine, Nippon University 30-1 Oyaguchi-kamicho Itabashi-ku, Tokyo 173
July 16-21	ISEC '90 International Solvent Extraction Conference	Kyoto, Japan	Conference Secretariat ISEC '90 Department of Chemistry Science University of Tokyo Kagurazaka, Shinjuku-ku, Tokyo 162
July 30- August 2	The 15th International Conference on International Association on Water Pollution Research and Control	Kyoto, Japan	Japan Society on Water Pollution Research and Control Yotsuya New Mansion 12 Honshiocho Shinjuku-ku, Tokyo 173
August 2-8	The 25th International *Conference on High Energy* Physics 1990	Singapore	Professor K.K. Phua South East Asia Theoretical Physics Association c/o Dept. of Physics National University of Singapore Kent Ridge, Singapore 0511
August 7-11	International Symposium on Analytical Chemistry	Changchun, People's Republic of China	Professor Qinhan Jin Dept. of Chemistry Changchun, China
August 12-17	The 15th International Carbohydrate Symposium	Yokohama, Japan	Dr. Ishido, General Secretary Faculty of Science Tokyo Institute of Technology Ookayama, Meguro-ku, Tokyo 152
August 21-29	International Congress of Mathematicians 1990 84-F1,500-J1,500	Kyoto, Japan	ICM 90 Secretariat c/o International Relations Office Research Institute for Mathematical Sciences Kyoto University Kitashirakawa Oiwake-cho Sakyo-ku, Kyoto 606
August 22-24	1990 International Conference on Solid State Devices and Materials	Sendai, Japan	c/o Business Center for Academic Societies Japan Crocevia Building 2F 3-23-1 Hongo Bunkyo-ku, Tokyo 113
August 23-30	V International Congress of Ecology 62-F900-J1,000	Yokohama, Japan	Secretary General's Office for INTECOL 1990 c/o Institute of Environmental Science and Technology Yokohama National University 156 Tokiwadai Hodogaya-ku, Yokohama 240

1990			
Date	**Title/Attendance**	**Site**	**Contact for Information**
September 3-5	International Symposium on Diagnostics and Modeling of Combustion in Internal Combustion Engines	Kyoto, Japan	Professor Makoto Ikegami Dept. of Mechanical Engineering Kyoto University Sakyo-ku, Kyoto 606
September 10-14	The 17th Congress of the Collegium International Neuro-Psychopharmacologicum	Kyoto, Japan	The 17th CINP Congress c/o Simul International Inc. Kowa Building No. 1 1-8-10 Akasaka Minato-ku, Tokyo
September 16-22	IUMS Congress: Bacteriology and Mycology - Osaka, Japan - 1990 71-F2,000-J3,500	Osaka, Japan	Secretariat: IUMS Congress c/o Institute of Medical Science University of Tokyo 4-6-1 Shirokanedai Minato-ku, Tokyo 108
September 19-22	The 2nd World Congress on Particle Technology	Kyoto, Japan	Secretariat: 2nd World Congress on Particle Technology Shibunkaku-kaikan 2-7 Tanakasekiden-cho Sakyo-ku, Kyoto 606
September 23-27	The 57th International Foundry Congress (CIF)	Osaka, Japan	Secretariat Japan Foundrymens Society Toyonaka Building 8-12-13 Ginza Chuo-ku, Tokyo 104
September 24-27	The 6th International Congress on Polymers in Concrete	Shanghai, People's Republic of China	ICPIC-90 Secretariat c/o Associate Professor Tan Muhua Institute of Materials Science and Engineering Tongji University Shanghai
September 24-27	The 3rd International Aerosol Conference	Kyoto, Japan	Professor Kanji Takahashi c/o Institute of Atomic Energy Kyoto University Uji, Kyoto 611
September 24-28	The 3rd International Aerosol Conference	Kyoto, Japan	Professor Kanji Takahashi, General Secretary Institute of Atomic Energy Kyoto University Uji, Kyoto 611
September 24-28	The 12th International Conference: Boundary Element Method Conference (BEM 12)	Sapporo, Japan	Mr. Hiroshi Mizoguchi JASCHOME, KKE Inc. Dai-ichi Seimei Building 24F 2-7-1 Nishi-Shinjuku Shinjuku-ku, Tokyo 160
September (tentative)	The 15th International Congress on Microbiology 57-F2,500-J2,500	Osaka, Japan	Preliminary Committee of International Congress of Microbiology c/o JTB Creative Inc. Daiko Building 3-2-14 Umeda Kita-ku, Osaka 530
October 1-5	International Conference on Information Technology Commemorating the 30th Anniversary of the Information Processing Society of Japan (IPSJ) - InfoJapan '90	Tokyo, Japan	InfoJapan '90 Secretariat: IPSJ Hoshina Building 3F 2-4-2 Azabudai Minato-ku, Tokyo 106

1990

Date	Title/Attendance	Site	Contact for Information
October 14-19	International Conference for New Smelting Reduction and Near Net Shape Casting Technologies for Steel	Pohang, Korea	Conference Department Institute of Metals 1 Carlton House Terrace London, SW1Y 5 5DB, U.K.
October 15-18	The 1st Asian-Pacific International Symposium on Combustion and Energy Utilization	Beijing, People's Republic of China	Professor Huang, Zhao Xiang and Song Jialin Institute of Engineering Thermophysics Chinese Academy of Sciences P.O. Box 2706, Beijing
October 15-19	The 4th International Symposium on Marine Engineering (ISME KOBE '90)	Kobe, Japan	ISME Organizing Committee c/o Kobe Shosen Daigaku 5-1-1 Fukae-Minami Higashinada-ku, Kobe 658
October 21-26	The 6th International Iron and Steel Congress 50-F300-J500	Nagoya, Japan	International Conference Department Iron and Steel Institute of Japan 3F, Keidanren Kaikan 1-9-4 Otemachi Chiyoda-ku, Tokyo 100
October 22-26	International Conference on Information Technology in Connection with 30th Anniversary Celebration of Information Processing Society of Japan N.A.-F200-J1,000	Osaka, Japan	Secretariat: International Conference on Information Technology c/o Simul International, Inc. Kowa Building, No. 9 1-8-10 Akasaka Minato-ku, Tokyo 107
October 28-November 2	The 2nd International Conference: HSLA Steels	Beijing, People's Republic of China	Chinese Society of Metals 46 Dongsixi Dajie, Beijing 100711
October 29-November 1	Japan International Tribology Conference Nagoya - '90 N.A.-F100-J500	Osaka, Japan	Secretariat: Japan ITC Nagoya - '90 c/o Toyota Technological Institute 2-chome, Hisakata Tempaku-ku, Nagoya 468
November 4-8	International Symposium on Carbon, 1990: "New Processing and New Applications"	Tsukuba, Japan	The Carbon Society of Japan Saito Building 2F 2-16-13 Yujima Bunkyo-ku, Tokyo 113
November 26-29	The 3rd International Polymer Conference (3rd IPC) 5-F100-J200	Nagoya, Japan	IPC Secretariat c/o Society of Polymer Science, Japan 5-12-8 Ginza Chuo-ku, Tokyo 104
November 26-29	The 5th International Photovoltaic Science and Engineering Conference (International PVSEC-5)	Kyoto, Japan	Professor Junji Saraie Secretariat of International PVSEC-5 c/o Japan Convention Services, Inc. Nippon Press Center Building 2-2-1 Uchisaiwai-cho Chiyoda-ku, Tokyo 100
1990 (tentative)	Chemeca 1990 Applied Thermodynamics	New Zealand	Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, ACT 2600

1991			
Date	**Title/Attendance**	**Site**	**Contact for Information**
February 7-12	The 10th International Conference on Offshore Mechanics and Arctic Engineering	Seoul, Korea	Korea Cmt for Ocean Resources and Engineering Dong-A University 840 Sahagu Pusan, Korea
February 10-15	POLYMER '91: International Symposium on Polymer Materials	Melbourne, Australia	Dr. G.B. Guise P.O. Box 224 Belmont, VIC 3216, Australia
May 7-13	Beijing Essen Welding '91	Beijing, People's Republic of China	Messe Essen Nobert Street D-4300 Essen Federal Republic of Germany
June (tentative)	International Conference on Stainless Steels	Tokyo, Japan	Secretariat: STAINLESS STEELS '91 The Iron and Steel Institute of Japan Keidanren Kaikan 1-9-4 Otemachi Chiyoda-ku, Tokyo 100
June (tentative)	JIMIS-6: Intermetallic Compound - Properties and Applications	Tokyo, Japan	Professor Osamu Waizumi Institute for Materials Research 2-1-1 Katahira Sendai 980
July 7-12	The 16th International Conference on Medical and Biological Engineering (ICMBE) 45-F600-J1,400	Kyoto, Japan	Japan Society of Medical Electronics and Biological Engineering 2-4-16 Yayoi Bunkyo-ku, Tokyo 113
July 7-12	The 9th International Congress on Medical Physics (ICMP) 45-F600-J1,400	Kyoto, Japan	National Institute of Radiological Science 4-9-1 Anagawa Chiba 260
July 24-26	The 3rd International Conference on Residual Stresses (ICRS-3)	Tokushima, Japan	Society of Materials Sciences, Japan 1-101 Yoshida Izumidono-cho Sakyo-ku, Kyoto 606
July 24-30	The 17th International Conference on the Physics of Electronic and Atomic Collisions	Brisbane, Australia	Dr. W.R. Newell Department of Physics University College of London Gower Street London WC1E 6BT UK
July 29-August 2	The 6th International Conference on Mechanical Behavior of Materials (ICM-6)	Kyoto, Japan	Society of Materials Sciences, Japan 1-101 Yoshida Izumidono-cho Sakyo-ku, Kyoto 606
August 25-31	International Congress on Analytical Science-1991 (ICAS '91)	Chiba, Japan	The Japan Society for Analytical Chemistry Rm 304 Gotanda Sun Heights 1-26-2 Nishi Gotanda Shinagawa-ku, Tokyo 141
August (tentative)	The 16th International Conference on Medical and Biological Engineering (ICMBE)	Kyoto, Japan (tentative)	Japan Society of Medical Electronics and Biological Engineering 2-4-16 Yoyogi Bunkyo-ku, Tokyo 113
Undecided 1991	The 9th International Conference on Hot Carriers in Semiconductors 10-F50-J100	Osaka or Nara, Japan	Department of Electronics Osaka University 2-1 Yamada-Oka Suita, Osaka 565

1992			
Date	**Title/Attendance**	**Site**	**Contact for Information**
February (tentative)	The 19th Australian Polymer Symposium	Perth, Australia	RACI Polymers Division P.O. Box 224 Belmont, VIC 3216
May 10-15	NETWORKS '92: The 5th International Network Planning Symposium 20-F250-J100	Undecided, Japan	NTT Telecommunication Networks Laboratories 3-9-11 Midori-cho Musashino-shi, Tokyo 180
October 26-30	The 14th International Switching Symposium (ISS '92) 60-F1,200-J800	Yokohama, Japan	NTT Communication Switching Laboratories 3-9-11 Midori-cho Musashino-shi, Tokyo 180
Autumn	XIVth International Switching Symposium (ISS '92)	(to be decided)	Institute of Electronics, Information and Communication Engineers (IEICE) Kikai Shinko Kaikan 3-5-8 Shiba-koen Minato-ku, Tokyo 105

1993			
Date	**Title/Attendance**	**Site**	**Contact for Information**
May 23-28	The 18th International Mineral Processing Congress	Sydney, Australia	AUSIMM, Conference Department P.O. Box 122 Parkville, VIC 3052
1993 (tentative)	International Federation of Automatic Control Congress	Sydney, Australia	Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, ACT 2600

1994			
Date	**Title/Attendance**	**Site**	**Contact for Information**
Tentative	XXX International Conference on Coordination Chemistry	Kyoto, Japan	Professor Hitoshi Ohtaki Coordination Chemistry Laboratories Institute for Molecular Science Myodaiji-cho, Okazaki 444
Tentative	The 10th International Conference on the Strength of Metals and Alloys (ICSMA-10)	Undecided, Japan	Professor Hiroshi Oikawa Faculty of Engineering Tohoku University Aoba, Aramaki Aza Sendai 980

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