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<p>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.</p> <p>Subscription requests to the Scientific Information Bulletin should be directed to the Superintendent of Documents, Attn: Subscription, Government Printing Office, Washington, DC 20402. The annual subscription charge is: domestic, \$13.00; foreign, \$16.25. Cost for a single copy is: domestic, \$4.50; foreign, \$5.65.</p>				
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Zirconia ceramics
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Cover: The statue of Ninomiya Sontoku (1787-1856) is a familiar sight in or near many elementary schools in Japan. Ninomiya was a farm technologist and the leading agricultural philosopher of the latter part of the Edo period (1600-1868). His practical and moral teachings, which urged cultivators to raise output and pay their taxes, helped strengthen the economic basis of the Tokugawa Rule. Because of these accomplishments, he was later praised as a paragon of virtue in the national ethics textbooks of the 1930s, thus prompting the placement of statues in elementary schools to remind children of the virtue of hard work and study. Photo courtesy of Edward Mark Lenoe.

THE 1988 JAPAN PRIZE

Sandy Kawano

Five doctors, crusaders against smallpox and AIDS, and a French nuclear physicist who established fast breeder reactor technology are this year's winners of the Japan Prize.

On Thursday, February 4, the Science and Technology Foundation of Japan announced the winners of the 1988 Japan Prize. The Japan Prize was established in 1985 to deepen the understanding of the role played by science and technology in furthering world peace and prosperity. Drs. Donald Henderson of the United States, Isao Arita of Japan, and Frank Fenner of Australia were cited for their efforts in the eradication of smallpox, a disease that plagued mankind for 30 centuries. Drs. Robert C. Gallo of the United States and Luc Montagnier of France won the prize for their respective research in identifying and developing tests for the Human Immunodeficiency Virus (HIV), the AIDS pathogen. These five doctors shared the Japan Prize in the category of Preventative Medicine. In the category of Energy Technology, French scientist Dr. Georges Vendryes was honored for his work in establishing fast breeder reactor technology, deemed by many to be mankind's best energy hope of the future. This year marks the first time a Japanese has been chosen as a prize winner, and it is also the first time awards were made to French and Australian scientists.

Dr. Donald A. Henderson, as the first chief medical officer of the World Health Organization (WHO) World Smallpox Eradication Office, dedicated his efforts to the development of group vaccination programs and contributed to its historical success through the worldwide eradication of smallpox.

Dr. Henderson received an A.B. in 1950 from Oberlin College, an M.D. in 1954 from the University of Rochester, and an M.P.H. in 1960 from Johns Hopkins University, School of Hygiene and Public Health. His professional career began in 1955, after his internship. From 1955 to 1966 he was responsible for epidemiological surveillance at the Center for Disease Control in Atlanta, GA. From 1967 to 1976 he was the chief medical officer for smallpox eradication for the World Health Organization in Geneva, Switzerland. In 1977 he was appointed dean of the School of Hygiene and Public Health at Johns Hopkins University.

Dr. Henderson has been honored with many awards including the Albert Schweitzer International Prize for Medicine (1985) and the National Medal of Science (1986).

Dr. Isao Arita, as the second chief medical officer of the WHO World Smallpox Eradication Office, established basic disease control knowledge and performed epidemiological analyses as well as surveys and research into vaccine quality improvement.

Dr. Arita received an M.D. in 1949 and a Doctorate in Medicine in 1957 from the University of Kumamoto, Japan. From 1957 to 1958 he studied communicable disease control in Denmark, the Federal Republic of Germany, the Netherlands, Switzerland, and the United Kingdom.

Dr. Arita began his professional career with the Public Health Bureau, Ministry of Health and Welfare, Japan, where he served as epidemiologist from 1950 to 1962. From 1962 until 1985 he worked for the World Health Organization in various capacities. From 1962 until 1964 he was a medical officer at the WHO Regional Office in Brazzaville, Africa. From 1964 until 1967 he was a medical officer in the Virus Program at WHO Headquarters, Geneva. In 1967 he transferred to the Smallpox Eradication Program, where he became chief medical officer in 1977. In 1985 he assumed his present position of director of Kumamoto National Hospital.

Dr. Arita's major awards include the Fourth Ohyama Health Award (1978) and the Asahi Award of Science (1981).

Dr. Frank Fenner, as the chairman of the WHO Smallpox Eradication Surveillance Committee, supervised implementation of the global smallpox eradication program. His consistent efforts greatly contributed to its success.

Dr. Fenner is a graduate of the University of Adelaide in Australia. He studied virology at the Department of Microbiology, Australian National University, under Professor Burnet. From 1967 he has held various positions with the Australian National University. From 1949-67 he was professor of microbiology at the John Curtin School of Medical Research, assuming the directorship of that

school in 1967. From 1973-79 he served as director of the Centre for Resource and Environmental Studies. Currently Dr. Fenner is president of the Institute of Resources and Environment.

Dr. Fenner's awards include the ANZAAS Medal (1980) and the ANZAC Peace Prize (1980).

Dr. Luc Montagnier, as leader of the joint research staff at the Pasteur Institute in 1983, became the first researcher in the world to discover HIV, the pathogen behind AIDS, thus launching the start of genuine HIV research. He also developed practical blood serum diagnostic methods for the establishment of basic preventative countermeasures.

Dr. Montagnier received a B.Sc. in 1955 from Poitiers and Paris and a Doctorate in Medicine in 1960 from Paris. In 1955 he joined the staff of the Paris University of Sciences as an assistant professor. From 1960 Dr. Montagnier has held various positions with the National Center for Scientific Research, including head of research (1967), director of research (1974), and chief of the Associated Research Unit UA1157 (1984). In addition to his work with the National Center for Scientific Research, Dr. Montagnier has also been associated with the Pasteur Institute since 1972, first serving as chief of the Viral Oncology Division (1972) then as head of the Virology Branch (1982-85). Currently he is chief of the Department of Virus Tumors.

Dr. Montagnier has received numerous prizes and awards including the Chevalier of the Legion of Honor (1984) and the Albert Lasker Prize (1986).

Dr. Robert C. Gallo, leading his own independent research group, established a method of culturing human T cells and

succeeded in isolating the HIV virus, making a major contribution to analysis of its relationship with AIDS. He is also a pioneer in the research and development of AZT, the most effective AIDS treatment thus far, as well as in the effort to manifest a virus gene and realize an AIDS vaccine.

Dr. Gallo received a B.A. in biology in 1959 from Providence College and an M.D. in 1963 from Jefferson Medical College. He has received numerous honorary D.Sc. degrees from all over the world from such institutions as Providence College; Thomas Jefferson University; the School of Medicine and Dentistry, University of Rochester; the University of Turin, Italy; and the University of Tel Aviv, Israel (D.Ph.).

After completing his internship and residency in 1965, he joined the staff of the National Cancer Institute in Bethesda, MD. From 1965-68 he was a clinical associate in the Medical Branch, from 1968-69 he was a senior investigator in the Human Tumor Cell Biology Branch, from 1969-72 he was head of the Section on Cellular Control Mechanisms in the same branch, and from 1972 until the present he has been chief of the Laboratory of Tumor Cell Biology.

Dr. Gallo's major awards and honors include the American Cancer Society's Medal of Honor (1983), the Third Armand Hammer Prize for Cancer Research (1985), and the Albert Lasker Clinical Medical Research Award (1986).

The sole recipient in the category of Energy Technology, Dr. Georges Vendryes has been honored for his contribution to the establishment of the fundamentals of nuclear power design and the promotion of

fast breeder reactor development. His work led to the successful completion of "Super Phoenix," the world's first large-scale test breeder, establishing practical technologies for a solution to mankind's energy problem in the future.

Dr. Vendryes received an M.S. degree in 1942 from Ecole Polytechnique and a Doctorate in Physics in 1951 from Paris University. From 1952 until the present he has served in various positions with the Commissariat a l'Energie Atomique. From 1952-59 he was chief then head of the Experimental Neutronics Branch, from 1959-71 he was head of the Physics Research Department, from 1971-74 he was director of the Division of Nuclear Reactors Research and Development, from 1974-85 he was managing director then vice president of Industrial Nuclear Applications, and in 1985 he was appointed scientific advisor to the president.

Dr. Vendryes has received many awards and honors throughout his career including the Enrico Fermi Award from the U.S. Government (1984) and Grand Officer, l'Ordre du Merite National (1985).

This year's Japan Prize winners join the ranks of past distinguished recipients who have all strived through their research and accomplishments to improve the quality of life for all mankind.

Sandy Kawano is the editor of the Scientific Information Bulletin. 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.

GROWTH OF LOW RESISTIVITY II-VI CRYSTALS AT THE TOKYO INSTITUTE OF TECHNOLOGY

George B. Wright

The possibility of using wide bandgap semiconductors, particularly the II-VI compounds, for optoelectronic devices is a goal that has eluded workers for three decades, primarily because of the inability to develop low resistivity materials of both n-type and p-type conductivity. The physical reasons behind this problem, the models that were employed to analyze it, and recent breakthroughs in solving the problem are the subject of this article. Possibilities for future developments are suggested.

INTRODUCTION

Soon after the discovery of transistor action in germanium and its extension to silicon, both elemental semiconductors crystallizing in the diamond structure, it was realized that there are compound semiconductors, such as GaAs, crystallizing in the closely related zincblende structure, whose bulk properties seemed to offer high promise for application in improved devices. In fact it has proven remarkably difficult to make Nature deliver on that promise.

Within the zincblende clan, there are two prominent families, the III-Vs, exemplified by GaAs and its siblings, and the II-VIs, represented, for example, by ZnSe and HgTe. A spectacular III-V device success in the early 1960s was the achievement of semiconductor injection laser operation in GaAs, simultaneously by groups at

GE, IBM, and MIT Lincoln Laboratory. More recently, with the introduction of GaAs-AlAs superlattices at Bell Labs and IBM, very high speed field effect transistors (FET) have been fabricated from GaAs and named high electron mobility transistors (HEMT) by the Fujitsu group that first introduced them. Very successful and sophisticated laser engineering is now possible using a wide variety of III-V materials and structures (Ref 1). Japan is a world leader in its vigorous pursuit of this important field, and the prospect of important markets has supported heavy investments in the improvement of growth techniques for bulk crystals of GaAs, which will serve as substrate materials for compound semiconductor devices and integrated circuits (Ref 2).

In the II-VI family, by contrast, virtually the only successful device application has been the infrared detectors developed in the HgCdTe alloy system. It has been a struggle of two decades to make these work, and there are still problems with material instability. The more general goal of using the II-VIs to provide wide bandgap, short wavelength optoelectronic devices has not been achieved, and the reason is not far to seek. To make an efficient semiconductor light emitting diode (LED) or laser, one needs low electrical resistance material of both n-type and p-type, and these have not been available in II-VI compound semiconductors. The reasons behind this problem, and a recent research breakthrough at the

Tokyo Institute of Technology that provides a solution to the problem, will be the subjects of this article.

THE DIAMOND, ZINCBLLENDE, CHALCOPYRITE SEMICONDUCTOR FAMILY

To understand the problem with II-VI compounds, we need first to review a little semiconductor physics. Germanium and silicon crystallize in the diamond

structure, which is composed of two interpenetrating, face-centered cubic lattices so arranged relative to one another that each atom on one sublattice is surrounded by four atoms on the second sublattice, in a tetrahedral symmetry. This geometry is shown in Figure 1a. There are two atoms in the unit cell, and each atom has four (IV) valence electrons, so there are eight valence electrons in each unit cell. The elements with four valence electrons are shown in column IV of the Periodic Table inset in Figure 1.

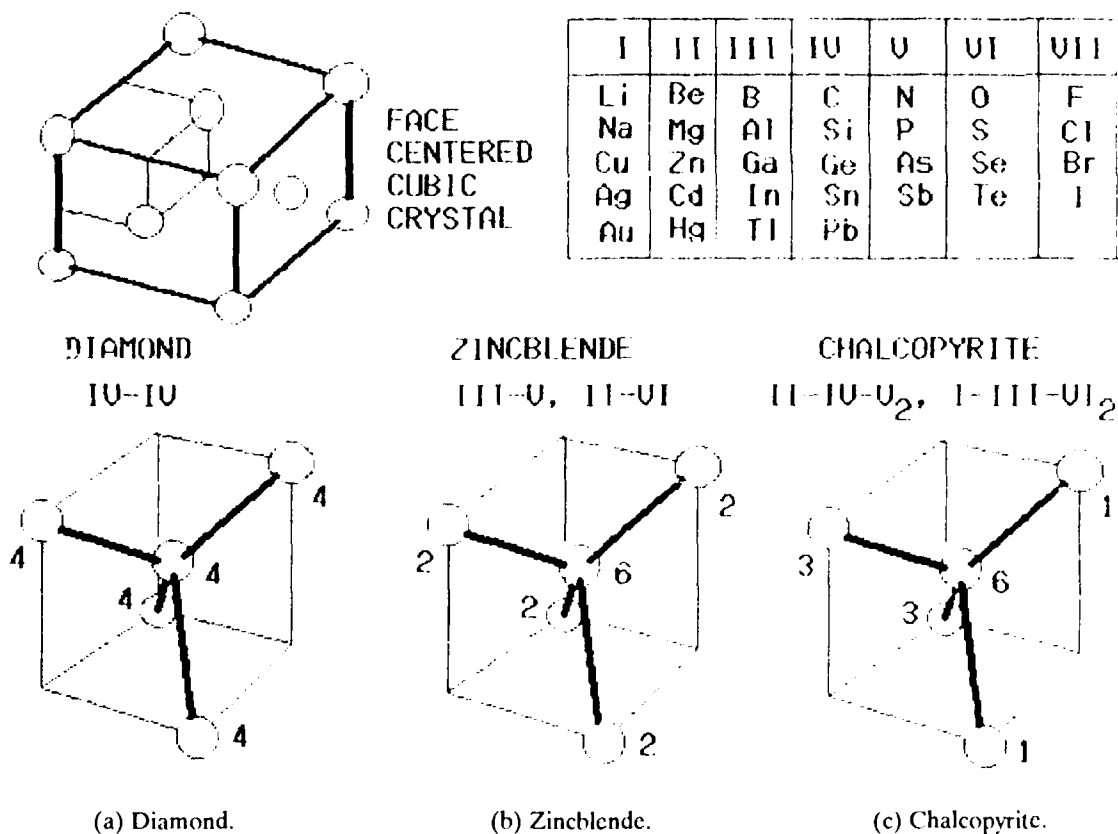


Figure 1 The diamond, zincblende, chalcopyrite family of crystals.

To derive the zincblende structure, we replace the atoms on sublattice A with an element from column III (three valence electrons) and the atoms on sublattice B with elements from column V (five valence electrons). This symmetrical move away from column IV elements preserves a count of eight valence electrons per unit cell. Now because the atoms on the two sublattices are different, the bonds between the atoms become polar but retain some of their previous homopolar character. The energy gap increases and becomes a direct gap for most members of the family, in contrast to the indirect gap of silicon and germanium. This makes for greater optical transition probability and makes semiconductor lasers possible. We could have substituted column II atoms on sublattice A and column VI atoms on sublattice B, which would have given a still wider energy gap and a more polar bond. These are the II-VI compounds, which crystallize in the zincblende structure (Figure 1b) and in a hexagonal form, wurzite, which is not shown in Figure 1. The atomic coordination is still tetrahedral, and there is only one type of bond, the A-B bond. As we move symmetrically from germanium to gallium arsenide to zinc selenide, the crystal becomes more ionic and the energy gap increases, but the lattice constant changes very little.

Finally, in a II-VI compound, we can take the A sublattice and subdivide it symmetrically between atoms from column I and atoms from column III to obtain the chalcopyrite structure shown in Figure 1c. We have to double the unit cell in the process, and the composition becomes I-III-VI₂, which maintains the same average electron concentration as before. We could have done the same procedure on a III-V crystal to obtain a II-IV-V₂ chalcopyrite. An

important new feature in these compounds is that the symmetry of an atomic site is no longer tetrahedral; we have introduced "chemical symmetry breaking" with important consequences for the nonlinear optical properties, to which we shall return later.

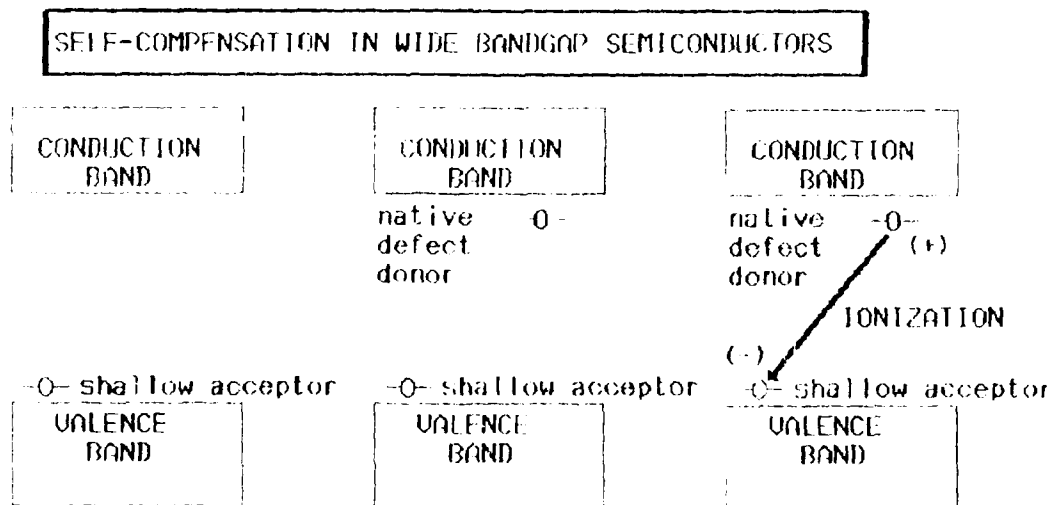
SHALLOW DONORS AND ACCEPTORS IN SEMICONDUCTORS

In a germanium crystal, if we replace one atom with an arsenic impurity atom, there is an extra electron present that is weakly bound to the arsenic atom at low temperatures, but it breaks free at elevated temperatures and "donates" itself to contribute to the electrical conductivity of the crystal. The impurity is called a "donor" and can be modeled as a hydrogen atom immersed in the dielectric medium of the crystal with the effective mass of the germanium conduction band. The binding energy is very much reduced below that of the hydrogen atom in a vacuum, so we speak of a "shallow" impurity. If the impurity had been gallium, there would have been a deficiency of one electron, which leads to a "hole" in the valence band, associated with the "acceptor" impurity. This leads to "p-type" conductivity (positive type), compared with the "n-type" conductivity associated with donors. The conductivity is proportional to the number of excess electrons or holes present, and the solubility limits for impurities may be in the range of 10^{19} to $10^{20}/\text{cm}^3$. If we put about $10^{17}/\text{cm}^3$ acceptor atoms into a ZnSe crystal, we would expect a conductivity of about one reciprocal $\Omega\text{-cm}$. Instead, conductivities 8 to 12 orders of magnitude less have often been observed! This failure to obtain reasonable p-type conductivity has been a major impediment to using the II-VI compounds in devices.

SELF-COMPENSATION

A reduction of p-type conductivity in a crystal doped with acceptor impurities occurs if there are also donors present. Then the electrons from the donors simply cancel the holes from the acceptors. This cancellation is termed "compensation." This compensation commonly occurs because there are residual donor impurities present in even the purest chemical materials used to prepare the crystal, but usually the compensation due to this cause can be reduced far below the intentional doping level of the acceptors. A more difficult case to deal with is "self-compensation," which is illustrated in Figure 2. It has been known for a long time (Ref 3) that a vacancy or interstitial atom in the host crystal may act as a donor. This is termed a "native" defect donor because it is not a chemical impurity. We show in Figure 2 that a native defect donor can form to compensate a chemical

impurity acceptor if the energy required to form the defect is less than the energy given up by moving the electron from the donor to the acceptor, namely, the energy gap of the host semiconductor. Another type of self-compensation has been postulated in the case of lithium impurities in zinc selenide (Ref 4). There it was proposed that Li substituted for a host atom was an acceptor, while interstitial Li was a donor, so the self-compensation would occur by movement of the lithium atom from a substitutional site to an interstitial one, followed by a transfer of the resultant donor electron to a substitutional acceptor. The energy arguments were unchanged. It should be noted that compensation to one part in ten thousand most probably involves deep donors as well as shallow donors. This is an issue well studied in the case of "semi-insulating" gallium arsenide and is discussed in the Appendix.



SELF-COMPENSATION MAY OCCUR WHEN THE BANDGAP ENERGY IS GREATER THAN THE ENERGY REQUIRED TO FORM THE COMPENSATING NATIVE DEFECT

Figure 2. Self-compensation in wide bandgap semiconductors.

These self-compensation arguments, proceeding from equilibrium thermodynamics, seemed rather overwhelmingly conclusive against the possibility of exploiting II-VI compounds in useful devices, and in the late 1960s and early 1970s support for research programs in these materials was rather sharply curtailed in the United States. The II-VI compounds had been the premier hosts for research on excitons, and much pioneering work had been done to show the value of photoluminescence as a tool for understanding impurities at very low chemical concentrations. This work now shifted to gallium phosphide and the II-VIs were largely abandoned. In Japan, by contrast, a lively interest was sustained, and when molecular beam epitaxy (MBE) was introduced, Japanese workers were among the first to apply it to II-VIs. Plasma chemical vapor deposition (CVD) and metalorganic chemical vapor deposition (MOCVD) were also applied. We shall see how this persistence paid off with the development of low resistivity zinc selenide, both n-type and p-type.

MOCVD EPITAXIAL GROWTH OF ZnSe ON GaAs SUBSTRATES

Since most future device applications are expected to involve epitaxial growth, research workers had directed their efforts to achieving growth of high quality crystalline films at low temperatures on substrates that will be readily available. For growth of zinc selenide, the obvious choice of substrate is GaAs because its bulk crystals are the most readily available of any compound semiconductor and because its

lattice constant of 5.6533 Å differs from that of ZnSe (5.687 Å) by only 0.27 percent. Experiments using MOCVD growth with dimethylzinc (DMZn) and diethylselenide (DESe) and a substrate growth temperature of 400 °C established that the lattice strain is accommodated by misfit dislocations for film thicknesses greater than 0.15 micron, and it was established that the flow rate of DESe/DMZn should be 10:1 (Ref 5).

CONDUCTIVITY CONTROL BY SHALLOW IMPURITIES

A simple view of shallow impurities leads us to expect that we could obtain shallow donors by substituting a column VII halogen atom on the Se site or a column III impurity on the Zn site. In fact Al, Cl, and most recently iodine have all been successfully substituted for Se to produce low resistivity n-type zinc selenide. By analogy the alkali metals (column I) substituting for Zn or column V atoms substituting for Se should produce shallow acceptors, and thus p-type material. A problem with the alkali impurities is that they are amphoteric; that is, they produce both donor and acceptor centers, with the donor most probably being an interstitial atom. Nevertheless, p-type bulk crystals doped with Li were demonstrated in 1985 (Ref 6 and 7). Nitrogen and phosphorus have been shown to act as shallow acceptors, but with the DESe/DMZn flow ratio of 10:1 it would be difficult to incorporate them as substitutes for Se during MOCVD. Accordingly the group at the Tokyo Institute of Technology chose Li₃N as a dopant. Note that Li substituting on the Zn site and N substituting on the Se site would both act as acceptors.

The first successful MOCVD growth of low resistivity p-type ZnSe was reported in 1987 (Ref 8), with the results shown in Table 1. A p-n junction, fabricated on a p-type GaAs substrate, exhibited the I-V characteristic shown in Figure 3, with an electroluminescence spectrum shown in Figure 4. An investigation of the acceptor binding energy in the material suggested that compensation was still present, and for the most heavily doped material an impurity band probably formed. In retrospect, success depended upon the low substrate temperature available through the MOCVD method; choice of chemically pure MO source materials, which were also optimized to produce a high quality host crystal; and finally, choice of a suitable dopant. The thermodynamic problem of self-compensation was overcome by metastable growth at the low temperature. In particular, the deep levels must have been eliminated; the successful bulk growth of p-type material took place in an overpressure of Zn (Ref 7), suggesting control of this factor. High crystalline quality also probably prevented in-migration of compensating Ga atoms from the GaAs substrate. With the achievement of low resistivity ZnSe of both n-type and p-type, and the fabrication of a blue-light emitting LED, the door to optoelectronic applications of ZnSe can fairly be said to be wide open. What possible future directions for development may we expect?

Table 1. Li-Doped ZnSe

Sample No.	Carrier Concentration (p-type) (cm^{-3})	Mobility ($\text{cm}^2/\text{V}\cdot\text{s}$)	Resistivity ($\Omega\text{-cm}$)
154A-C	6.4×10^{17}	39	0.25
155A-C	3.9×10^{17}	44	0.37
164A-C	8.8×10^{17}	38	0.19
172A-C	5.9×10^{16}	38	2.8

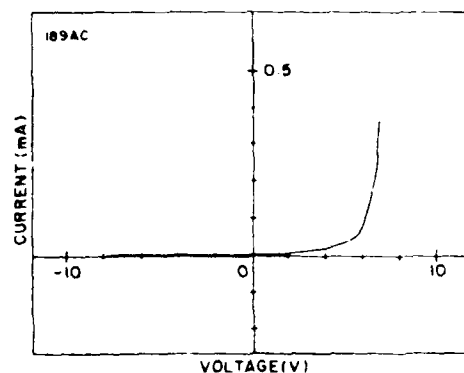


Figure 3. Current-voltage characteristic of a ZnSe p-n diode (from Ref 8).

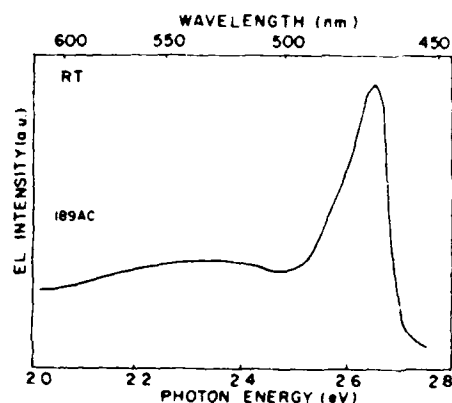


Figure 4. Electroluminescence spectrum at 300 K of a ZnSe p-n diode (from Ref 8).

EPITAXIAL GROWTH OF LATTICE-MATCHED CHALCOPYRITES

For optoelectronic devices involving epitaxial films, two very important design parameters are the lattice constant of the film and the energy bandgap of the resulting material. For ease in visualization of the system to be designed, it is common to plot these parameters for the available materials in a diagram similar to that shown in Figure 5. On this diagram, a line drawn

between two compounds, such as ZnSe and ZnS, means that as the two compounds are alloyed together, the lattice constant and energy bandgap vary as shown. A horizontal line means that the lattice constant does not vary. We mentioned earlier that ZnSe has a slightly larger lattice constant than that of GaAs, leading to strain in epitaxial growth. We note that by alloying ZnSe with a small amount of ZnS, the alloy can be brought into a better match with the GaAs substrate, leading to better crystal quality of the epitaxial layer. Such an experiment has actually been performed (Ref 9), and the results are shown in Figure 6, where the minimum in the diffracted x-ray linewidth indicates improved crystal quality. Removing crystalline strain by this method

is very important for prevention of semiconductor laser degradation under long-time operation.

On the diagram of Figure 5 we also note a system based on four compounds: CuGaSe_2 , CuGaS_2 , CuAlS_2 , and CuAlSe_2 . These are all II-VI derived chalcopyrites, and their alloys provide an attractive system to be grown on GaP substrates. As a start in this direction, CuGaS_2 has been successfully grown by MOCVD on both GaAs and GaP substrates despite the substantial mismatch (Ref 10). Interesting anisotropies in the growth direction behavior were observed, related to the nonideal c/a ratio in the crystal. Quite recently the quaternary alloy $\text{CuGa}(\text{SSe})_2$ lattice-matched to GaAs has also been successfully grown by MOCVD (Ref 11).

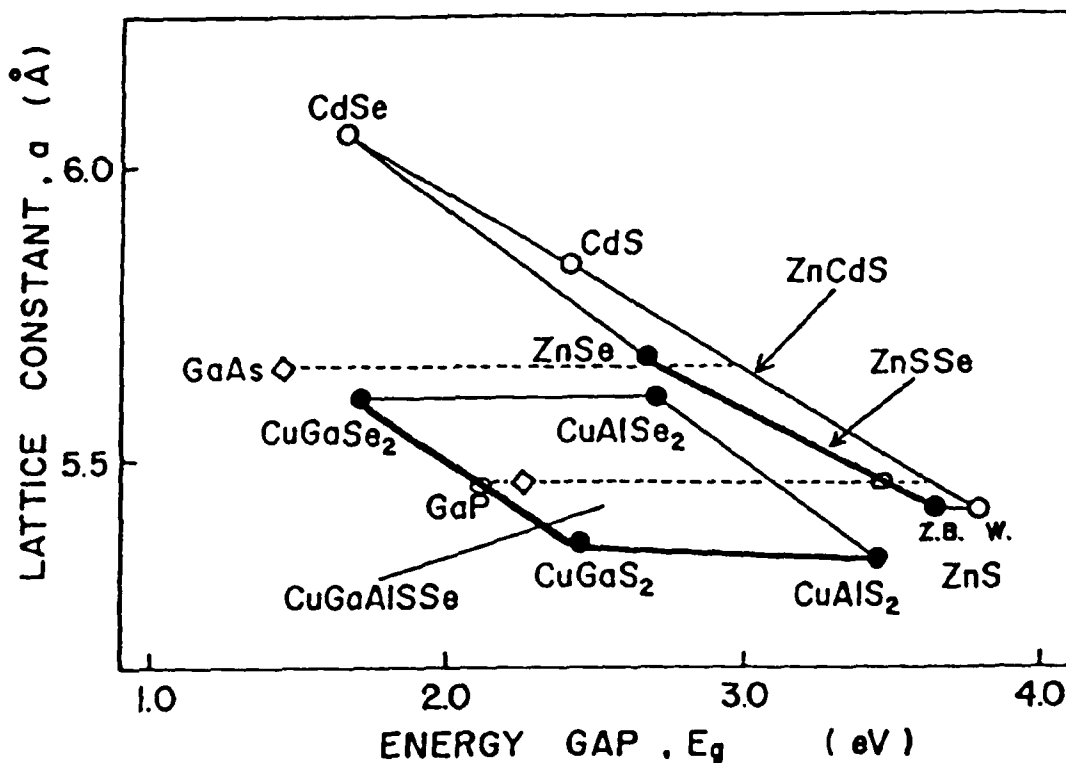


Figure 5. Lattice constant - Bandgap diagram for the II-VI compounds and their derivatives (courtesy of H. Kukimoto).

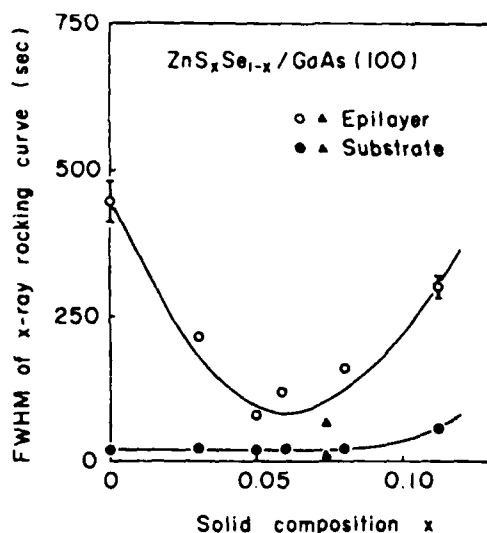


Figure 6. Linewidth (full width at half maximum) of x-ray rocking curves as a function of composition in $\text{ZnS}_x\text{Se}_{1-x}$ epitaxial layers grown on GaAs (100) substrates. Open and filled circles are for 2-micron-thick epilayers and their substrates, respectively, and open and filled triangles are for a 1.4-micron-thick epilayer and its substrate, respectively (from Ref 9).

In the initial discussion of the chalcopyrites in connection with Figure 1, we alluded to the fact that the column VI element is no longer tetrahedrally surrounded by four identical atoms, as would be the case for the zincblende structure. In GaAs, the A-B chemical bond would actually possess substantial nonlinear optical properties were it not for the tetrahedral symmetry, which causes cancellation. In the chalcopyrites, the symmetry is broken, and this family of materials has some of the highest known nonlinear optical Figures of Merit. This means that if these materials can be successfully incorporated into optoelectronic devices, then mixers, phase-conjugators, and other classes of nonlinear

optical devices become possible. The successful epitaxial growth of chalcopyrites by MOCVD represents a first step in this direction.

Even without the nonlinear optical applications, the chalcopyrite system of Figure 5 offers the possibility of optical devices with wavelengths from the near infrared to the near ultraviolet. Another possibility apparent from Figure 5 is the use of GaAs and GaP substrates to support superlattices of either GaAs/ZnSeS or GaP/ZnSeS in lattice-matched compositions. The superlattices can be tailored by varying the layer thicknesses to give "artificial alloys" of the desired bandgaps. The ability to dope either n-type or p-type makes possible "doping superlattices" or "nipi" structures.

This brief list of possibilities and others that will be invented give some hint of the great importance that the development of MOCVD epitaxial growth of n-type and p-type II-VI compounds represents to optical device engineering.

ACKNOWLEDGMENTS

I would like to acknowledge the generosity of Dr. H. Kukimoto for interesting and stimulating discussions of his research and to thank my former colleague, Dr. E.J. Johnson, for originally pointing out to me the interesting role which deep levels play in semi-insulating semiconductors.

REFERENCES

1. G.B. Wright, "The Tenth IEEE International Semiconductor Laser Conference," Scientific Bulletin 11(4), 91 (1986).

2. G.B. Wright, "Optoelectronics Joint Research Laboratory: A review of accomplishments," Scientific Bulletin 12(2), 112 (1987).
3. F.A. Kroger, *The Chemistry of Imperfect Crystals* (North-Holland, Amsterdam, 1964).
4. G.F. Neumark and S.P. Herko, "Li doped ZnSe and problems of p-type conduction," J. of Crystal Growth 59, 189 (1982).
5. H. Mitsuhashi, I. Mitsuishi, M. Mizuta, and H. Kukimoto, "Coherent growth of ZnSe on GaAs by MOCVD," Jpn. J. Appl. Phys 24, L578 (1985).
6. J. Nishizawa, K. Itoh, Y. Okuno, and F. Sakurai, "Blue light emission from ZnSe p-n junctions," J. Appl. Phys. 57, 2210 (1985).
7. J. Nishizawa, R. Suzuki, and Y. Okuno, "p-type conduction in ZnSe grown by temperature difference method under controlled vapor pressure," J. Appl. Phys. 59, 2256 (1986).
8. T. Yasuda, I. Mitsuishi, and H. Kukimoto, "Metalorganic vapor phase epitaxy of low-resistivity p-type ZnSe," Appl. Phys. Lett. 52, 57 (1988).
9. H. Mitsuhashi, I. Mitsuishi, and H. Kukimoto, "MOCVD growth of $\text{ZnS}_{1-x}\text{Se}_x$ epitaxial layers lattice-matched to GaAs using alkyls of Zn, S, and Se," Jpn. J. Appl. Phys. 24, L864 (1985).
10. K. Hara, T. Kojima, and H. Kukimoto, "Epitaxial growth of CuGaS_2 by metal-organic chemical vapor deposition," Jpn. J. Appl. Phys. 26, L1107 (1987).
11. K. Hara, T. Shinozawa, J. Yoshino, and H. Kukimoto, "MOVPE growth and characterization of I-III-VI₂ chalcopyrite compounds," paper presented at the Fourth International Conference on Metalorganic Vapor Phase Epitaxy, Hakone, Japan, May 1988.

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SEMI-INSULATING SEMICONDUCTORS: Close Compensation and Deep Levels

The high resistivity of many II-VI compounds (10^4 to 10^8 Ω -cm) when doped with substantial amounts of shallow impurities implies the presence of deep level impurities/defects that are partially ionized, in addition to the fully ionized shallow impurities. To see why this is so, we discuss compensation, with and without deep levels.

Since the resistivity of ZnSe with $10^{17}/\text{cm}^3$ holes is about 1 Ω -cm, a resistivity of 10^8 Ω -cm implies that the hole (or electron) concentration is only about $10^9/\text{cm}^3$. But the background impurity concentration of shallow impurities in ZnSe is unlikely to be below $10^{14}/\text{cm}^3$, so observation of a concentration five orders of magnitude less implies a very precise compensation mechanism.

In a semiconductor, the number of holes in the valence band, and the number of electrons in the conduction band, decreases exponentially with the distance of the Fermi level, E_f , from the respective band edge. In a pure, perfect crystal, the number of holes equals the number of electrons, and the Fermi level is at the **intrinsic** energy, E_i . Figure 7a shows a logarithmic plot of carrier concentration versus Fermi energy. There N_v is the effective density of states in the valence band and N_c is the effective density of states in the conduction band, while n_i is the **intrinsic** carrier concentration. The product $np = n_i^2$. If there are N_d shallow donors and N_a shallow acceptors, we assume that they are fully ionized at room

temperature; the donor ions are positive and the acceptor ions are negative. Then electrical neutrality requires that the positive charge equals the negative charge

$$p + N_d^+ = n + N_a^-$$

We plot these two quantities as heavy lines in Figure 7a. The Fermi level will adjust to the position where the lines cross. Then

$$p = N_a - N_d + n_i^2/(N_a - N_d)$$

Suppose we try to decrease p by making $N_d = N_a$. If N_d precisely equaled N_a everywhere in the crystal, then p would be reduced to n_i . In fact, even if the **average** value of N_a and N_d were equal, nonuniformity would be at least of the order 10^3 , so that electrostatic differences would develop between different regions, and the band edge would fluctuate within the bounds given by the lines $N_v - E_f - N_c$.

The problem with this method of compensation came because we were dealing with fully ionized shallow impurities, represented by horizontal lines on the diagram. As the horizontal lines become superposed, great fluctuations are possible because they coincide over a wide range of Fermi energies. Suppose we introduce N_{dd} deep donors at an energy E_{dd} slightly below E_i . For graphical simplicity, assume that when E_f is below E_{dd} , the deep donors are fully ionized, while for E_f above E_{dd} , the

ionization falls off exponentially. This is an approximation that is excellent on our logarithmic scale. The charge neutrality equation now becomes

$$p + N_d^+ + N_{dd}^+ = n + N_a^-$$

If $N_d + N_{dd}$ is less than N_a , no essential change occurs, but if $N_d + N_{dd}$ is greater than N_a , as shown in Figure 7b, then the solution point for charge neutrality can place the Fermi energy close to E_i , and the resultant p is close to n_i . The resistance will be high.

In fact, it doesn't matter if E_i is **above** E_i so long as it is not far above. Then we would have a highly insulating n-type crystal.

We note that since the crossover point is down the slope from E_{dd} , the deep levels are only **partially** ionized. This reservoir effect is what makes the precise **concentration** of the compensation levels unimportant, and in fact makes the high resistivity possible. It is also important that E_{dd} not be too far from E_i . So finally, "When high resistivity is present in a material known to contain shallow impurities - Look for the Deep Levels!"

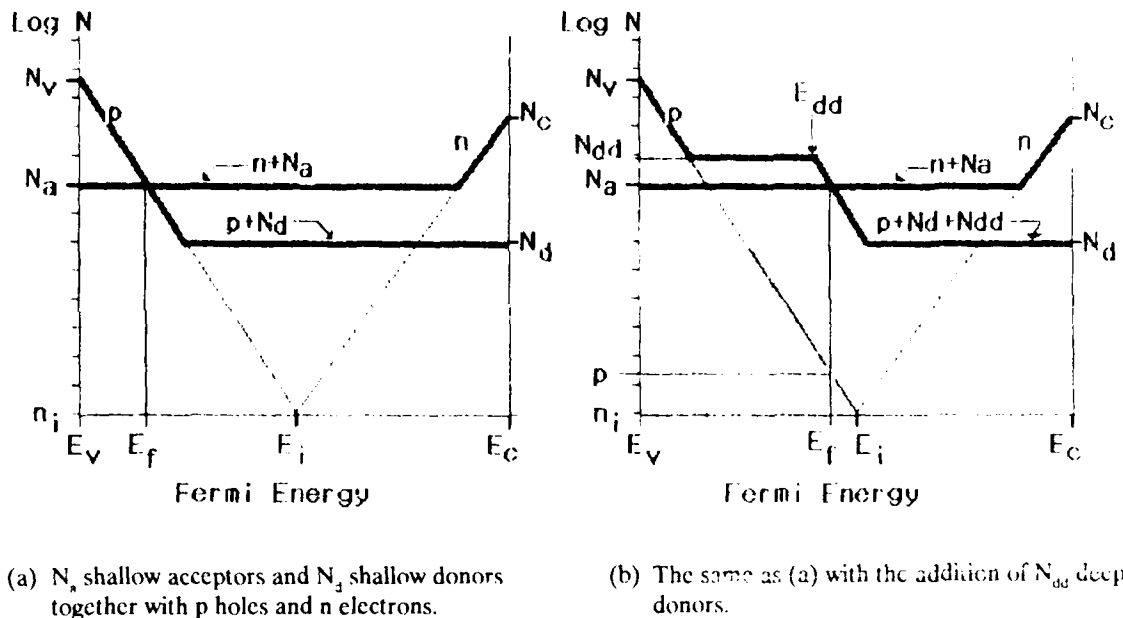


Figure 7. The charge concentration in a semiconductor versus Fermi level.

A SURVEY OF HIGH-TECHNOLOGY TRANSFER PRACTICES

Robert S. Cutler*

The high-technology transfer practices of Japan and the United States are described and compared to determine how U.S. companies can make better use of the basic research performed in the United States and abroad.

INTRODUCTION

A number of reasons have been offered to explain Japan's commercial success with high-technology products. One frequently cited is the Japanese ability to assimilate and apply new technologies derived from basic research performed in the United States and Europe. Another is the policy of the Japanese Government to organize and stimulate the civilian technology transfer process.

In this paper, I present some empirical results describing the principal ways in which industrial researchers in Japan and in the United States use certain new technologies resulting from university research. The findings are from a survey conducted in Japan and the United States between October 1986 and December 1987.

THE TECHNOLOGY TRANSFER SURVEY

The investigation involved a comparative study of Japanese and U.S. high-technology transfer practices, particularly regarding the use of university research in three fields: robotics, biotechnology, and ceramic materials.

The focus was on three fundamental engineering fields where Japanese and U.S. firms appear to be comparable in terms of technological capability. I had read in the press (Ref 1) that former attitudes about technology transfer were beginning to shift and, in some new fields, the Japanese were beginning to innovate, rather than import, patented technology and to export and license their latest technology to international markets.

During the early part of my 9-month stay in Japan, I recognized the face of the so-called "Japanese Miracle," the rapid economic development over the past two decades based on technology. I then set out to investigate and compare the ways new technologies are acquired and commercialized in Japan, and hopefully to learn how it is done so well and so fast.

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Technology transfer involves many functional as well as cultural factors. When interpreting the differences observed between Japanese and American technology practices, I believe it important to view the Japanese--their institutions and their behaviors--from a cultural perspective.

Simply stated, the Japanese have a different language, a different thought process, and different social and business processes than Americans. To attempt to observe technology separately from its environment is to lose sight of this larger picture. I was soon to discover that there are strong cultural elements in the ways the Japanese acquire, evaluate, and transfer new technology. I elaborate on those elements later in this article.

Scope of Survey

My research in Japan primarily involved a survey of Japanese university and industrial researchers who are working in three high-technology fields. Fifty-five interviews were conducted at 12 universities, 9 companies, and 6 Government research and development (R&D) organizations. The parallel survey in the United States included 51 researchers at 11 universities, 8 companies, and 3 Government organizations. In total, 106 researchers were polled in the two surveys (Table 1).

The questions focused on the professional behavior of the researcher himself, rather than on the research, per se. The objective was to identify the principal transfer mechanisms used by the particular researcher in Japan or the United States and his professional colleagues at universities and other R&D organizations.

In addition, information was sought about career objectives and hiring practices, awareness of significant research advances, and attitudes toward collaborative arrangements with foreign counterparts.

Approach

First, let me offer the succinct definition of "technology transfer" that Jacques Bagur of Gulf South Research Institute recently presented to members of the Federal Laboratory Consortium:

"Technology Transfer" is the process by which knowledge concerning the making or doing of useful things contained within one organized setting is brought into use within another organizational context.

The concept of "technology transfer" that I use in this study consists of several functional mechanisms that are classified into three domains:

1. Publications--journals, technical reports, trade press
2. Patents--invention disclosures, patents, and licenses
3. People Links--meetings, collaborations, joint projects

These domains are operationally defined by the principal mechanisms used for communicating, facilitating, or otherwise moving the results of university research into industrial application. These principal technology transfer mechanisms are as follows:

Table 1. Survey Sample

Japan		United States	
Place	No. of Interviews	Place	No. of Interviews
Universities			
Hokkaido Univ.	1	Carnegie Mellon Univ.	4
Kyoto Univ.	1	Mass. Inst. of Technology	3
Nagoya Technology Inst.	2	Penn State Univ.	3
Nagoya Univ.	1	Stanford Univ.	3
Osaka Univ.	1	Rutgers Univ.	2
Saitama Univ.	1	Univ. of Arizona	2
Sophia Univ.	1	Univ. of CA/Santa Barbara	2
Tokyo Inst. of Technology	2	Univ. of Delaware	2
Tohoku Univ.	3	Univ. of Massachusetts	3
Tsukuba Univ.	2	Univ. of Nebraska	3
Univ. of Tokyo	3	Univ. of Utah	2
Waseda Univ.	1		
Subt. total	21		29
Industrial Laboratories			
Hitachi Central R&D Lab	3	Ceramatec, Inc.	2
Hitachi Production Automation	3	Eaton Corp.	3
IBM Tokyo Research Lab	5	IBM Corp.	3
Kyorera Corp., Inc.	1	ICR Associates, Inc.	1
Mitsubishi Metal Corp.	3	Monsanto Co.	2
NEC Central Research Labs	2	J.D. Searle, Inc.	2
Nippon Steel Co.	2	Repligen, Inc.	2
Nissan Motors Co., Ltd.	4	United Technologies Corp.	1
Smith Klein Beckman Japan, Ltd.	1		
Subtotal	24		14
Government R&D Organizations			
Mechanical Engineering Lab (MEL)	4	National Bureau of Standards	4
Electrotechnical Lab (ETL)	2	National Institutes of Health	2
Institute for Agricultural Research (NIAR)	1	National Science Foundation	2
Ministry of International Trade & Industry (MITI)	1		
Ministry of Education and Culture (Monbusho)	1		
Japan Research Development Corp. (JRDC)	1		
Subtotal	10		8
Total	55		51

1. Meetings, Seminars, Intensive Conferences
2. Professional Society Meetings
3. Journal Publications, Newsletters
4. International Conferences
5. Advisory Boards, Councils, Committees
6. Study Missions, Site Visits, Trade Shows
7. Patent and Licensing Agreements
8. Consulting Arrangements
9. Joint University/Industry Research Projects
10. Visiting Scientists and Resident Researchers

The approach supports the "multiple factor" philosophy, wherein technology transfer is seen as a process involving many functional and environmental factors working in concert.

AN APPROPRIATE RESEARCH MODEL

As a researcher myself, I was compelled to devise an appropriate model and to collect relevant data, something useful to count. From the kinds of program evaluation studies we do at the National Science Foundation (NSF), I have learned that a proper evaluation design involves a simple model that describes the principal factors

and the relationship of the data to the results. Here is my reasoning for choosing the three domains of the model:

1. When one attempts to compare research activities, albeit there is some professional controversy as to what things count, it is generally accepted among science policy researchers that the publication of journal articles and citations to those articles in other publications are reasonable measures of scientific advancement and research productivity.

2. Patent counts are now becoming useful to econometricians who study the process of technological innovation. The use of such numbers is less exact than citations to the literature; nonetheless, some carefully selected patent statistics reflecting large quantities can be a useful indicator. There is also new interest in university patents because such patents can attract industrial support.

3. The third domain of the model is what I call "People Links." From talking with several policy analysts before going to Japan, and from my experience as an R&D engineer in industry and a research administrator at NSF, I have learned that technology transfer also occurs in activities such as professional societies, workshop seminars, and employee mobility.

The three-domain model expresses the notion that technology transfer is more than simply the exchange of technical publications, or the licensing of patents. Rather, the model of the transfer process includes various contact mechanisms and communications activities that essentially

are "person-to-person" linkages. Such mechanisms actually serve to bring the desired technology "know-how" into actual use.

An interview questionnaire was designed to obtain information from each researcher on:

1. Publication activities--which journals are most frequently read and where authored articles were most recently published.
2. Patent activity--whether listed as an inventor on patents issued within last 5 years, and whether patents are licensed or used.
3. People links--whether active in professional society activities, consulting, collaborative work, conferences, and career mobility.

FINDINGS

Based upon an analysis of the surveys* conducted in Japan and in the United States, the following comparative results are reported.

Publications

- In Japan nearly all (94 percent) of the researchers surveyed were able to read and write in English. In the United States very few (4 percent) of the Americans interviewed admitted any technical competence in the Japanese language.
- In Japan a majority of those researchers surveyed (85 percent) published and read English language journal articles as well as those in Japanese. In the United States few (9 percent) said they read any translated Japanese journal articles in their field (Table 2).
- In Japan journal publications do not necessarily contain new work. Most U.S. journal editorial policies insist upon new and original work only.

Patents

- In Japan few university professors (14 percent) hold patents. In the United States nearly 46 percent of the university researchers surveyed do.

* Survey sample (n = 106) consists of 55 Japanese and 51 U.S. researchers. The population it represents would be hard to describe fully, but I hope it is an important part of the university, industry, and Government R&D organizations performing advanced research in the fields of robotics, biotechnology, or ceramic materials between October 1986 and December 1987 (Table 1).

Table 2. Principal Journals Mentioned in Survey

Area	Japan	United States
Robotics	<ul style="list-style-type: none"> ■ Journal of the Robotics Society of Japan ■ International Journal of Robotics Research ■ IEEE Journal of Robotics and Automation 	<ul style="list-style-type: none"> ■ IEEE Journal of Robotics and Automation ■ ASME Journal of Dynamic Systems Measures and Control ■ International Journal of Robotics Research
Biotechnology	<ul style="list-style-type: none"> ■ Journal of Biotechnology ■ Science ■ Journal of the American Chemical Society 	<ul style="list-style-type: none"> ■ Journal of Biological Chemistry ■ Biochemistry ■ Journal of Plant Physiology
Ceramic Materials	<ul style="list-style-type: none"> ■ Journal of the Ceramics Society of Japan ■ Journal of the Physical Society of Japan ■ Journal of the American Ceramics Society 	<ul style="list-style-type: none"> ■ Journal of the American Ceramics Society ■ Journal of Materials Science ■ Journal of Applied Physics

- In Japan, between 1981 and 1985, the number of university patents reported to the Japanese Society for the Promotion of Science (JSPS) by the top five universities increased from 24 to 32 patents (66 percent), while licensing agreements increased from 2 to 6. In the United States, between 1981 and 1985, the number of patents reported by the top five research universities increased from 122 to 177 (45 percent). Licensing for the same 5 years increased from 53 to 96 (81 percent).

People Links

- In Japan 93 percent of the university researchers and 80 percent of the industrial researchers surveyed said they attend technical meetings outside their work location at least twice per month. In the United States 43 percent of university researchers and 17 percent in industry said they did so.

- In Japan the average proportion of Ph.D.s reported in the work unit (Ph.D. ratio) was 18 percent for the universities, 17 percent for industry, and 33 percent for Government labs. In the United States the ratios were 38 percent for universities, 57 percent for industry, and 61 percent for Government labs.
- In Japan 62 percent of the high-technology university researchers surveyed and 46 percent of those in industry said they were involved in at least one joint university/industry project. In the United States the level was 84 percent for universities and 93 percent for those surveyed in industry.
- In Japan 78 percent said they have worked for their current employer since graduating from college, while 23 percent of those surveyed in the United States said they did.
- In Japan 59 percent reported having attended at least one international meeting during the past 2 years. In the United States the proportion was 28 percent.
- In Japan 65 percent of those surveyed said they spent a year or more in the United States or in Europe. In the United States 34 percent said that they had spent more than one year abroad: 4 percent had worked in Japan and 17 percent had visited Japan for brief periods ranging from 1-3 weeks.

Additional Observations

- In Japan 83 percent of the researchers surveyed said they were aware of current research advances made by foreigners in their field. In the United States only 30 percent said they knew of any.
- In the United States the following attitudes and interests were expressed by researchers interviewed regarding the work of Japanese colleagues:
 - 68 percent of the university researchers, 35 percent of the industrial researchers, and 60 percent of the Government researchers acknowledged having had at least one Japanese research colleague or visiting researcher in his laboratory.
 - 78 percent said that they would welcome some type of research collaboration with an appropriate counterpart in Japan.
 - 63 percent said they would be willing to work in a laboratory in Japan for an extended period of time. (Most favored 4 to 6 months.)
 - Among those surveyed in both countries, the mechanisms preferred most for effecting high-technology transfer are as follows:

In Japan:

- Meetings, seminars (90%)
- Professional conferences (75%)
- Study missions, site visits (58%)

In the United States:

- Meetings, talks (84%)
 - Gordon-type conferences (62%)
 - Publications (55%)
- In addition, some two-thirds of the robotics researchers surveyed in Japan said they currently exchange VCR video recordings with colleagues in their own country. However, it was not clear how widespread the use of VCR tapes is among U.S. researchers.

CAVEAT ON THE ANALYSIS

Due to limitations in the data and the sampling method used, one should not draw definitive conclusions from this study. However, there are some interesting findings that are more suggestive than indicative. Moreover, the concept of "technology transfer" itself is complex and difficult to define precisely. This is an emerging area requiring more study and analysis.

DISCUSSION

From the findings outlined above, it is clear there are similarities as well as some important differences in the way technology is transferred between university and industrial researchers in Japan and in the United States.

In contrast to the kinds of scientific research performed in the United States, most of the research I observed in Japanese universities can be described more accurately as "fundamental engineering science" rather than basic scientific research. It usually is done in groups rather than by individual investigators, and it consists largely of experimental verification work. However, there are a few senior professors doing some theoretical work at the more basic end of the research process.

Publications

To describe what the Japanese do differently, first I will discuss journal publications.

The principal sources of basic research information for the Japanese researchers I interviewed are the journal articles published by leading university researchers in the United States and in Europe, rather than by other Japanese researchers.

Japanese engineering researchers work in teams to carry through a particular project, from the initial research stage, through development to prototyping, and even on to production and marketing. It is difficult to track research activities in Japan because there are no paper trails, no intermediate publication points. On the other hand, being closely associated with one particular item or development project gives the Japanese researcher a tremendous sense of pride and attachment to the project and to the final product.

Journal editors in Japan apparently do not insist on publishing only original work. Their journals often consist of progress reports as well as reports on setting up and testing methods of experimentation that may have been published elsewhere. This practice is related in part to the Japanese feelings about originality,* which are quite different from ours, and in part to Japanese research funding practices, particularly in universities, which require progress reports to be published.

In the United States, typically, a university researcher does the fundamental work and then publishes his or her findings in the open literature. From those publications in the primary literature, another researcher picks up the new knowledge and basic ideas which he/she considers to be feasible, carries them through the applied research phase, and again publishes the results either in the journal literature, as a company report, or as a patent disclosure. The industrial R&D community picks promising projects out of this pool of new technology. In this process user requirements are rarely cited or integrated into the research.

Patents

Although the proportion of surveyed Japanese professors holding patents is smaller (14 percent) than that of the Americans (46 percent), the top five universities in Japan reported an increase of 66 percent between 1981 and 1985 and the American top five universities reported a 45-percent increase.

*The traditional Japanese attitude about originality is one which prefers to follow a pattern rather than to break new ground. In Japanese, the term "learn" (manabu) comes from "imitate" (manebu) (Ref 2).

The difference between the two groups in the number of patents acquired stems largely from the traditional belief in Japan that universities are primarily for the teaching of students rather than for commercializing research results, which is the domain of industry. However, this picture is now changing.

Although the numbers of Japanese university inventions since 1981 are smaller than those for U.S. universities, the JSPS data show a remarkable increase in the licensing of those patents during the past 5 years.

This increase appears to reflect the recent shift in the patent policy of both countries (since 1978 and 1980) that authorized universities and research laboratories to promote inventions resulting from Government-funded projects. Both in Japan and the United States there are programs now in place to assist university professors to transfer their inventions to commercial use. The Japan Research Development Corporation (JRDC) is the agency responsible for promoting the transfer of university patents to industry. In the United States there is no central Government responsibility for this activity, rather each research university has its own patent licensing office.

People Links

I observed throughout this study that the most preferred and also the most effective technology transfer mechanisms are "people-intensive" rather than "paper-intensive."

This conclusion became clear to me from the amount of time (two-thirds) the researchers said they devote to exchanging "new ideas" by participating in talks, meetings, and working with leading colleagues, as compared to the remaining one-third of their time spent reading, extracting, or preparing new information for publication or for patents. This allocation of time appears to be as true in the United States as it is in Japan, at least for the three high-technology fields surveyed.

Apparently there are strong personal needs for face-to-face discussions leading to bench-to-bench collaboration in order to better communicate new complex ideas from one person to another, and then to use them elsewhere in the research lab or in another organization or institutional setting. I conclude that high-technology transfer is largely a "contact sport": meeting with people, carrying new ideas forward, and joining individual efforts toward a common goal.

The rapid transfer of university research to industrial technology also requires the necessary "know-how," which is a skill attribute of a researcher. In tracing the transfer paths within the fields of robotics, biotechnology, and ceramic materials, in both countries, I find a similarity in the preferential use of "person-to-person" contacts for obtaining substantive information. Many of these links involve long-term collaborative work between university and industrial researchers. Examples of successful transfers of university research to industrial applications can be found in computer-vision robotics, genetic engineering, and functional ceramics.

FACTORS AFFECTING TECHNOLOGY TRANSFER PRACTICES

If one is attempting to compare the principal technology transfer practices observed in the two countries, three significant factors that underlie the Japanese R&D system are worth mentioning. They are attitudes about cooperative research, the "old-boy" network, and R&D management styles.

Japanese Technology Transfer and Cooperative Research

Japanese companies achieve such effective use of high-technology research and its transfer between laboratory and production by holding many more technical meetings on an industry-wide basis than American companies do. Professor Thomas Eagar of the Massachusetts Institute of Technology observed that "there is not just technology transfer within a company in Japan, but also between companies, and companies and universities, through the many meetings of the various professional societies" (Ref 3).

The topics discussed at many of these meetings include more technical content and detail than is common in the United States. In addition, major research laboratories become familiar with the work at other labs, resulting in rapid dissemination of new results and less duplication of effort. The meetings also permit researchers to communicate very effectively their knowledge of work outside of Japan.

There are a number of reasons why the Japanese meetings system works. One is the strong leadership of the university professors who serve as committee chairmen. There are strong ties between these professors and their former students that do not seem to exist in the United States.

Several of the robotics engineers interviewed in Japan showed me VCR tapes documenting their current experiments and work of their colleagues abroad. This low cost, highly effective, audio-visual reporting mechanism is yet another example of the way Japanese researchers rapidly exchange research results.

I do not believe there is such a system in the United States that pools, analyzes, and disseminates current information on international research activities as effectively as the Japanese system does.

The Japanese Old-Boy Network

The process was described by several speakers at a seminar on high-technology competitiveness held by the Japan Technology Transfer Association in Tokyo on March 13, 1987. That discussion helped to crystallize what I discovered during my four dozen interviews in Japan.

Japanese industry has two powerful assets: a cohesive national policy on technology development and a scientific "old-boy network," with links to practically every board room and laboratory in the country. The Government spends nearly one-third of its R&D budget (20 percent of total R&D spending) at universities and at Government research institutes, and nearly all of this activity is centrally coordinated through Government committees and the scientific old-boy network.

Here is how the two circles of power work. Perhaps you noticed that Japanese companies seem to sell similar products. So much so that it looks like they must be collaborating on the designs and specs. That is because "high-tech" Japan is a small country and the top engineers in the companies all know each other. For that matter, so do the company presidents, who most likely went to the same university at the same time. When one company starts something new, the president calls his friends to discuss it.

Japanese companies do not suffer from the "not-invented-here" syndrome, that attitude which stifles ideas from external sources. Instead, they are eager to please their customers and would rather have their people involved in making something better for the marketplace than trying to capture all of the profits from a new technology product. In fact, the licensing of patents from other companies and from foreign sources is widely practiced.

Many foreigners imagine that Government officials at the Ministry of International Trade and Industry (MITI) stand over the R&D stage like grand puppeteers, manipulating private industry at will. This is not the case, particularly because the average MITI officer changes jobs every 2 years.

MITI's method of influence is through its "committees." Mixtures of industry leaders, academics, and consumers (users) are selected for dozens of committees on new technology and industry matters, ranging from restructuring a weak industrial sector to organizing a national program for advanced robotics or for manned spaceflight.

Through committee debate, MITI helps industry form a consensus on which areas of new technology it should concentrate. By this "committee method" policy is actually negotiated by the leaders of industry, so it is accepted naturally by all the companies. That is what I found to be the secret of Japan's cohesive industrial policy: the Government acts as the organizer and coordinator of private industry action. Eightypercent of the R&D funding in Japan comes from private industry rather than from the Government.

R&D Management

A final remark about Japanese methods for running research organizations and their methods for decision-making.

What I observed closely resembles what author William Ouchi of the University of California at Los Angeles calls "Theory Z" (Ref 4). One main feature of Japanese society that Ouchi describes as being essential for the success of each work unit is the great trust that exists between superiors and those who work for them.

One of the best inventions of Japanese industry is the "quality circle," where 5 to 10 workers meet almost daily to discuss possible improvements in their work. This method works in Japan where it serves to give group sanction to innovative departures from the old ways of doing things.

There is a general sense of family solidarity that seems to characterize Japanese endeavor, whether at home, at work, or in professional pursuits. The personal commitment, trust, and desire for

cooperation among researchers serve as a glue that keeps the Japanese R&D organization together. "In Japan it is difficult to move people, but it's easy to move ideas," one Hitachi laboratory director told me.

In the United States the antitrust laws have required each competing firm to carry on its own industrial research. Technical cooperation not only is limited but is often perceived as unlawful by corporate management. Recently, however, the law has been liberalized to allow certain consortia like MCC, SEMATECH, and the Semiconductor Research Corporation (SRC) to be organized.

Things are different for industrial research in Japan. The Government there actively promotes the formation of research associations among leading companies in particular fields for purposes of developing and transferring new technologies. Patents resulting from these arrangements are pooled for participating companies to use. And there is a remarkably high degree of communication and collaboration between professors at leading Japanese universities and their colleagues who work in competitive companies.

CONCLUSION

This study surveyed a variety of mechanisms being used to effect high-technology transfer among, and between, researchers in the United States and in Japan. The approach tested the multiple factor philosophy whereby technology transfer is seen as a process involving many functional behaviors working in concert.

The empirical data confirm the conventional view that the flow of new information, for the three high-technology fields surveyed, is largely from U.S. university researchers to industrial researchers in Japan. The ratio of Ph.D. researchers in the labor force (Table 3) indicates the relative capacity to do high-technology work (Ref 5). However, the data also show that some of the advanced technology used in the United States increasingly is derived from research initiated in Japan.

Table 3. Ph.D. Ratio (%) in Laboratories Surveyed

Sector	Japan (n = 27)	U.S. (n = 22)
Universities	18	38
Industry	17	57
Government Labs	33	61

Journal publications and university patents are more widely used in the United States, where university professors both teach and do basic research. Meetings and intensive conferences, however, are by far the most popular means for technology transfer among those U.S. researchers surveyed.

In Japan the results of university research are used primarily in industrial settings. Typically industry uses outside professional meetings and close collaboration as the means for translating the scientific knowledge and new engineering "know-how" into commercial use.

I conclude that personal communication and technical collaboration are the key factors in the rapid diffusion of high-technology research results in both countries, rather than widespread availability of the scientific journal literature and recent efforts to promote university patents. The differences observed in practice stem largely from cultural and institutional factors.

In the United States Government agencies support most of the basic and applied research performed at universities primarily for public purposes such as military defense, public health, and space exploration. By contrast, most of the high-technology research in Japan is funded and performed by industrial companies for commercial purposes. Further, Japanese Government agencies and professional societies take a more active role in organizing and energizing the civilian technology transfer process than do the counterpart organizations in the United States.

This study attempts to plow new ground in an uncharted and complex area: the cross-cultural comparison of technology transfer mechanisms used in Japan and the United States. The database was constructed from information obtained during an exploratory investigation of active researchers who were recommended by peers in both countries. They were not randomly selected. Care was taken during the survey to avoid undue geographic concentration and institutional bias. The results presented, therefore, are indicative,

rather than definitive. Nonetheless, I believe they represent what is happening in the mainstream of the three high-technology fields sampled.

The author hopes this study is of interest to science policy observers and to researchers concerned about the nature of technology transfer and how it occurs differently in Japan and in the United States.

ACKNOWLEDGMENT

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REFERENCES

1. A.J. Pollack, "The Patent Barrier," The New York Times (July 5, 1984).
2. R.S. Cutler, "Impressions and Observations of Science and Technology in Japan," a report to the Japan-U.S. Educational Commission (Fulbright Foundation) (University of Tokyo, Japan, May 1987).
3. T.W. Eagar, "Technology Transfer and Cooperative Research in Japan," ONR Far East Scientific Bulletin 10(3), 32-41 (1985).

4. W.G. Ouchi, *Theory Z* (Addison-Wesley Publishing Co., 1981).

5. J. Walsh, News and Comment, Science, 1506 (11 December 1987).

BIBLIOGRAPHY

Bloom, J.L. (1987), "Japan enters the World Series of technology," The World & I, September.

Havelock, R.G., and V. Elder (1987), Technology transfer in Japan: An exploratory review (Center for Productive Use of Technology, George Mason University, June).

Hill, C.T. (1987), Japanese technical information: Opportunities to improve U.S. access (Congressional Research Service, October).

Kobayashi, H. (1987), "Scientific creativity and engineering innovation in Japan," *Symposium on Science in Japan*, 153rd Annual Meeting, American Association for the Advancement of Science, Chicago, Ill., February 16.

Marcus, R.J. (1983), "Observations on science in Japan," ONR Far East Scientific Bulletin 8(3), 1-12, March.

Peters, L.S. (1987), Technical network between U.S. and Japanese industry (Center for Science and Technology Policy, Rensselaer Polytechnic Institute, Troy, N.Y., March).

Samuels, R.J. (1987), Japanese scientific and technical information in the United States: Public policy and private initiatives, MITJSTP 87-95 (MIT-Japan Science and Technology Program, September).

Vogel, E.A. (1980), *Japan as Number One* (Charles E. Tuttle Co., Tokyo).

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SURVEY OF HOT ISOSTATICALLY PRESSED CERAMICS

Edward Mark Lenoe

More than 30 years have passed since the original research on gas pressure bonding was conducted. Since that time there has been truly impressive growth of hot isostatic pressing (HIP) technology, particularly in the last 10 years, and particularly in Japan. Nowadays Japan may well have the greatest number of high temperature HIP facilities engaged in ceramics research and development. In the same time frame and worldwide there has been extensive activity in fine ceramics for a variety of applications. Therefore, this article attempts to survey the more recent studies of HIPed ceramics and discusses the increasing number of ceramics and expanding complexity of processing techniques. Examination of the literature demonstrates that impressive improvements in strength, fracture toughness, creep resistance, hardness, and wear resistance have been achieved and that the process reliability of ceramic components has been greatly improved. The fundamental question remains: which of these promising materials and process combinations can and will be economically and reliably scaled-up for meaningful applications.

ADVANCES IN EQUIPMENT AND GROWTH OF THE TECHNOLOGY

Most workers in this field know that the hot isostatic pressing (HIP) method dates back more than 30 years when researchers in the United States developed a specific process they referred to as "gas pressure bonding." These first experiments

in 1955 used a hot-walled vessel, heated externally and pressurized by helium. The working zone was about 5 mm in diameter and 900 mm in length. From that modest beginning, progress in the technology has been truly amazing. For instance, Figure 1 illustrates the size increases in HIP units in the United States, while Figure 2 shows HIP facilities by size in three industrialized nations. Figure 3 indicates the wide range of applications for HIP facilities in Japan, the United States, and West Germany as of 1985. At that time it was apparent that the United States was heavily committed to research and development (R&D) studies as well as to a variety of industrial fields including production of cemented carbides, superalloys, castings, and general HIP services.

In 1985 a survey of industrial applications of hot isostatic pressing in Europe was conducted by ASEA, AB (Ref 1). During that period in Western Europe there were over 50 hot isostatic presses in operation or on order. About 30 were for research and the remainder were for production. ASEA and ASEA Pressure Systems supplied at least 50 percent of these units, followed by Autoclave Engineers (about 29 percent) and National Forge (8 percent). ASEA's survey found that the primary application was postdensification of cemented carbide. About 600 tons per year were being processed on 13 presses. The second most important application was specialty steels and the third was healing of superalloy and titanium castings.

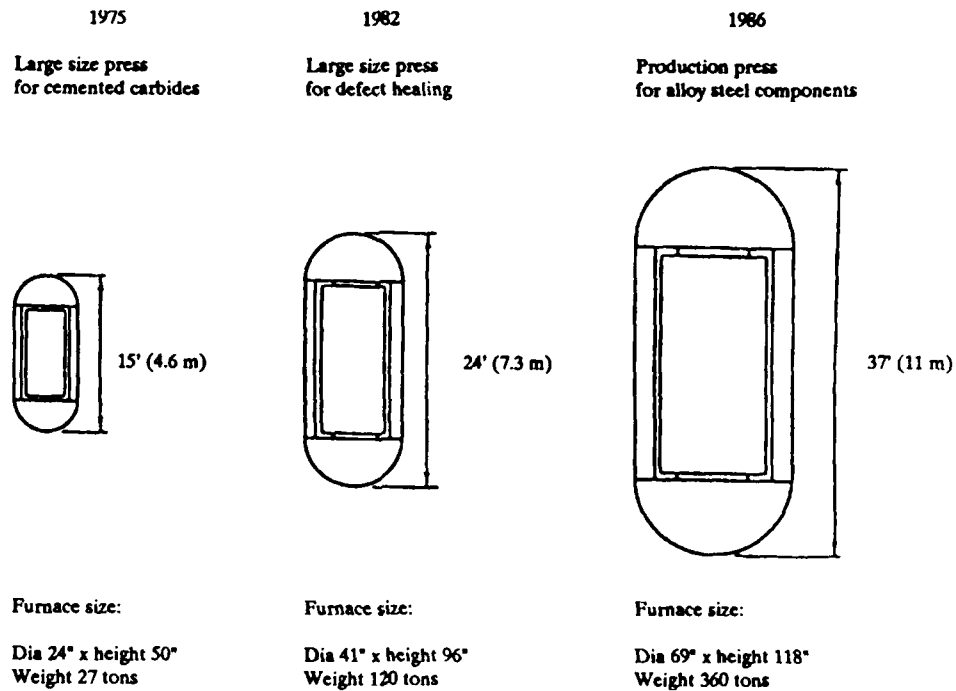


Figure 1. Trend for increasing size of HIP units.

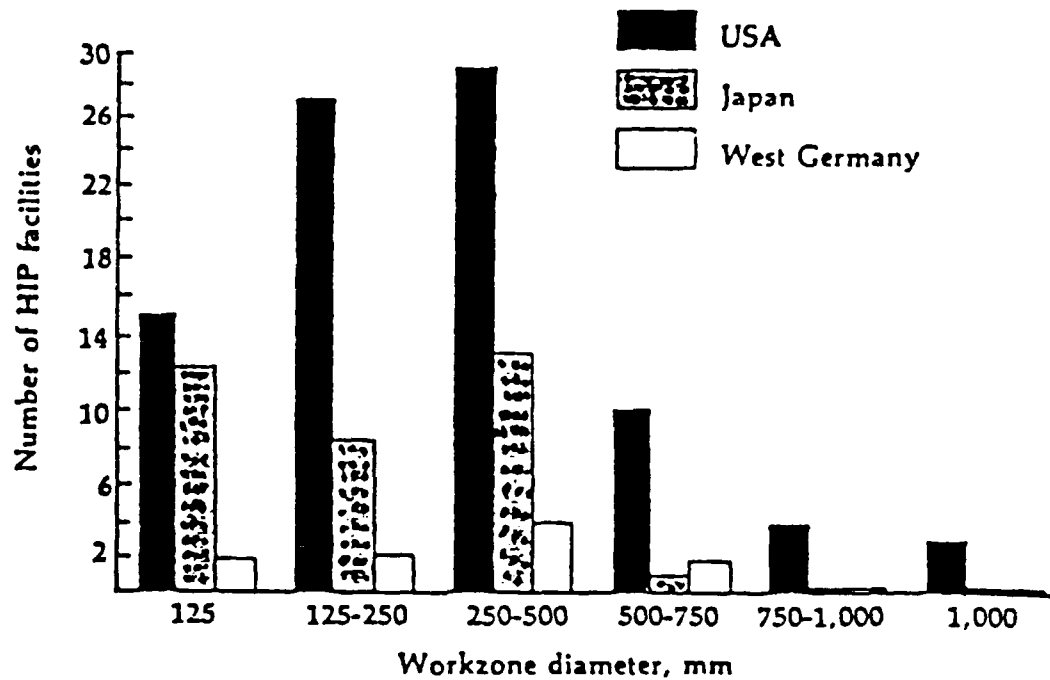


Figure 2. HIP workzone diameters in several industrialized nations.

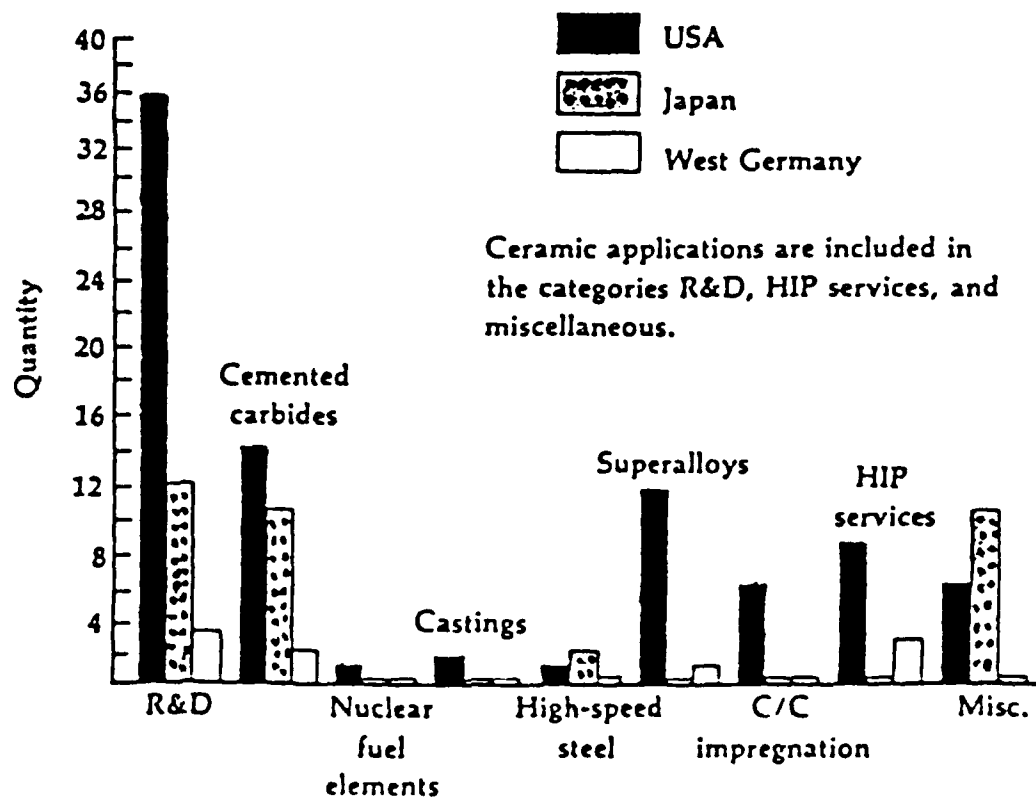


Figure 3. Fields of application for hot isostatic pressing in several nations.

With the advanced HIP technology available today, it is evident that production rates at thousands of tons per year can be achieved in a single HIP unit. HIP technology is commonly thought to be a very expensive and time-consuming process that is used almost exclusively for cemented carbide and aerospace materials. Process costs in these industries as much as \$1 to \$10/lb are commonplace. However, for large-scale alloy steel production, HIP costs can be reduced to fractions of a dollar per pound.

Of key importance to reducing costs are larger presses, better automation, and vastly improved process controls. Over the

years refinements to equipment and processing methods have led the way not only in cost reduction but also to many new applications for various composites, glasses, and ceramics. Currently in powder metallurgy and in ceramics there is a merging of hot isostatic pressing with sintering as the increasingly flexible HIP furnaces become operable with higher pressures and strictly controlled and variable atmospheres. For metals production there is very strong competition from a variety of processes. For instance, some experts think that improvements in precision casting and melting technology, rapidly solidified alloy powders, and other methods may slow down

use of HIP technology. However, a more likely happening is that any significant processing advances will probably be incorporated as a substep of the HIP process and that we will witness ever increasing complexity of the HIP technology as a result. Therefore, it is imperative that leading HIP equipment manufacturers not only continue their research but also seek to expand into all appropriate areas to significantly advance the technology. This appears to be happening worldwide and especially here in Japan. When I first visited Japan in late 1983 there were about 50 HIP units, and now there are well over 120. Kobe Steel has played the major role in that market growth with the largest portion of sales (see Figures 4a and 4b). The KOBELCO seminars on hot isostatic pressing, dating back to 1981, are a well-respected reference source of leading edge technology (see Appendix A for a discussion of a recent seminar).

We have witnessed a phenomenal growth in the technology of HIP materials and components. Some experts predict that in the next 5 years ceramics will be one of the faster growing technology areas. In particular, new types of electronic and structural ceramics are expected to be placed on a production basis soon and are expected to experience continued growth through the 1990s. Application of hot isostatic pressing to electronic ceramics continues to grow and this includes products such as multilayer capacitors and magnetic tape heads. Representative HIP units for ferrite processing may have dual capacity ratings such as 43 ksi/3,600 °F (300 MPa/2,000 °C) and

14.5 ksi/2,550 °F (100 MPa/1,400 °C) with 80 percent argon/20 percent oxygen environment. Hot isostatic pressing results in higher densities and more uniform pore-free microstructures that significantly improve magnetic as well as mechanical properties. Generally, larger size equipment and higher temperatures and pressures are required for production of structural ceramics. One of the more advanced units for structural ceramics operates at 45 ksi/4,000 °F (310 MPa/2,200 °C). There is a wide range of possible methods and increasing variations in HIP processing. One of the more popular methods is sinter-plus-HIP. A summary of the more common methods and their advantages and disadvantages is shown in Table 1.

EARLY DEVELOPMENTS IN HOT PRESSING AND GAS PRESSURE SINTERING

Hot pressing ceramics offers the ability to fabricate dense and strong products with a small amount of sintering aids; however, fabrication is limited to relatively simple shapes. Pressureless sintering can be used to fabricate complex shapes, but the components have generally lower densities and the additives necessary for densification usually result in poor high temperature performance. Gas pressure sintering has made it possible to sinter a variety of ceramics and complex shapes with small amounts of additives. Let us briefly consider the situation of silicon nitride, in which high pressure nitrogen gas depresses thermal decomposition at temperatures

greater than 1,800 °C. Table 2 summarizes studies of gas pressure sintering of silicon nitride, an early contender for high temperature applications. These efforts date back more than 10 years. As can be seen by examining the table, rare earth oxides were generally used as additives for improvement of high temperature properties and enhanced formability. It was learned that adding a rare earth oxide alone, e.g., less than 10 wt. %, is not as effective as a sintering aid. However, concurrent additions of rare earth oxide (Y_2O_3 and CeO_2) and Al_2O_3 or SiO_2 increase the sinterability. While addition of Al_2O_3 effectively increases sinterability, the amount of alumina must be minimal to improve the oxidation resistance of sintered silicon nitride with Y_2O_3 additives. It should be apparent that successful gas pressure sintering requires indepth knowledge of sintering response and precise control of processing conditions and especially raw materials control. But even now phase diagrams for many possible compositions remain unexplored.

PROPERTY DATA AND PROCESSING PARAMETERS

During the past several years a large number of papers dealing with hot isostatic pressing of ceramics have been published in Japan. With our available resources, it is not possible to translate the reference material in its entirety; however, we can discuss property data and processing parameters, which will prove of use to researchers in the field.

Silicon Nitride

Hot Isostatic Pressing and Sinter-HIP. There is, as mentioned earlier, a variety of possible production routes, and it is well known that the properties of HIP-silicon nitride strongly depend on the processing conditions and starting materials.

Postsintered Hot Isostatic Pressing. High temperature properties of postsintered silicon nitride were investigated by NTK researchers Shimamori, Matsuzaki, Kato, Tajima, and Matsuo (Ref 2). The behavior of post-hot-pressed compacts started with silicon powder and hot-pressed compacts started with silicon nitride powders was investigated. Three types of powder produced by three types of processes were used, including silicon nitridation, vapor phase reaction, and silica reduction. Compared with material produced from silicon nitride powders, the postsintered ceramic had higher elevated temperature properties. Shimamori et al.'s processing routes are shown schematically in Figure 5 and some of their results are presented in Figure 6. Table 3 summarizes powder characteristics.

In the postsintered (PS) route the compacts were nitrided at temperatures less than 1,450 °C in a mixture of hydrogen and nitrogen. Hot pressing was by heating at 1,800 °C for 2 hours under pressures of 20 MPa. Flexure specimens 400 by 3 by 4 mm were tested in three-point flexure on 30-mm spans. Fracture toughness was obtained via the indentation fracture method.

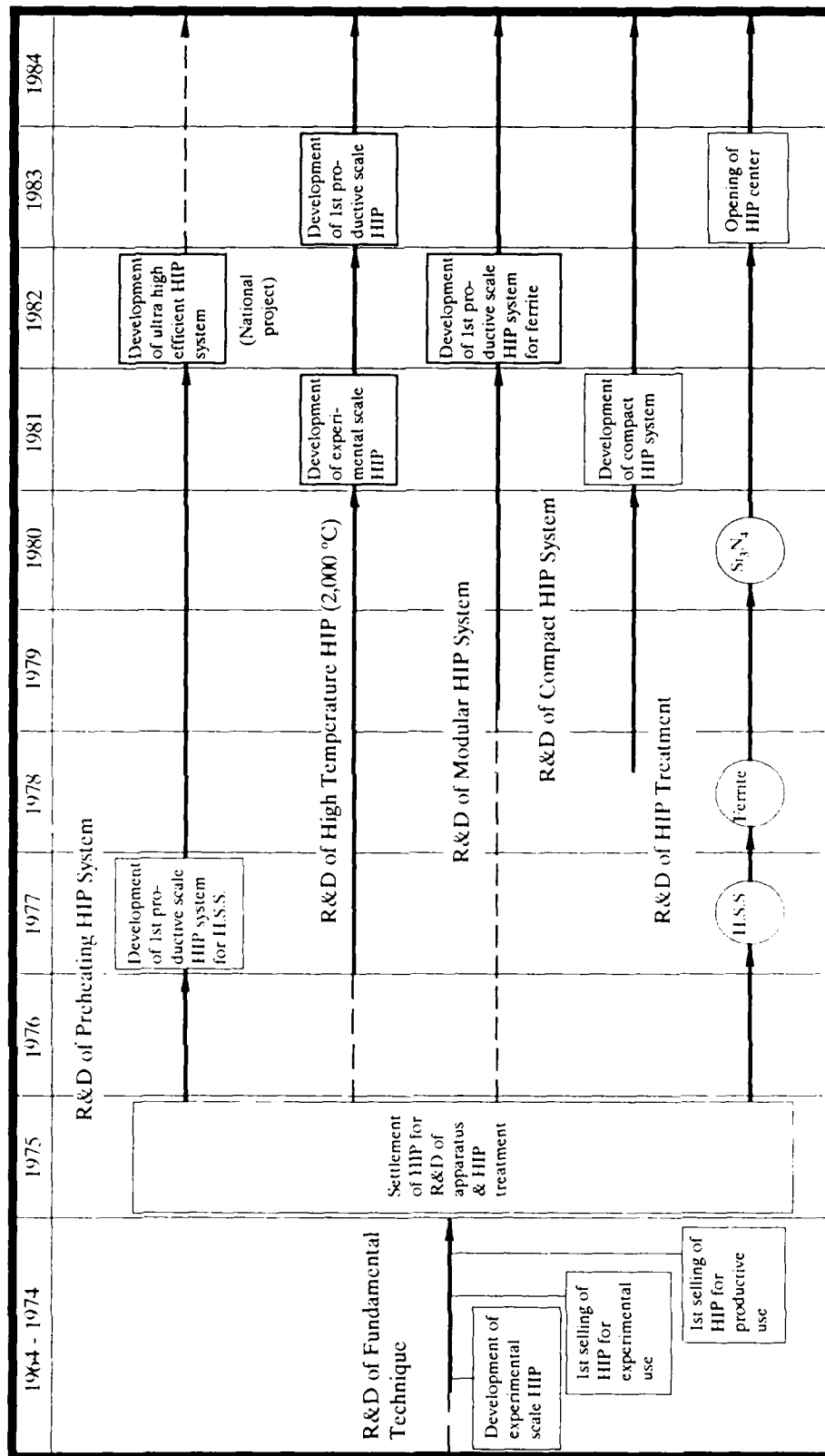


Figure 4a. History of hot isostatic pressing (HIP) at Kobe Steel (courtesy of T. Fujikawa, Kobe Steel, Ltd.).

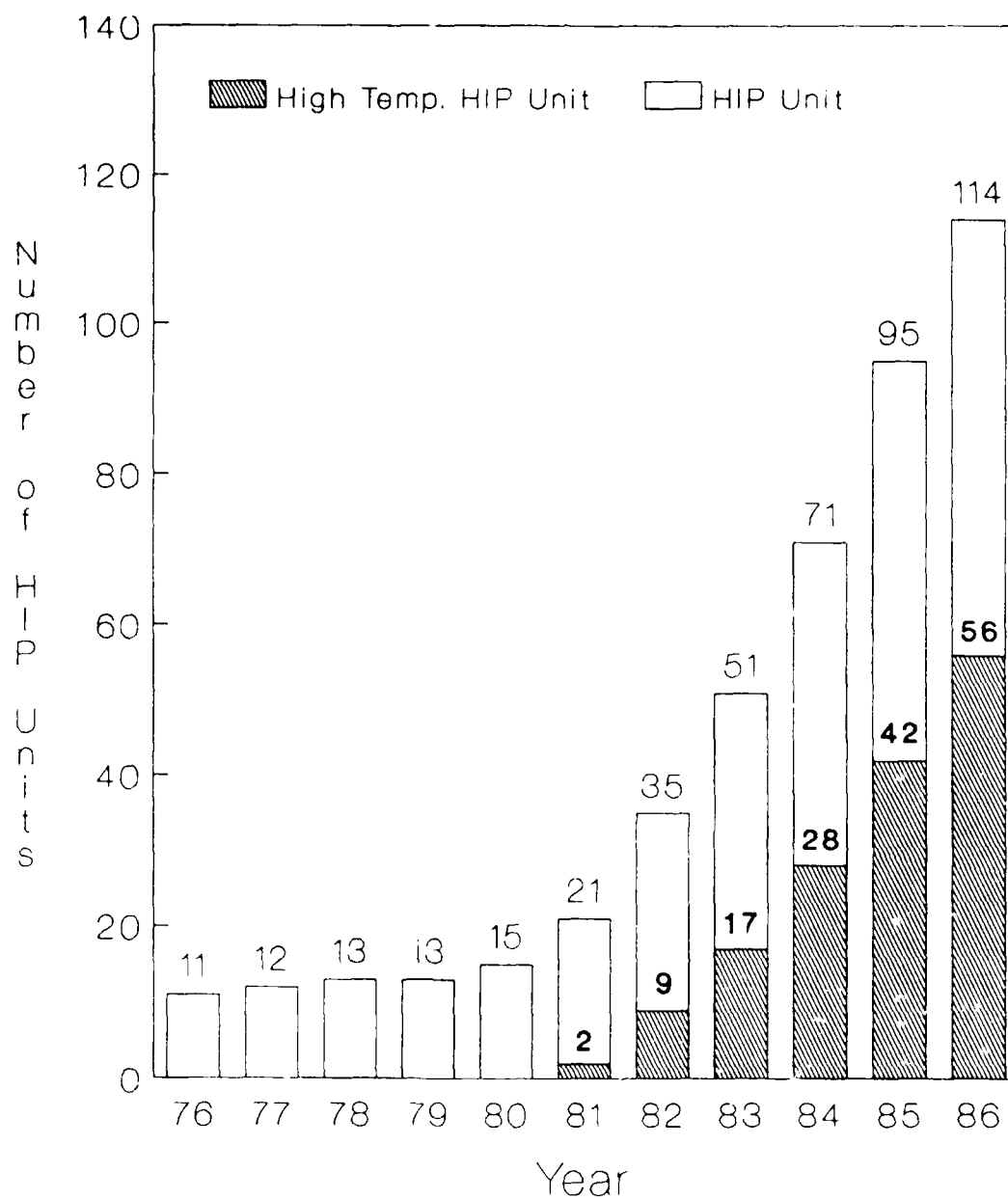


Figure 4b. Installations of HIP units in Japan (courtesy of T. Fujikawa, Kobe Steel, Ltd.).

Table 1. Hot Isostatic Pressing Methods, Advantages, Disadvantages, and Applications

Method	Advantages	Disadvantages	Applications
Pressure impregnation	Near isotropic	Requires repeated cycles	Impregnate graphite preforms, porous ceramics Other composites
Diffusion bonding	No additives needed Complex shapes Improved bonding strengths Isotropic	Requires canning Dependent on bonding temperatures	Metal-ceramic and ceramic-ceramic bonding Metal-matrix composites
Powder consolidation	No presintering Low temperature densification Less additives needed Minimal grain growth Loss of volatile species prevented Good dimensional control	Requires canning Lower packing density in autoclave Preforms may be difficult to handle Lower operating pressure if glass is used	Transparent ceramics BaTiO ₂ dielectrics Silicon nitride structural ceramics Large alumina containers Superalloys Composites
Sinter plus HIP	No canning required Sintered parts are easier to handle Higher packing density in autoclave No die friction losses No geometric limitations Multiplicity of parts/cycle	Requires sintering to state of closed porosity Addition of sintering aids can degrade properties Excessive grain growth Surface defects are not removed Potential volatilization	Cutting tools-ceramic, carbides Multilayer capacitors Magnetic ferrites Cemented carbides
Sinter/HIP	No canning required Full density achieved in one cycle Lower cost, pressure Control grain size Improved surface finish	Furnace design limitations Higher temperatures	Cemented carbides Ceramic cutting tools Titanium alloys
Overpressure sintering	Low temperature densification Less structural damage	Higher pressure Equipment size Expensive	Refractory metals Ceramics

Table 2. Gas Pressure Sintering of Silicon Nitride Studies With Rare Earth Additives

Researcher	Remarks
Mitomo	Achieved 95% density Si_3N_4 + 5 wt. % MgC, sintered @ 1,800 °C, 1 MPa N_2 , 2.98 g/cm ³ for Si_3N_4 + 5 wt. % CeO_2 , sintered @ 1,900 °C, 2 MPa
Priest	Obtained full density for Si_3N_4 + 20 wt. % CeO_2 , sintered @ 1,800 to 1,950 °C, 2 MPa N_2
Galasso	95% density for Si_3N_4 + 15% Y_2O_3 , sintered @ 1,950 C, 2 MPa, 3 g/cm ³ for Si_3N_4 + 15 % Y_2O_3 + 3% Al_2O_3 , sintered at 1,800 C, 2 MPa
Gazza	Full density for Si_3N_4 + 10 wt. % $\text{Y}_3\text{Al}_5\text{O}_{12}$, sintered at 1,770 to 1,780 °C, 2 MPa
Greskovich	Two-step gas pressure sintering, obtained 99.7% density for Si_3N_4 + 7 wt. % SiO_2 + 7 wt. % BeSiN_2 , sintered @ 2,000 °C, 2 to 7 MPa
Sanders	Full density for Si_3N_4 + 5.3 to 8.7 wt. % SiO_2 + 8.3 to 23.5 wt. % CeO_2 , sintered @ 1,900 to 2,090 °C, 2.5 MPa; Full density for Si_3N_4 + 4 to 6.3% rare earth oxide + 3.6 to 4.0% SiO_2 , sintered @ 2,140 °C, 2.5 MPa
Tani	3.23 g/cm ³ for Si_3N_4 + 10% CeO_2 , sintered @ 2,000 °C, 4 MPa

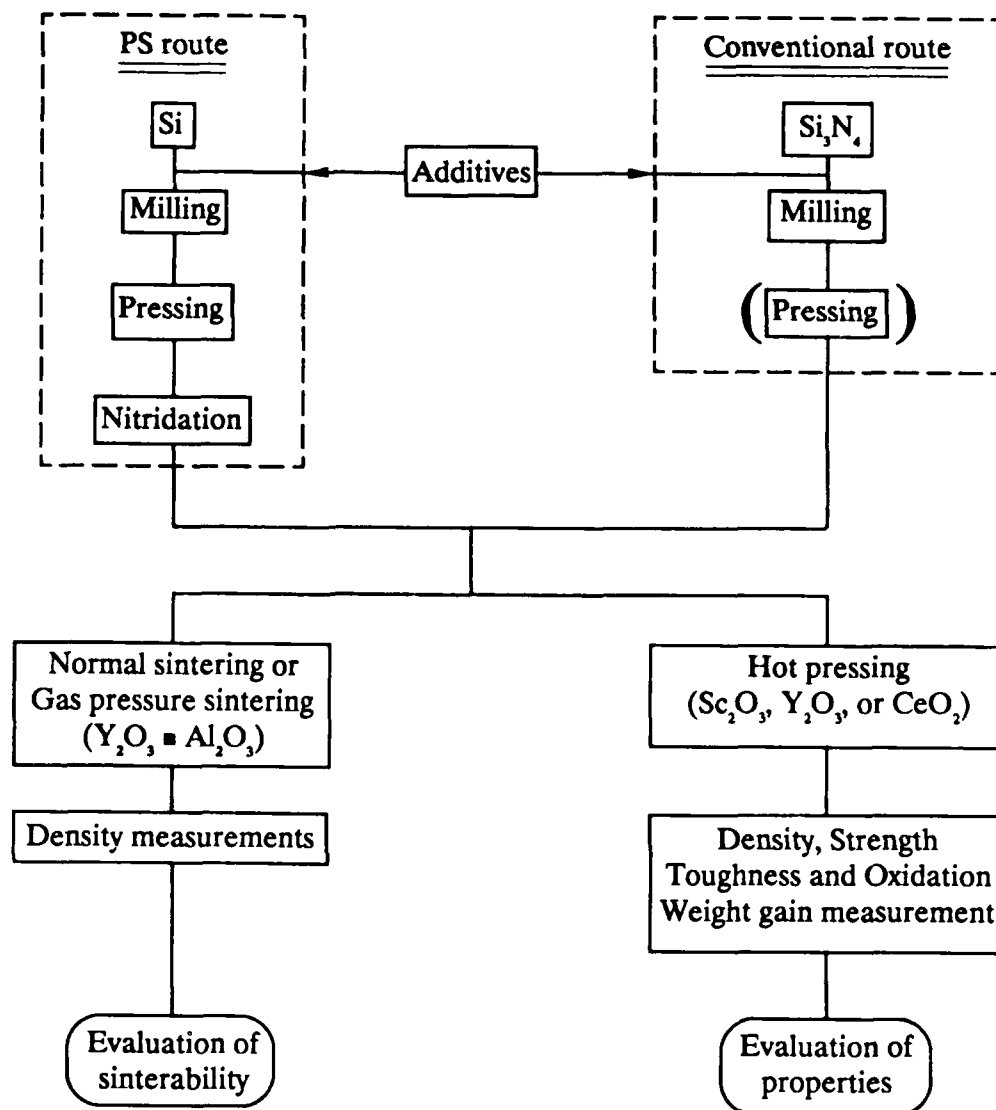
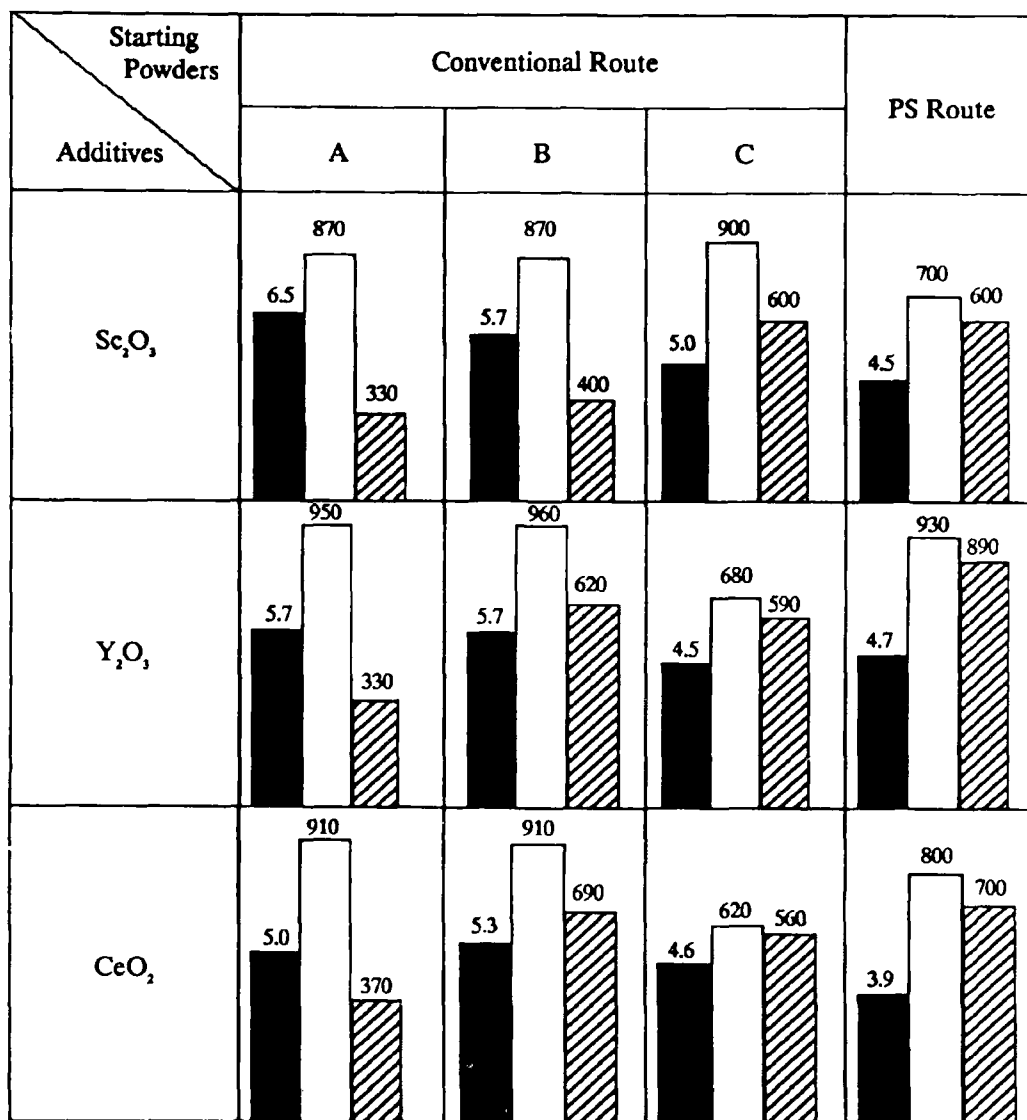
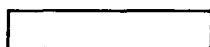


Figure 5. Schematic of processing route.



Legend: Modulus of Rupture (MPa)

Fracture Toughness (MPa $\sqrt{\text{m}}$)



Room temp.



1,300 °C



Figure 6. Flexural strength and fracture toughness results (after Ref 2).

Table 3. Silicon Nitride Powder Characteristics

Item	Silicon Nitridation (Route A)	Vapor Phase Reaction (Route B)	Silica Reduction (Route C)
BET, m ² /g	20	7.1	10.9
FSSS, μ m	0.50	0.70	0.90
α content, %	94	96	99
Chemical analysis			
Si, %	59.2	59.4	59.2
N, %	38.4	39.4	38.0
O, %	1.46	0.46	1.79
C, %	0.30	0.03	0.75
free SiO ₂ , %	0.24	0.36	1.04
Fe, ppm	80	4	160
Ca, ppm	9	<1	220
Al, ppm	130	6	92
M, ppm	20	<1	8

Hot Isostatic Pressing Without Additives. In anticipation of gaining improved high temperature performance, many efforts have been made to densify silicon nitride without additives and using high pressure techniques. Yamada et al. (Ref 3) sintered silicon nitride to nearly full density by hot pressing high purity powders at 3 GPa and 1,600 °C for 1 hour. These studies showed that high pressure can promote the rate of alpha to beta transformation and also reduce the sintering temperatures. Okuda et al. (Ref 4) produced 99-percent-dense silicon nitride by HIPing pure powder prepared by nitriding silicon at 150 MPa and 1,900 to 2,000 °C for 2 hours. Interestingly, while they measured strengths of 240 MPa at room temperature, the material strength at 1,200 °C was reported as 460 MPa!

Recently, Miyamoto et al. (Ref 5) HIPed four kinds of starting powders from different commercial sources. Specimens were fabricated at 180 MPa and 1,850 to 1,900 °C for 1 hour using glass containers and with heating rates of 9°C/min. Figure 7 is a schematic of their fabrication process, along with HIP schedules.

In this research four kinds of commercially available powders were used; their characteristics are listed in Table 4. Powders noted as SN-A and SN-B are pure powders synthesized by nitridation of Si, and SN-C and SN-D are also highly pure powders made by thermal decomposition of Si(NH)₂. These powders were formed into pellets 6.8 mm in diameter and 18 mm long and pressed isostatically at 100 MPa at room temperature. Next they were pre-fired at 1,200 °C for 1 hour in a vacuum (10⁻³ Pa).

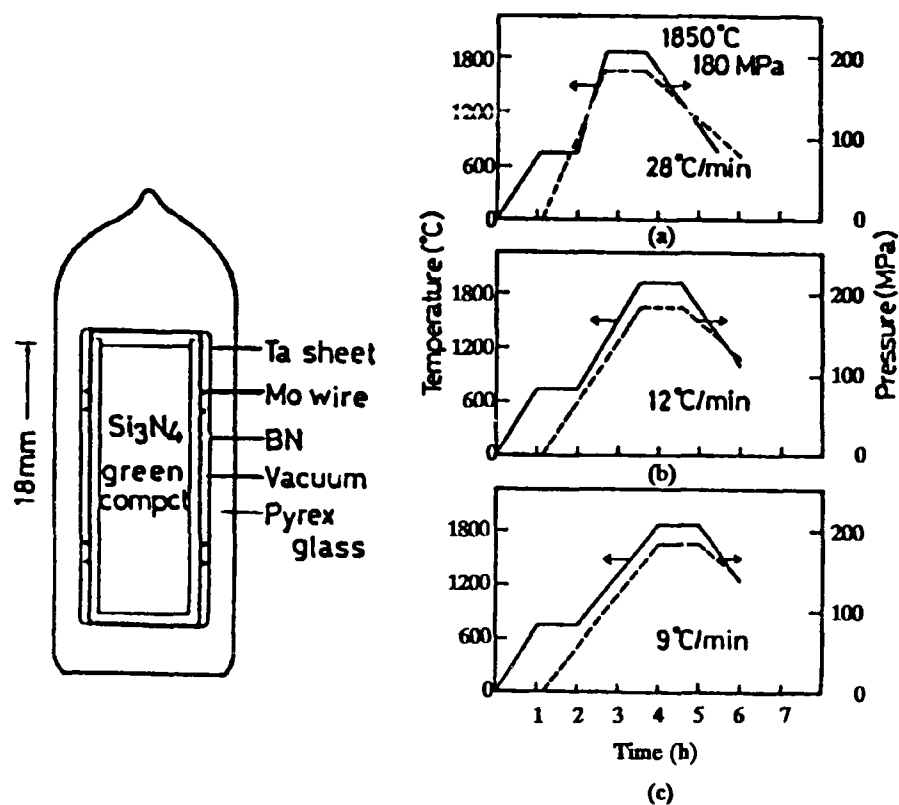


Figure 7. Schematic of fabrication process and HIP cycle (after Ref 5).

Table 4. Powder Characteristics

Powder	α Phase Content (wt. %)	Chemical Composition (wt. %)									Specific Surface Area (m ² /g)
		N	O	C	F	Fe	Al	Ca	Na	Cl	
SN-A	93	38.47	1.30	0.14	0.07	0.03	0.05	0.008	0.001	--	10
SN-B	93	38.47	1.40	0.17	0.12	0.01	0.04	0.005	0.001	--	23
SN-C	88.7	39.0	1.20	0.08	--	18 ^a	--	10 ^a	--	0.1	7
SN-D	97	38.0	1.70	--	--	<50 ^a	<50 ^a	<50 ^a	--	<50 ^a	13

^appm.

SN-A: H.C. Starck, LC 1 (nitridation of Si)

SN-B: H.C. Starck, LC 13 (nitridation of Si)

SN-C: Toyo Soda Manufacturing, TS-7 [thermal decomposition of Si(NH)₂]

SN-D: Ube Industries, E-10 [thermal decomposition of Si(NH)₂]

The resulting green bodies were placed into a BN capsule, folded into tantalum foil, and placed in a pyrex glass container that was evacuated to 0.1 Pa and sealed. These sealed containers were then packed in BN powder in a graphite crucible. All HIP experiments were completed in argon gas pressure. Initially the container was heated to 730 °C under 2 MPa pressure, then the heating rates shown in Figure 7 were applied. Sintering was for about 1 hour at 180 MPa and about 1,850 °C. After sintering the glass container was stripped away and specimen surfaces cleaned by polishing. The cylinders were cut into disks by a diamond saw and polished with several grades of alumina lapping cloth, then flexure specimens 3 by 3 by 15 mm were prepared. Five flexure specimens were made for each type of powder. Crosshead speeds of 0.5 mm/min and 10-mm spans were applied. The Vicker's microhardness was measured with 200-g loads for 5 seconds up to temperatures of 1,200 °C. Fracture toughness was measured by an indentation

method up to temperatures of 1,000 °C. Results of the tests are shown in Table 5.

Tahatori, Kobayashi, and Wada (Ref 6) investigated strength and fracture toughness of HIPed silicon nitride with various additives. Table 6 summarizes their results. Note the relatively high strengths at both room and elevated temperatures. Yoshida et al. (Ref 7) studied sintered HIPed silicon nitride without additives. Their data are shown in Figure 8.

Hot Isostatic Pressing of Other Ceramics

Regarding other materials, Suzuki et al. (Ref 8) studied the oxidation behavior of sintered silicon carbide with the addition of alumina oxide. It was found that the oxidation kinetics in air at 1,200 to 1,300 °C were parabolic with oxidation time up to 1,000 hours and the 1,300-°C flexural strength did not change with time up to 1,000 hours. Therefore, HIPed SiC with low alumina content exhibited excellent oxidation resistance.

Table 5. Summary of Test Results (Density and Mechanical Properties) of Silicon Nitride Ceramics Without Additives Sintered by Hot Isostatic Pressing

Specimen	Density (g/cm ³)	Relative Density (%)	H _v (GPa)	K _{IC} (MN/m ^{3/2})	Flexural Strength (MPa)
SN-A	3.17	99.3	20.8	3.40	570
SN-B	3.15	98.7	21.2	3.76	620
SN-C	3.15	98.7	25.3	3.54	836
SN-D	3.12	97.8	20.6	3.40	499
Average	3.15 (±0.02)	98.6 (+0.7)	23.5 (±3.0)	3.53 (±0.20)	630 (±200)

Table 6. Hot Isostatically Pressed Silicon Nitride With Additives (after Ref 7)

Material No.	Additive (wt. %)	Sintered Density (g/cm ³)	Flexural Strength (Four-Point Bending Test) (MPa)			Hardness (GPa)	Fracture Toughness (IF Method) (MPa√m)
			RT	1,200 °C	1,400 °C		
1	1Y	3.19	843	462	326	15.9	4.8
2	3Y	3.22	702	583	367	15.0	3.0
3	5Y	3.25	715	457	257	13.8	5.8
4	10Y	3.31	667	391	288	13.5	6.2
5	1Z	3.13	538	408	254	14.9	4.6
6	3Z	3.22	512	560	411	16.4	3.8
7	5Z	3.25	506	628	463	16.3	4.0
8	10Z	3.32	583	656	461	16.1	4.5

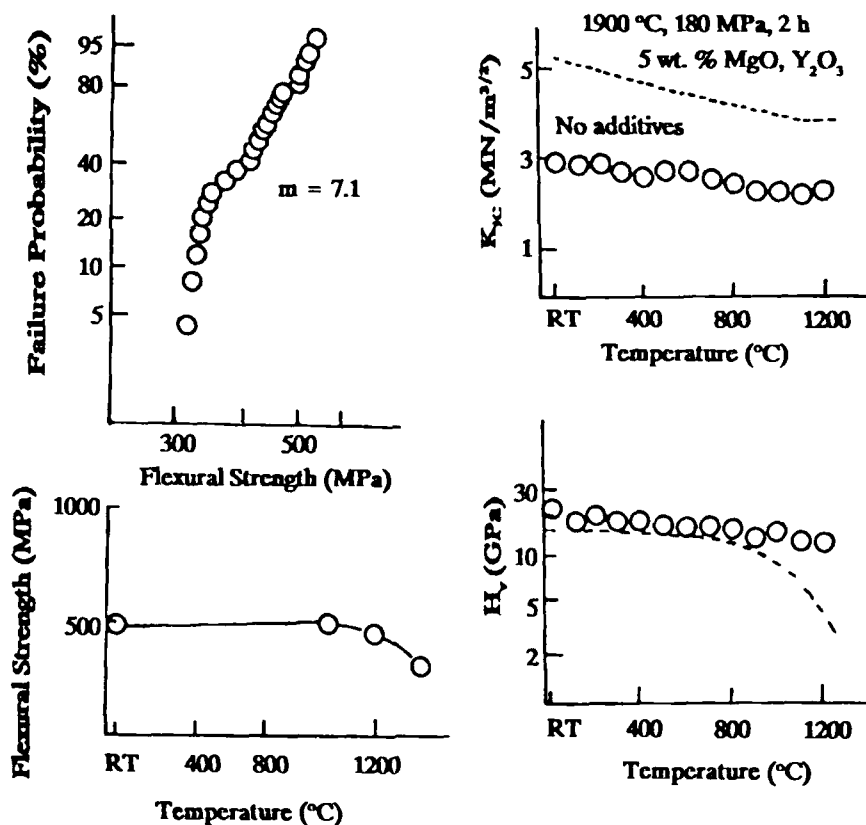


Figure 8. HIP-sintered silicon nitride properties (after Ref 7).

As for other materials, substantial efforts have been devoted to partially stabilized zirconia. For example, consider the work of Shimada of Tohoku University (Ref 9). Figure 9 is an interesting summary of some of his studies in terms of strength and fracture toughness. The marked effect of hot isostatic pressing is apparent in the graph, as is the nonlinear relationship of strength and fracture toughness.

Alumina zirconia ceramics have also been studied extensively. Significant increases of strength, toughness, modulus,

and hardness have led to use of such materials for certain types of cutting tools. Shin et al. (Ref 10) investigated the behavior of presintered Al_2O_3 and $\text{Al}_2\text{O}_3/\text{ZrO}_2$ compacts via HIP processing. The room temperature flexural strength and fracture toughness results appear in Figure 10. It was learned that at both low and high temperatures, strength values of zirconia-toughened alumina were markedly higher than those of alumina.

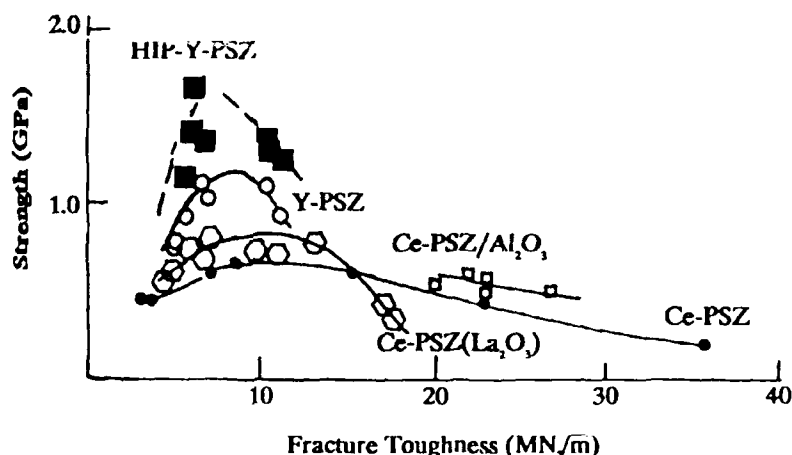


Figure 9. Strength versus fracture toughness of various partially stabilized zirconia (after Ref 9).

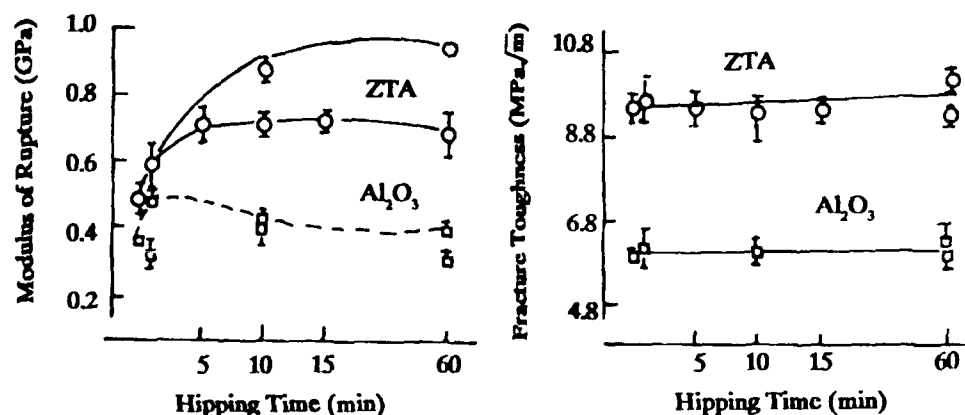


Figure 10. Room temperature flexural strength and fracture toughness (after Ref 10).

Some Hot Isostatic Pressing Applications

Hot isostatic pressing has been applied to enhance the strength of turbochargers and other components. In another type of application, Kurihayashi et al. (Ref 11) demonstrated the improvements achieved by HIP treatment of plasma-sprayed ceramic coatings on stainless steel. Coatings of alumina, zirconia oxide, and yttria and titanium carbide were used. The effects of HIP treatment between 1,100 and 1,300 °C on plasma-sprayed Al_2O_3 , ZrO_2 , and TiC coatings on the stainless steel were to considerably improve both Vicker's hardness and bond strength in all the coatings. Recently, Takano et al. (Ref 12) studied fabrication of TiB/Ti composites via sintering under self-combustion and hot isostatic pressing!

Zirconia Ceramics

Strengthening With Zirconia Addition. Zirconia addition has been shown to be effective in strengthening

various ceramics. Kobayashi and Wada (Ref 13) examined the strengthening effect of various types of ZrO_2 powders in conventionally sintered silicon nitride ceramics. They observed enhanced densification with the addition of both Y_2O_3 and MgAl_2O_3 . For instance, room temperature strength of specimens with $\text{ZrO}_2/\text{Y}_2\text{O}_3$ was 880 MPa, and this was increased to about 1,100 MPa by adding MgAl_2O_3 . Relatively high toughness values of 7.0 to 7.5 $\text{MPa}/\sqrt{\text{m}}$ were achieved. High temperature strength of the $\text{ZrO}_2/\text{Y}_2\text{O}_3$ containing materials was about 600 MPa at 1,200 °C. Variation of flexural strength with temperature is shown in Figure 11. Masaki and Sinjo (Ref 14) studied yttria-stabilized zirconia, both partially stabilized (PSZ) and stabilized tetragonal zirconia polycrystals (TZP), fabricated by hot isostatic pressing. Fracture toughness increased nonlinearly with a decrease of 2.5 to 2.0 mol % Y_2O_3 , and a maximum value of 20 $\text{MPa}/\sqrt{\text{m}}$ was achieved. Figure 12 shows flexural strength and fracture toughness of Y-TZP and Y-PSZ sintered at 1,300 to 1,600 °C.

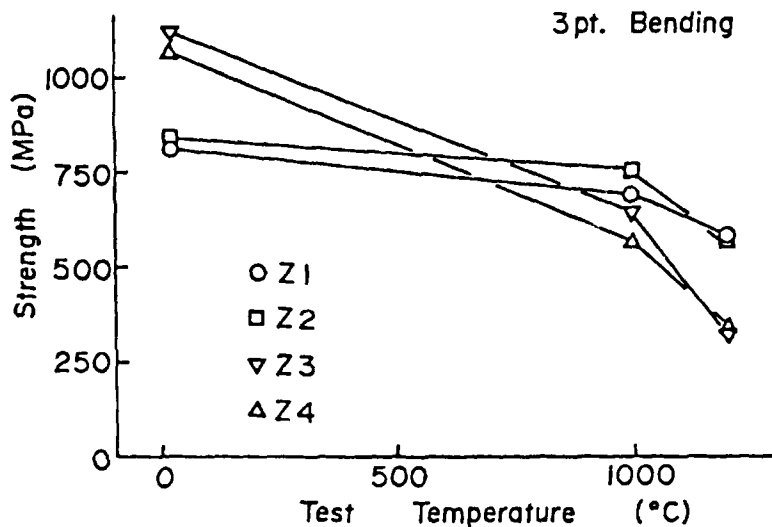


Figure 11. Variation of flexural strength of yttria-stabilized zirconia with temperature (after Ref 13).

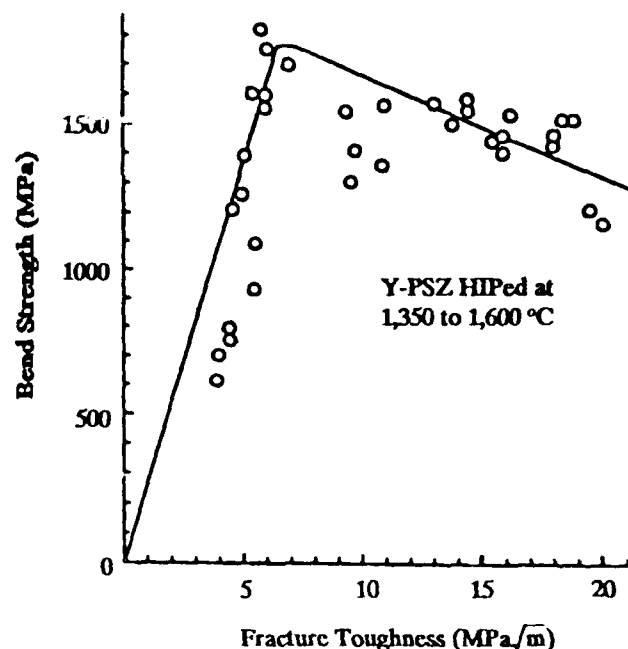


Figure 12. Relation between flexural strength and fracture toughness of Y-PSZ and Y-TZP HIPed at 1,300 to 1,600 °C (after Ref 14).

Takahata et al. (Ref 15) investigated the strength-toughness relationship of four kinds of TZP-based ceramics, including Y-TZP, Y-TZP/ Al_2O_3 , Ce-TZP, and Ce-TZP/ Al_2O_3 . It was found that the Al_2O_3 additive was effective for strengthening TZP while CeO_2 was effective in increasing fracture toughness. The four powders used were prepared by the hydrolysis method. Green compacts were sintered at 1,400 to 1,600 °C, and hot isostatic pressing of the sintered materials was accomplished at 1,500 °C and 100 MPa in argon gas. Strength was determined on specimens (3 by 4 by 40 mm) measured via three-point bend tests using spans of 30 mm at room temperature and at 1,200 °C. Fracture toughness was measured by the indentation microfracture (IM) method and the chevron notched short rod (SR) method. Figure 13 summarizes some of the results.

Hot isostatically pressed Y-TZP/20 wt. % Al_2O_3 had high room temperature strength greater than 2 GPa, while 12 mol % CeO_2 -TZP had high fracture toughness of more than 30 $\text{MPa}\sqrt{\text{m}}$ by the IM method (12 $\text{MPa}\sqrt{\text{m}}$ by SR). The HIPed Y-TZP/ Al_2O_3 materials showed the highest elevated temperature strengths.

Whisker Reinforcement. Other researchers have sought to enhance high temperature strength by other methods. Yasuda et al. (Ref 16) used silicon carbide whiskers and found good strength retention using 20 to 30 vol % of whiskers in PSZ. Figure 14 illustrates the influence of volume fraction at room and elevated temperatures in their study of whisker reinforcement. Note that four-point flexure tests (13.3/40-mm spans) were conducted on 3-by 4-by 50-mm specimens.

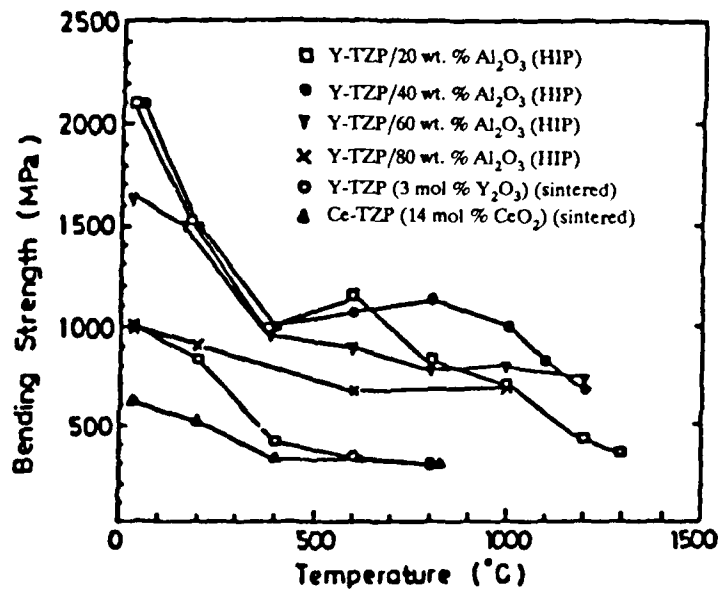
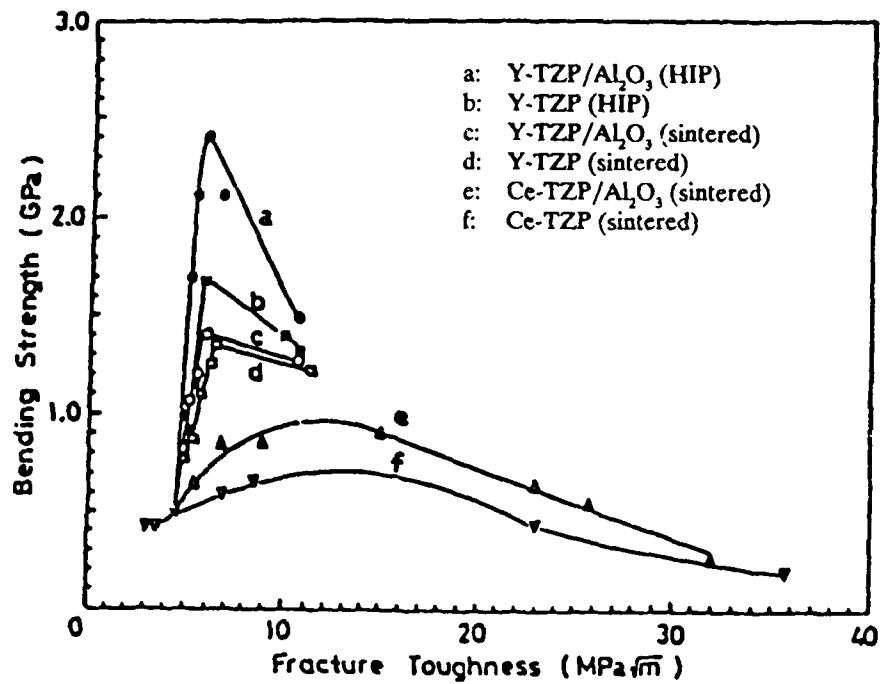


Figure 13. The relationship between strength and toughness for four kinds of TZP-based ceramics (after Ref 15).

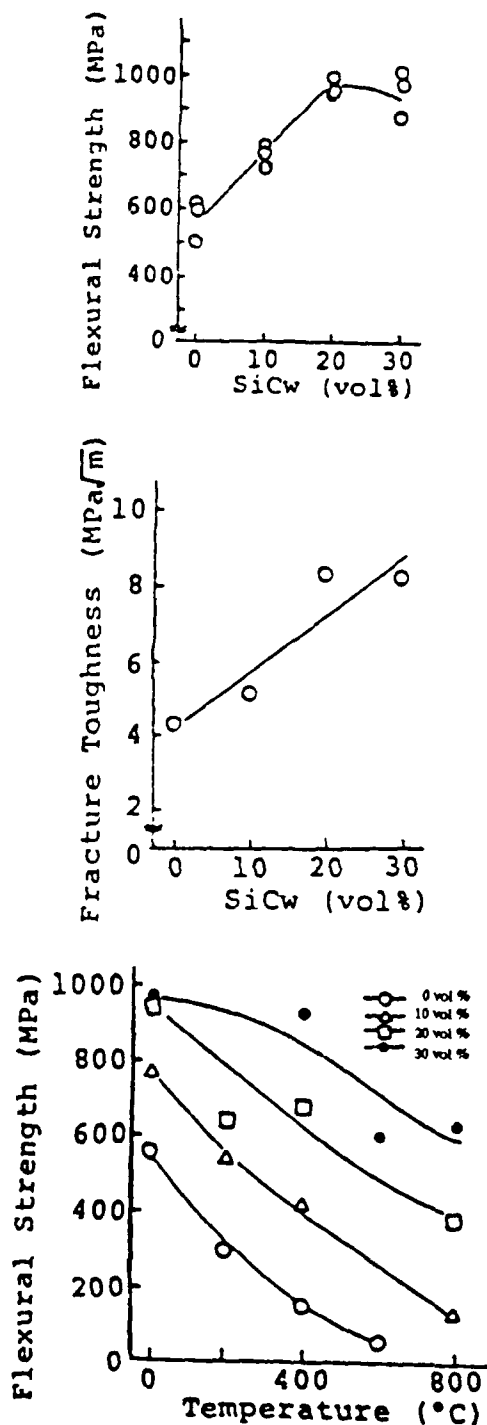


Figure 14. Flexural strength and fracture toughness of whisker-reinforced PSZ as a function of temperature and volume fraction of SiCw (after Ref 16).

Process Optimization. Nakajima and Masaki (Ref 17) determined the effects of hot isostatic pressing in an oxygen-containing atmosphere. In their study, yttria partially stabilized zirconia was made by pressureless sintering at 1,450 to 1,500 °C for 2 hours in air and HIPing under argon atmospheres with varying oxygen contents at 1,400 to 1,450 °C. PSZ materials HIPed in pure argon were found to suffer much more degradation than those prepared in an oxygen-containing atmosphere. Results for the different materials are shown in Figure 15.

OVERALL COMPARISON OF PROPERTIES

Figures 16 and 17 summarize some of the estimates a Japanese committee gathered together. These results are based on questionnaires, meetings, and manufacturers' catalogues. Figure 16 shows both the range of "current" values for the silicon carbide (structural) ceramics at that time (1983-85) and also indicates the participants' estimated "anticipated" or future potential for these materials. Figure 17 presents similar "current" and "anticipated" modulus of rupture versus temperature values for silicon nitride and several other structural ceramics. Contrasting the current and anticipated values for nitrides and carbides, it is interesting that this committee seems to believe that the nitrides are capable of greater improvements. Perhaps this is due to lack of experience with carbides. Note also that the strength versus temperature curves for anticipated properties are more or less flat out to 1,500 °C. There is also optimism in projecting improved high temperature performance for both carbide and nitrides, as well as

enthusiasm for hot isostatically pressed partially stabilized zirconia (HIPPSZ.) In any case these estimates are for modulus of rupture; there are numerous other mechanical and physical properties that control the selection of a material for any specific

application. Of course it is not a simple task to arrive at such estimates. Many types of test methods and specimens are used, even in flexure testing, and this leads to some confusion in the data base.

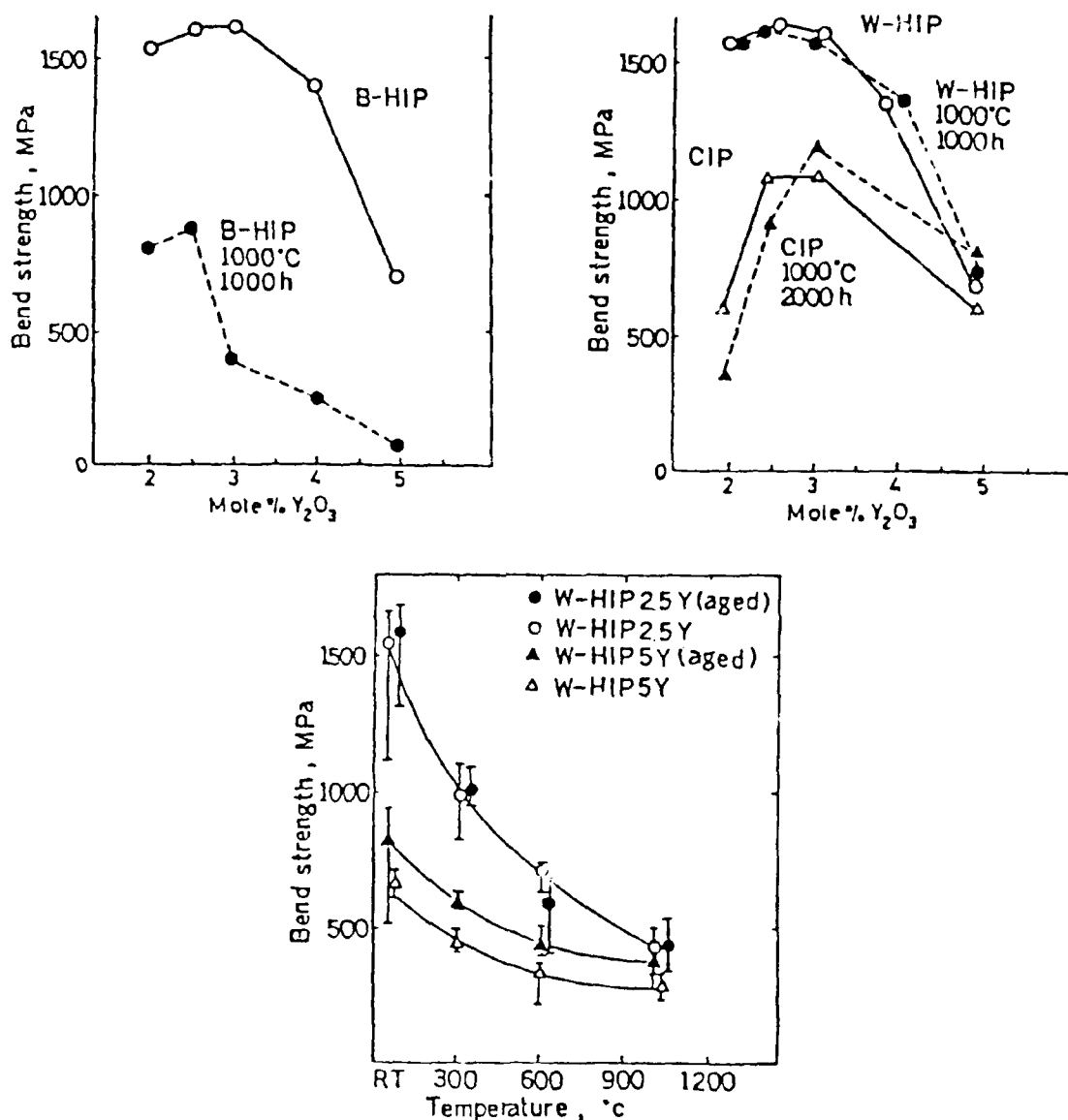


Figure 15. Effects of HIPing on the bend strength of Y-PSZ as a function of yttria mole fraction and temperature (after Ref 17).

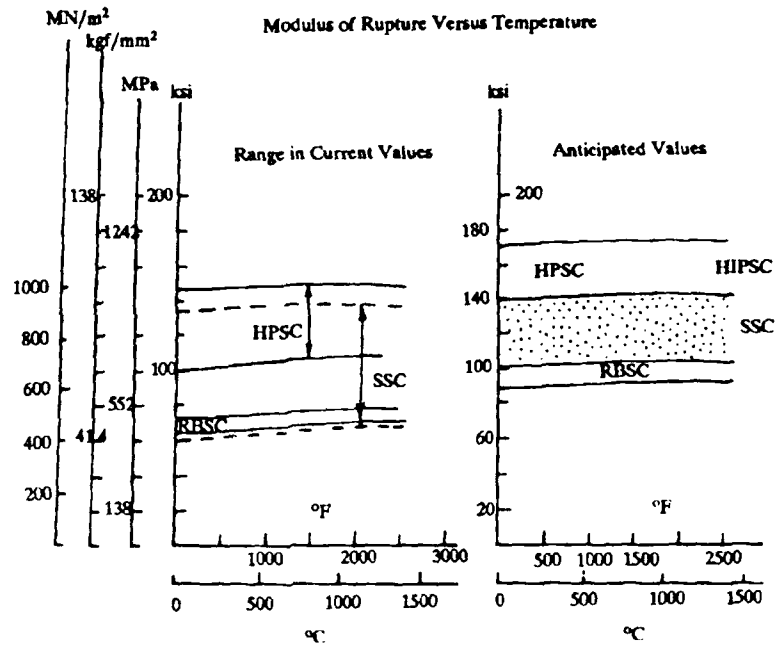


Figure 16. Current and future property values for various types of silicon carbide (JSAE estimates circa 1985).

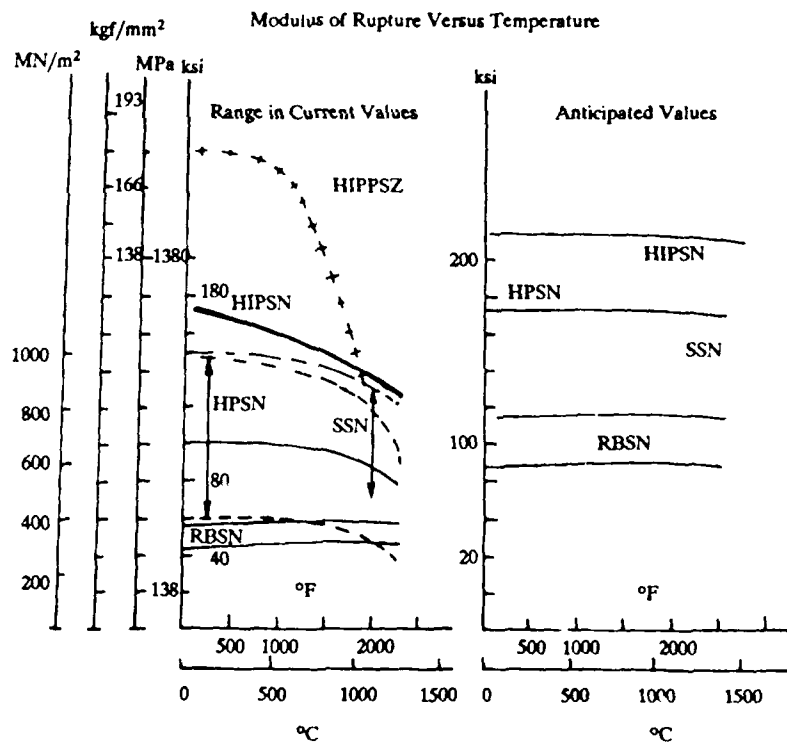


Figure 17. Current and anticipated property values for silicon nitride and other structural ceramics (JSAE estimates circa 1985).

It is true that the majority of data for the newer ceramic materials developments has been generated on relatively small specimen sizes and scale-up of the processes is a major requirement. Nonetheless, the improvements and varieties of new materials and processes are impressive and encouraging. Let us glance at Figure 18, which shows in a schematic way the trends in modulus of rupture versus temperature for various materials. Modulus of rupture data for early (1970s) reaction-bonded silicon nitride (RBSN) and hot-pressed silicon nitride (HPSN) are shown along with some of the more recent results for sintered

silicon nitride (SSN) and hot isostatically pressed silicon nitride without additives. Included is a set of results described by Chen (Ref 18). This is for mullite produced by sintering of spray-dried power containing 68 wt. % Al_2O_3 . Chen mentioned three procedures to improve room temperature properties of mullite: ZrO_2 alloying, SiC whisker reinforcement, and diphasic mullite with amorphous SiO_2 . He states that bending strengths were increased from 200 to over 500 MPa and fracture toughness improved from 2 to 7 $\text{MPa}\sqrt{\text{m}}$. Another interesting ceramic variety is partially stabilized zirconia with various additives, such as alumina, and with SiC whiskers.

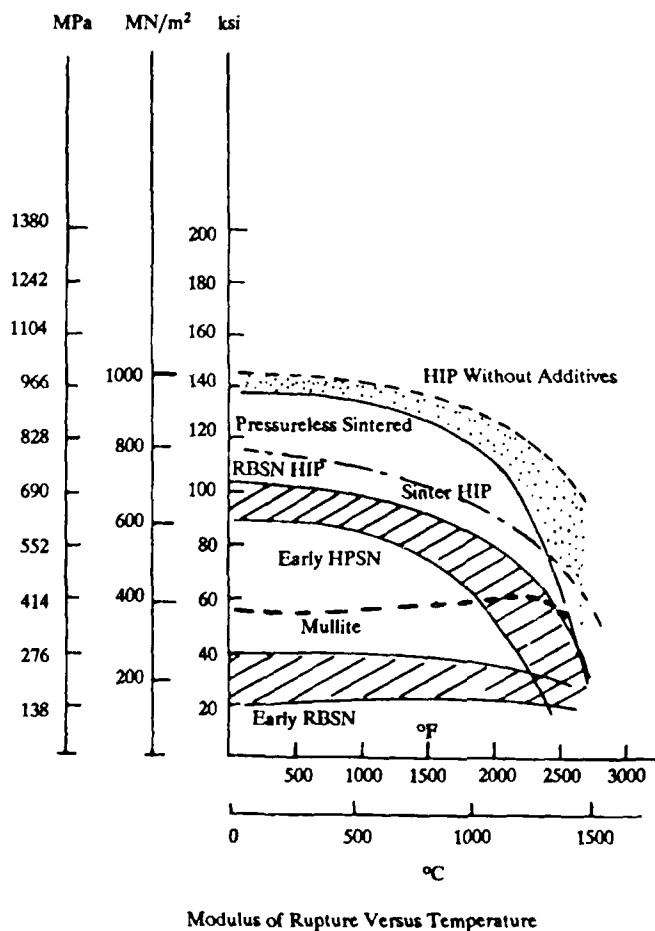


Figure 18. Trends in strength improvement for various ceramics.

Regarding other HIPed ceramic materials, significant progress has been made. Development of zirconia-toughened ceramics, for instance, has proceeded at a rapid pace. Recently, strengths of sintered Y-TZP (tetragonal zirconia polytype) ceramics were attained as high as those measured about 1 year ago on sintered and HIPed materials (4 to 6 wt. % Y_2O_3). Values obtained for these ceramics for room temperature were 1,137 MPa bend strength and 7 to 10 MPa \sqrt{m} fracture toughness. At 1,000 °C the values dropped about 65 percent. Encouraging results were obtained with Ce-ZTA (zirconia-toughened alumina) with better toughness than Y-TZP, and strength reduction was about 34 percent of ambient strength (740 MPa). Aging behavior remains to be more fully explored and improved. In the meanwhile this class of HIPed materials has achieved higher strengths, toughness, and improved thermal aging behavior. For instance, HIPed Y-TZP/20 wt. % Al_2O_3 had high room temperature strength greater than 2 GPa, while 12 mol % CeO-TZP had high fracture toughness of more than 30 MPa \sqrt{m} . The HIPed Y-TZP/ Al_2O_3 materials showed the highest elevated temperature strengths of over 1 GPa at 1,000 °C.

CONCLUSIONS

From the application viewpoint the consistency of ceramic products remains problematical for high performance ceramics in general, particularly in scale-up of components. However, we have seen the marked improvements that can be achieved in properties and uniformity of components via hot isostatic pressing technology

(Ref 19). Post-HIPing can markedly improve properties. The HIP process not only in itself but in combination with other processes permits fabrication of materials that would otherwise be impossible. As for typical effects of post-HIP, these include improvements to microstructure and also enhancement of properties. HIP effects on microstructure range over a wide number of aspects including eliminating residual pores, minimizing agglomerates, and healing small subsurface cracks. HIP effects on properties include improvements to final density, strength, creep resistance, fracture toughness, oxidation, and wear resistance. Such results are based on proper indepth knowledge of processing parameters and techniques. Numerous examples have been presented in this article of new combinations of materials and process techniques.

The interested reader is referred to the Selected Bibliography (Appendix B) for additional information.

REFERENCES

1. S. Skogun, ASEA Metallurgy, AB, and H. Larker, ASEA Cerama, AB (private communication) Feb 1986.
2. T. Shimamori, H. Matsuzaki, T. Kato, Y. Tajima, and Y. Matsuo, "High temperature properties of post sintered silicon nitride," in *Proceedings of the Second International Symposium, Ceramic Materials and Components for Engines*, Lubeck-Travemunde, FRG, April 1986.
3. T. Yamada, M. Shimada, and M. Koizumi, "Densification of Si_3N_4 by high pressure-hot-pressing," *Am. Ceram. Soc. Bull.* **60**(12), 1281-88 (1981).

4. H. Okuda, K. Homma, J. Miyanaga, and M. Moritoki, "Densification of Si_3N_4 by HIP with no additives," from *Collected Abstracts of the Annual Meeting of the Ceramic Society of Japan*, Tokyo, 435-36 (1984).
5. Y. Miyamoto, K. Tanaka, M. Shimada, and M. Koizumi, "Survey for HIP sintering condition and characterization of dense silicon nitride without additives," in *Proceedings of the Second International Symposium, Ceramic Materials and Components for Engines*, Lubeck-Travemunde, FRG, April 1986.
6. K. Takatori, S. Kobayashi, and S. Wada, "Strength and fracture toughness of silicon nitride applying direct HIP," Japan Ceramics Society 25th Basic Sciences Forum, January 1987 (in Japanese).
7. K. Yoshida, K. Nezuka, K. Miyamoto, and M. Koizumi, "Various characteristics of Si_3N_4 sinter prepared by HIP process without additives," Japan Ceramics Society 25th Basic Sciences Forum, January 1987 (in Japanese).
8. K. Suzuki, N. Kageyama, K. Furukawa, and T. Kanno, "Oxidation of sintered silicon carbide with addition of aluminum oxide," in *Proceedings of the Second International Symposium, Ceramic Materials and Components for Engines*, Lubeck-Travemunde, FRG, April 1986.
9. M. Shimada, "Sintering of high strength partially stabilized zirconia and improvement of its thermal stability," in *Proceedings of the International Symposium on Fine Ceramics*, Vol 1, Arita, Japan, November 1986.
10. D.W. Shin, H. Schubert, G. Petzow, K.K. Orr, and C.K. Lee, "Microstructural development of Al_2O_3 and $\text{Al}_2\text{O}_3\text{-ZrO}_2$ in post-HIP treatment," in *Proceedings of the Second International Symposium, Ceramic Materials and Components for Engines*, Lubeck-Travemunde, FRG, April 1986.
11. H. Kuribayashi, K. Suganuma, Y. Miyamoto, and M. Koizumi, "Effects of HIP treatment on plasma-sprayed ceramic coating onto stainless steel," *Am. Ceram. Soc. Bull.* 65(9), 1306-10 (1986).
12. Y. Takano, S. Ohmura, K. Miyamoto, M. Koizumi, K. Motoyoshi, and M. Masaya, "Preparation of TiB-Ti composite, sintered by self-combustion under HIP," Japan Ceramics Society 25th Basic Sciences Forum, January 1987 (in Japanese).
13. S. Kobayashi and S. Wada, "Strengthening of Si_3N_4 ceramics with ZrO_2 addition," in *Extended Abstracts, The Third International Conference on the Science and Technology of Zirconia*, Ceramic Society of Japan, 9-11 September 1986.
14. T. Masaki and K. Sinjo, "Mechanical properties of high toughened $\text{ZrO}_2\text{-Y}_2\text{O}_3$ ceramics," in *Extended Abstracts, The Third International Conference on the Science and Technology of Zirconia*, Ceramic Society of Japan, 9-11 September 1986.
15. T. Takahata, K. Taukuma, M. Shiomi, and T. Tsukidate, "Strength and toughness of Y-TZP, Ce-TZP, and TZP/ Al_2O_3 composites," in *Extended Abstracts, The Third International Conference on the Science and Technology of Zirconia*, Ceramic Society of Japan, 9-11 September 1986.

16. E. Yasuda, S. Kimura, Y. Katano, and Y. Akimune, "Mechanical properties of SiC whisker reinforced PSZ," in *Extended Abstracts, The Third International Conference on the Science and Technology of Zirconia*, Ceramic Society of Japan, 9-11 September 1986.

17. K. Nakajima and T. Masaki, "High temperature mechanical properties of Y-PSZ HIPed under oxygen containing atmosphere," in *Extended Abstracts, The Third International Conference on the Science and Technology of Zirconia*, Ceramic Society of Japan, 9-11 September 1986.

18. E.S. Chen, "First International Workshop on Mullite: New developments for an old material," *Scientific Bulletin* 12(4), 48-50 (1987).

19. L. Hermansson et al., "Strength controlling defects in HIP silicon nitride," *Revue de Chimie Mineral*, 1985.

Edward Mark Lenoe, on leave from the Army Materials and Mechanics Research Center, joined the staff of ONRFE/AFOSRFE/AROFE in October 1985. Previously he 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. He completed a 2-year ONR assignment on structural ceramics. Now he is on an ARO assignment. His studies for ARO will be devoted to advanced materials and relevant emerging technologies. Dr. Lenoe is the author of more than 120 publications and has edited four technical books.

Appendix A

SEVENTH KOBELCO SEMINAR

Recently I attended the Seventh HIP Seminar Program sponsored by KOBELCO at the Kobe International Conference Center. There were over 300 attendees and 15 presentations during this symposium. Two presentations were in English and the others were in Japanese.

After the opening remarks, Professor M. Koizumi reviewed the June 1987 international conference, which was held in Lulea, Sweden. He outlined the presentations of that meeting and briefly gave selected highlights, including reported results on sialons; HIP developments in other advanced ceramics, metals, and alloys; and the analytical modeling of the HIP process.

T. Mihara of Kubota Ltd. described his company's activities in hot isostatic pressing of machine parts. These activities included evaluations of some metal matrix composites, which showed a sevenfold reduction in wear rates compared to unreinforced matrix material. Professor Ichinose (Waseda University) reviewed superconducting materials development. He cited the challenges to the materials community as: developing improved density, shaping and forming techniques, and microstructural design techniques for enhanced high field performance; increasing fracture resistance; and understanding the role of grain boundaries. He presented some data that indicated that specimen polishing caused a slight reduction in T_c (96.8 to 95) in his samples. He stated that replacing barium with strontium had not proven effective in his studies.

A. Fujiwara discussed powder preparation and manufacturing techniques, describing various approaches for atomizing and combining powders and mixing techniques for additives. He presented data for aluminum and titanium and various alloys. Afterwards Professor R. Hayashi of Kyoto University gave a most interesting lecture on high pressure phenomena applied to manufacture and storage of foods. He presented a variety of results for different organic materials. Under room temperature and pressures ranging from 1,000 to 10,000 psi, germs and viruses are destroyed while taste and vitamin contents generally are unaffected. Most covalent bonds in proteins are unchanged by pressure. He indicated very few people are studying life sciences under high pressure environments.

Mr. Nakagawa (KSL) gave an in-depth lecture about numerical modeling of the cold isostatic pressing (CIP) process. Efforts were motivated by recurrent failures in preparing powder compacts. KOBELCO markets an Apollo workstation (¥4 million to ¥5 million) that has an interactive version of the CIP model. A fairly conventional set of constitutive equations and failure theories is used in the simulation. To avoid powder compact failures, special rubber molds are designed, based on calculated deformations of the compact. Basically the mold geometry is changed to minimize distortion during cold isostatic pressing; essentially the mold is an inverse of the calculated deformations.

Professor K. Ishizaki, from the Technological University of Nagaoka, discussed the effects of Si_3N_4 particle size in HIP sintering. His main theme was the lack of understanding of the sintering cycle. Using recently acquired HIP equipment, he is attempting to obtain detailed data on the actual sintering environment and develop analytical models.

Dr. Rickinson, from the United Kingdom, reviewed the metal casting area, with emphasis on the role of hot isostatic pressing. Y. Narukawa and T. Naoi reported on the latest HIP and CIP equipment. Dr. T. Fujikawa described his research on oxygen atmosphere effects in hot isostatic pressing, particularly in superconducting materials. Y. Fuda (Tohoku Kinzoku Ltd.) gave a lecture on laminated, stacked, and HIPed piezo actuators.

Dr. K. Koga described Kyocera's efforts on HIP sintering of silicon carbide. He described microstructural changes and presented mechanical and tribological data for various CIP and HIP processing parameters, showing substantial improvements in properties and results competitive with the highest reported strength measurements.

The concluding paper, given by Dr. S. Wada of Toyota Central Laboratory, dealt with direct HIP sintering of silicon carbide. Dr. Wada stated: "We are a little bit behind Europe," and then proceeded to give a comprehensive summary of Toyota achievements in producing silicon nitride, including silicon nitride reinforced with four types of SiC whiskers. He concluded that both SiC and Si_3N_4 , produced via HIP sintering, without additives, can meet current engine requirements.

Appendix B

SELECTED BIBLIOGRAPHY

Bigay, Y., B. Cales, and J.P. Torre (1986), "Processing and properties of zirconia (Y-TZP) large parts for engine applications," in *Extended Abstracts, The Third International Conference on the Science and Technology of Zirconia*, Ceramic Society of Japan, 9-11 September.

Claussen, N., and E. Lutz (1987), "Microstructural design of oxide ceramic composites for high-thermal shock resistance," in *Proceedings of the International Symposium on Fine Ceramics Arita '87*, Arita, Japan, November.

Dutta, S. (1987), "A comparative study of sintering, HIPing and sinter-HIPing processes on densification, microstructure, and strength of silicon carbide," paper presented at Sintering '87, Tokyo, '87 International Symposium and Exhibition on Science and Technology of Sintering, Tokyo, Japan, 4-6 November.

Easterling, K.E. (1987), "Hot isostatic pressing of metallic and ceramic powders," paper presented at Sintering '87, Tokyo, '87 International Symposium and Exhibition on Science and Technology of Sintering, Tokyo, Japan, 4-6 November.

Galasso, F.S., and R.D. Veltri (1979), "Sintering of Si_3N_4 -15 Y_2O_3 under high N_2 pressure," *Am. Ceram. Soc. Bull.* 58(8), 793-94.

Gazza, G.E., R.N. Katz, and H.F. Priest (1981), "Densification of Si_3N_4 - Y_2O_3 / Al_2O_3 by a dual pressure process," *J. Am. Ceram. Soc.* 64(11), C-161-62.

Greskovich, C. (1981), "Preparation of high density Si_3N_4 by a gas-pressure sintering process," *J. Am. Ceram. Soc.* 64(12), 725-30.

Horiuchi, Y., I. Yabuguchi, and Y. Nakamura (1988), "Post-HIPing of Si_3N_4 ," paper presented at the 26th Symposium of Basic Science of Ceramics, Nagoya, Japan, 20-22 January.

Ichikizaki, T., K. Hori, T. Masaki, and T. Tonomura (1987), "Oxygen containing HIPing apparatus and technology," paper presented at Sintering '87, Tokyo, '87 International Symposium and Exhibition on Science and Technology of Sintering, Tokyo, Japan, 4-6 November.

Komatsu, M., T. Kameda, Y. Goto, and K. Komeya (1988), "Effect of some additives on sintering of Si_3N_4 - Y_2O_3 base ceramics," paper presented at the 26th Symposium of Basic Science of Ceramics, Nagoya, Japan, 20-22 January.

Matsuoka, M., Y. Miyamoto, M. Shimada, and M. Koizumi (1986), "Study on the densification of Y_2O_3 -PSZ by HIPing," in *Extended Abstracts, The Third International Conference on the Science and Technology of Zirconia*, Ceramic Society of Japan, 9-11 September.

Mitomo, M. (1977), "The sintering of silicon nitride under high nitrogen pressures," in *Proceedings of the International Symposium on Factors in Densification and Sintering of Oxide and Non-Oxide Ceramics*, Hakone, 539-44.

Murayama, N., S. Sakaguchi, and F. Wakai (1988), "Impact strength of silicon nitride at elevated temperatures," paper presented at the 26th Symposium of Basic Science of Ceramics, Nagoya, Japan, 20-22 January.

Niihara, K., S. Inoue, T. Uchiyama, and T. Hirai (1986), "Preparation, microstructure and mechanical properties of $\text{Al}_2\text{O}_3/\text{ZrO}_2$ SiC whisker composites," in *Extended Abstracts, The Third International Conference on the Science and Technology of Zirconia*, Ceramic Society of Japan, 9-11 September.

Nishio, H., A. Miyamoto, and K. Fukaya (1987), "HIP technology at Nippon Kokan," paper presented at Sintering '87, Tokyo, '87 International Symposium and Exhibition on Science and Technology of Sintering, Tokyo, Japan, 4-6 November.

Nohara, A., T. Nakagawa, and T. Soh (1987), "Numerical simulation of the densification behavior of metal powder during hot isostatic pressing," paper presented at Sintering '87, Tokyo, '87 International Symposium and Exhibition of Science and Technology of Sintering, Tokyo, Japan, 4-6 November.

Ohji, T., S. Sakai, M. Ito, Y. Yamauchi, W. Kanematsu, and S. Ito (1987), "Tensile strength properties of sintered silicon nitride," paper presented at Sintering '87, Tokyo, '87 International Symposium and Exhibition on Science and Technology of Sintering, Tokyo, Japan, 4-6 November.

Ohnuma, Y., H. Inoue, and A. Tsuge (1988), "Effects of sintering aids addition by sol-gel method," paper presented at the 26th Symposium of Basic Science of Ceramics, Nagoya, Japan, 20-22 January.

Priest, A.F., G.L. Priest, and G.E. Gazza (1977), "Sintering of silicon nitride under high nitrogen pressure," *J. Am. Ceram. Soc.* **60**(1-2), 81.

Rossi, G.A. (1986), " Y_2O_3 -doped ZrO_2 powder prepared in non-aqueous medium, Effect of powder crystallization method on sinterability and properties of Y-TZP ceramics," in *Extended Abstracts, The Third International Conference on the Science and Technology of Zirconia*, Ceramic Society of Japan, 9-11 September.

Sakuma, T., H. Eda, and H. Suto (1986), "Composition optimization of Y-PSZ for improving the fracture toughness," in *Extended Abstracts, The Third International Conference on the Science and Technology of Zirconia*, Ceramic Society of Japan, 9-11 September.

Sanders, W.A., and D.M. Mieskowski (1985), "Strength and microstructure of sintered Si_3N_4 with rare-earth-oxide additions," Am. Ceram. Soc. Bull. **94**(2), 304-9.

Tani, E., M. Nishijima, H. Ichinose, K. Kishi, and S. Umebayashi (1986), "Gas pressure sintering of Si_3N_4 with an oxide addition," *Yogyo-Kyokaishi* **94**(2), 300-5.

Tani, E., S. Umebayashi, K. Kishi, K. Kobayashi, and M. Nishijima, (1986), "Gas-pressure sintering of Si_3N_4 with concurrent addition of Al_2O_3 and 5 wt. % rare earth oxide: High fracture toughness Si_3N_4 with fiber-like structure," Am. Ceram. Bull. **65**(9), 1311-15.

Tatsuno, T., and T. Fujikawa (1987), "Properties of HIPed Si_3N_4 without additives," paper presented at Sintering '87, Tokyo, '87 International Symposium and Exhibition on Science and Technology of Sintering, Tokyo, Japan, 4-6 November.

Uematsu, K., K. Itakura, N. Uchida, A. Miyamoto, and T. Miyashita (1987), "Analysis of hot isostatic pressing - Alumina as a model material," paper presented at Sintering '87, Tokyo, '87 International Symposium and Exhibition on Science and Technology of Sintering, Tokyo, Japan, 4-6 November.

MEGAGAUSS MAGNETIC FIELD FACILITIES AND RESEARCH IN JAPAN

Dean L. Mitchell

Facilities for research in steady-state magnetic fields to 30 T now are available at laboratories in the United States, Japan, and Europe. Significantly higher dc fields for research are not expected in the near future. Pulsed-field facilities have been developed in a number of laboratories with peak fields extending upwards from 40 to 250 T for pulse times ranging from seconds to nanoseconds. The following is a summary of a survey of Japanese high magnetic field facilities, instrumentation, and research opportunities for the megagauss regime, i.e., fields in excess of 50 T.

INTRODUCTION

Modern developments in magnetism and magnetic field research owe their origins to the discovery by Oersted in 1820 that electrical currents generate magnetic forces indistinguishable from those associated with permanent magnets. Subsequent explorations of the origins of this equivalence have led to remarkable advances both in the generation and control of magnetic fields, in the use of laboratory fields to probe the microscopic properties of matter, and in applications to technology. During the present century, such investigations have yielded a dozen Nobel prizes beginning with the 1902 award in physics to H. Lorentz and P. Zeeman for their work on the influence of magnetic fields on atomic spectra and extending through to the 1985

physics award to K. von Klitzing for discovery of the quantum Hall effect. It is worth noting that both those investigations required high fields at the limits of then current dc magnet technology, i.e., 1 T for the Zeeman effect and 30 T for the quantum Hall effect.

Research in high magnetic fields was reviewed by the Solid State Sciences Committee of the National Research Council (NRC) in 1979. The published report (Ref 1) gives broad coverage of the magnet technology and current status of high magnetic field facilities in the United States and abroad and of scientific opportunities and technological applications. The report concluded that there were significant opportunities for advances and recommended major projects to provide laboratory facilities for quasi-static fields up to 1 megagauss (MG) (100 T) and short-pulse fields extending to 10 MG (1,000 T). These goals, while recognized as optimistic, were put forth by the panel in recognition of the importance of high field research to investigations of the properties of matter.

Recent developments in high magnetic field research support the vision of the Solid State Sciences Panel almost a decade ago. High field phenomena in low dimensional electronic systems have been discovered with high field thresholds extending beyond the range accessible with dc fields. These include the quantum Hall effect (Ref 2) and fractional quantum Hall effect (Ref 3) in semiconductor inversion

layers and quantum well devices, as well as a variety of field-induced electronic phase transitions observed in low dimensional conductors such as graphite (Ref 4), niobium tri-selenide (Ref 5), and organic charge transfer salts (Ref 6). Also, new materials systems under development require higher fields to characterize electronic and magnetic properties. These include the recently discovered heavy fermion superconductors (Ref 7) and hard magnetic materials based on rare-earth ion borides (Ref 8). Subsequent to the NRC study, the Major Materials Facilities Committee of the NRC reviewed the broader requirements for large facilities in materials research and related disciplines in 1984 (Ref 9). Improved capabilities for high magnetic field research were recommended, with new and upgraded facilities for synchrotron radiation and neutron scattering research as priorities during the next decade.

The scientific imperative for developing higher field research magnets has been reinforced dramatically by the recent discovery of new high temperature superconducting ceramic materials. Following the initial report of possible superconductivity at 35 K for Ba-La-Cu-O perovskite systems in 1986 (Ref 10), there has been an unprecedented rapid advance in the discovery of new materials with critical temperatures (Ref 11) and inferred upper critical fields increasing apace ($T_c > 90$ K and $H_{c2} > 100$ T). The rate-of-progress has indeed been so rapid as to outstrip the ability of normal publication channels to respond as exemplified by the New York Times report of the special session held at the American Physics Society Meeting at New York in March 1987.

The chaotic status of the field, at the present time, precludes a considered assessment of the impact of the new superconducting materials on high magnetic field facilities and research. The implications are profound both in terms of the long-range potential for high field magnets and in terms of the immediacy of the need for higher field research magnets to investigate the properties and phenomenology of these new material systems.

The status of high field facilities in the United States has not changed significantly since the time of the 1979 NRC report. Superconducting magnets are commercially available for fields up to about 15 T for research in individual laboratories. Steady-state fields to 17 T are available for research at the Naval Research Laboratory and to somewhat above 20 T at the Francis Bitter National Magnet Laboratory (FBNML) using Bitter-type resistive magnets. Higher dc fields, 30 T, are available at FBNML using a hybrid Bitter-superconductor magnet system. The design and construction of dc magnets for fields much above 30 T face increasingly severe thermal and mechanical constraints; fields above 50 T are not likely in the next decade.

Pulsed techniques using capacitive energy storage have been used in the United States to generate peak fields up to 70 T nondestructively (Ref 12, 13) and to above 1 MG (100 T) with coil destruction (Ref 14). Although techniques for generating pulsed fields above 50 T are well established, laboratory facilities for general research use in the United States are lacking. At present, FBNML provides user access to pulsed fields extending to 45 T with plans to extend the range to 60 to 70 T in the near future.

Peak fields in the multimegagauss regime have been produced in several U.S. laboratories, notably Los Alamos National Laboratory (LANL) (Ref 15), Lawrence Livermore Laboratory (Ref 16), and Sandia National Laboratories (Ref 17), using implosive flux compression and pulsed-power techniques. However, the scale and complexity of those field generation techniques obviate their routine use for small-scale laboratory experiments.

While the United States has remained relatively static for the last decade in developing higher field user facilities, laboratories in Japan have moved forward. The High Field Laboratory for Superconducting Materials at Sendai has several hybrid magnets with peak fields in the range 20 to 30 T. Facilities with pulsed fields in the range of 40 to 50 T are located at Sendai and Tokyo. The only laboratories presently operating above 50 T for small-scale laboratory experiments are in Japan. The high field laboratory at Osaka University can generate fields for research in excess of 60 T using nondestructive coils. The laboratory at the Institute for Solid State Physics (ISSP) in Tokyo can produce fields in excess of 2 MG (200 T) for experiments in which the coil is destroyed but the sample chamber is preserved. To date, only limited experiments have been carried out at fields above 1,000 T, mainly directed to measurement of the magnitude of the field.

It is now clear that order-of-magnitude increases in dc fields produced in the laboratory are not likely. Material constraints and practical power considerations indicate that factor-of-two increases over 30 T are the most that may be expected in the foreseeable future. For the most part,

the magnet facilities that have been developed for research applications in the megagauss regime have relied on the use of field coils driven by capacitive power supplies. This approach has obvious advantages in terms of simplicity, adaptability, and reliance on well-developed pulsed-power technologies. The experience at the ISSP in Tokyo indicates that this is a practical approach for peak fields up to at least 250 T.

Scaling arguments suggest that somewhat higher fields may be obtained by using field coils driven by other types of fast-discharge power supplies with pulse times shorter than those attainable with capacitor discharge. Experiments to demonstrate the feasibility of this approach have been carried out at the Institute of Laser Engineering (ILE) at Osaka. A focussed beam from the Gekko VIII CO₂ laser was used to produce a plasma rich in energetic electrons ($E > 5$ keV) which, in turn, provided a nanosecond current pulse to a 1-mm-diameter cylindrical coil. Peak fields of the order of 400 T, as measured by pick-up coils, were reported in experiments to date (Ref 18).

CURRENT STATUS: FACILITIES AND RESEARCH

dc Field Facilities and Research

Steady-state fields continue to be the choice for the majority of users involved in high magnetic field research. Superconducting magnets are available commercially for fields up to 15 T and are in wide use. The upper limit for laboratory superconducting magnets currently is 17.6 T. Steady-state fields in excess of 30 T are

available at the Francis Bitter National Magnet Laboratory (FBNML) at MIT and the High Field Laboratory for Superconducting Research at Tohoku University. The hybrid magnets used in the United States and abroad to generate 30-T fields consist of an inner resistive magnet, driven by a 5- to 10-MW power supply, and an outer superconducting coil operating at cryogenic temperatures. Maximum dc fields for hybrid magnets are subject to material limits and available power supplies. Significant increases (factor 2) in dc field strengths are not expected unless new superconducting materials become available with higher upper critical fields than for current commercial superconductors. The very recent discovery of copper-oxide-based ceramic materials with transition temperatures of the order of 100 K and inferred upper critical fields above 100 T may indeed make such a quantum step feasible in the future. In the interim, however, pulsed fields will likely be in even higher demand for studies of these materials in fields to 100 T and above.

Research in fields to 30 T is extremely broad based and multidisciplinary. Some of the topical areas with strong interest and activity are summarized in Table 1.

Pulsed-Field Facilities and Research

For many research applications, small-scale pulsed magnets with millisecond pulse times offer a convenient and inexpensive alternative to dc magnets for fields to 30 to 40 T. Cooled copper coils operate safely and reliably and require modest capacitive power supplies. Many

laboratories have built small magnets for magnetotransport and magneto-optical experiments to avoid moving experiments to larger scale dc facilities. Commercial magnet systems have been developed by Maxwell Laboratories under the trade name Magneform for industrial applications such as impact welding, metal swaging, and assembly of metal to nonmetal joints. An experimental unit, using a proprietary coil design, has been operated successfully at 70 T with microsecond pulse times without coil destruction (Ref 13). The Magneform magnet systems would require minimal modification for use as research magnets.

The generation of peak fields above 60 T with pulse times longer than milliseconds or above 40 T with pulse times longer than tenths of seconds requires facilities on a scale not practical for individual research projects. To meet this demand, pulsed-field facilities have been developed in a number of laboratories world wide for multipurpose experiments. A profile of typical peak field values and pulse times at the major Japanese centers is shown in Figure 1. Peak fields range from 40 to 400 T, pulse times from seconds to nanoseconds, and experimental volumes from several cubic centimeters to cubic millimeters or less. All of the centers except the Institute of Laser Engineering at Osaka have active research programs to use the facilities. The ILE datum (point 4) represents initial experiments using a new type of pulsed-power supply and is included to indicate a potential extension of the peak-field/pulse-time regime for coil-generated fields beyond the range accessible by capacitive power supplies.

Table 1. Some Current High Field Studies of Solids

Topics	Systems
Localization/Delocalization	Spin Glasses Amorphous Alloys
Low-Dimensional Conductivity (Quantum Hall Effect)	Inversion Layers Heterostructures
High Temperature/High Field Superconductivity	Rare-Earth/Copper-Oxide Ceramics Heavy Fermions
Electronic Phase Transitions	Organic Conductors Charge-Density-Wave Materials
Magnetic Properties and Phase Transitions	Rare-Earth/Iron Permanent Magnets Actinide/Rare-Earth Compounds

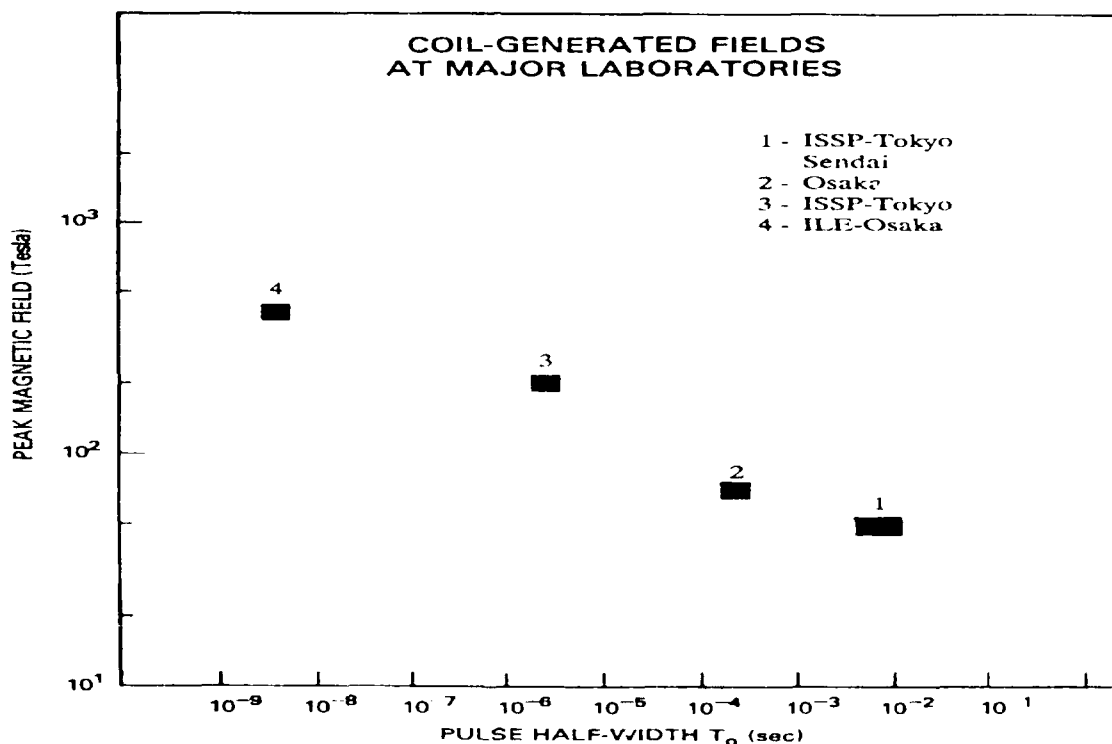


Figure 1. Representative values for the peak magnetic fields generated by field coils at major high field laboratories in Japan are shown together with corresponding values for the pulse times. The pulse half-width T_0 is taken to be the rise time to peak for capacitor driven coils. The peak fields and pulse times are typical of values reported for experiments carried out in pulsed fields except for the box listed for the Institute of Laser Engineering at Osaka. This datum, box 4, is included to indicate the potential extension of laboratory fields with ultra-short pulse times.

High Magnetic Field Laboratory, Osaka University

The high field laboratory at Osaka University (under the direction of Professor Muneyuki Date) has evolved over the past decade to rank as a major international center for pulsed-field research. Currently, fields up to 60 T (routinely) or 80 T (occasionally) are available for experiments with pulse times on the order of a millisecond. The fields are generated by capacitor discharge (1.25 MJ) through compound magnets consisting of concentric helical coils machined from maraging steel. Each of the mechanically independent coils is designed to operate near the stress limit for steel, which is considerably larger than that for copper-based conductors. Two helices are required to generate 80 T; three or more would be required for 100 T.

The laboratory is well instrumented for transport, magnetization, and magneto-optical experiments in pulsed magnetic fields. The techniques and instrumentation for high field magnetization experiments are particularly well advanced. They have been used to study magnetic interactions and magnetic phase transitions in a field range not otherwise accessible.

In addition to the extensive studies of magnetic phase transitions and high-order exchange interactions, the Osaka group and collaborators from other laboratories in Japan and abroad have used the pulsed-field facility for a variety of magnetotransport and magneto-optical experiments including the Zeeman effect for excitons in layer-type semiconductors, the Paschen-Bach effect in atomic sodium, and magnetic birefringence in liquid organics. An example is shown in Figure 2, which

gives the upper critical fields for superconductivity in the Chevrel phase system $\text{Pb}_{1-2x}\text{Eu}_x\text{Mo}_6\text{S}_8$ (Ref 19). These upper critical fields are among the highest reported to date and are considerably in excess of those for commercial superconductors.

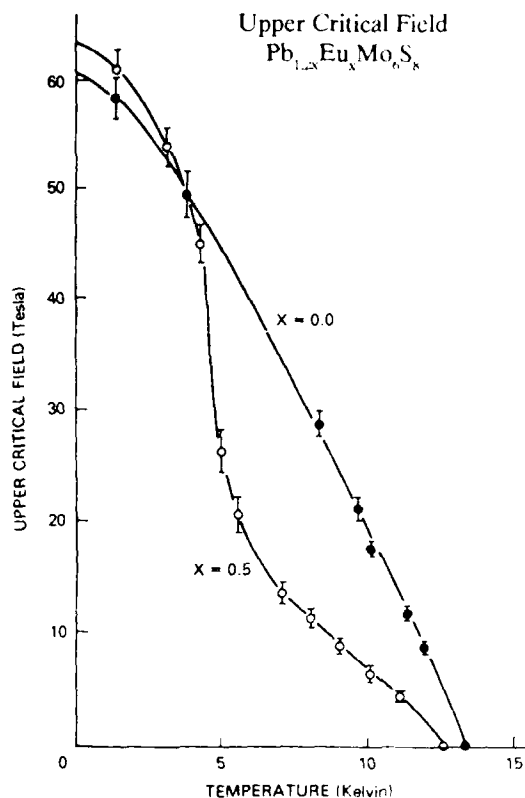


Figure 2. The upper critical field for the Chevrel phase compounds and alloys $\text{Pb}_{1-2x}\text{Eu}_x\text{Mo}_6\text{S}_8$ is shown for two alloy compositions over the temperature range from 1.2 K to the critical temperature. The values for H_{c2} were obtained from resistance measurements carried out in pulsed fields extending to 65 T. The shape of the curve for $x = 0.5$ is presumed due to the presence of mixed metallurgical phases (after Ref 19).

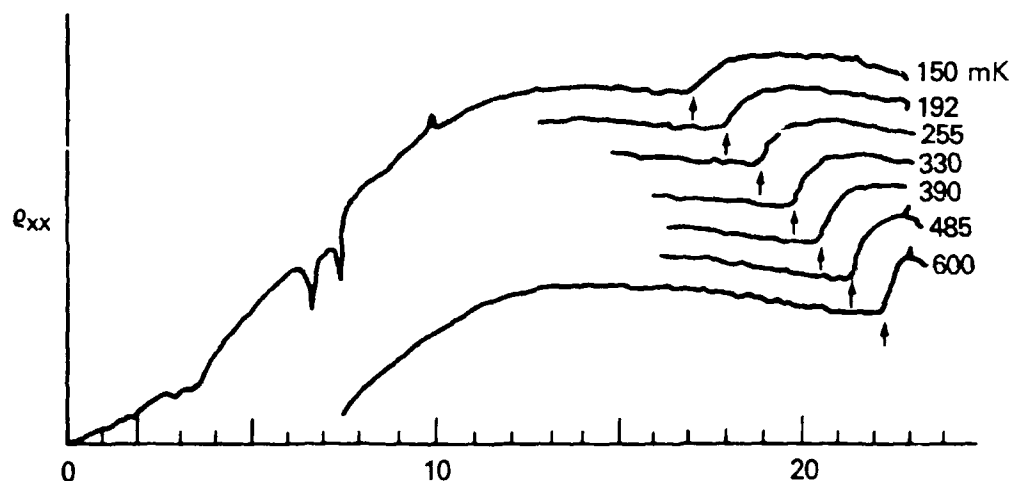
**Ultra-High Magnetic Field Laboratory,
Institute of Solid State Physics,
University of Tokyo**

The Institute of Solid State Physics (ISSP) in Tokyo, under the direction of Professor Noboru Miura, recently has focussed its efforts on development of techniques and facilities for research on matter under extreme conditions, such as micro-Kelvin temperatures, megabar pressures, and megagauss magnetic fields. Beginning in 1979, the high magnetic field facility has undergone a major upgrade including a new laboratory building and enhanced power supplies. The laboratory currently has three types of pulsed fields available for research:

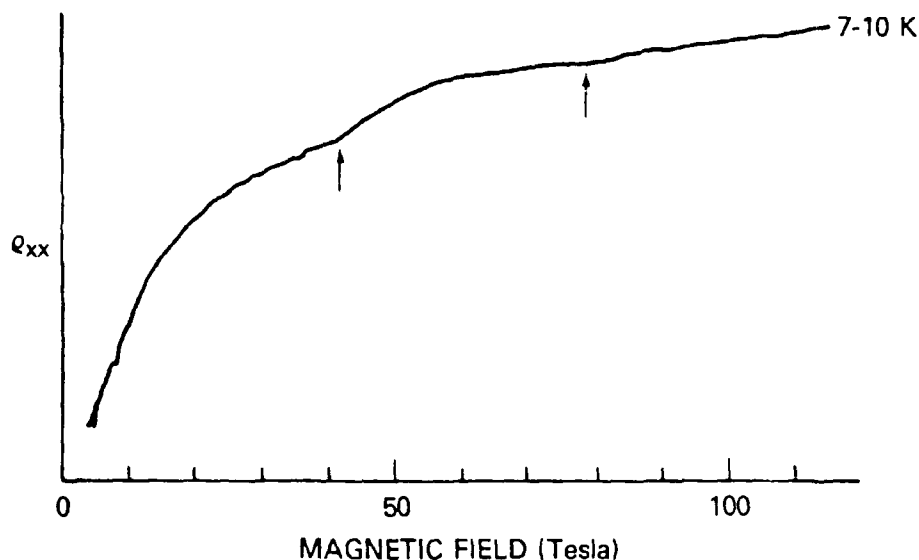
- Pulsed fields to 45 T are produced on a 10-ms time scale using multiturn copper coils precooled to 77 K. Capacitor banks of 200 kJ (5/10 kV) and 112 kJ (4 kV) are available to drive the coils.
- Pulsed fields to about 250 T on a micro-second time scale are generated by direct discharge of a 100-kJ (40-kV) fast capacitor bank into inertially stabilized, single-turn coils. The coil is destroyed; the sample chamber, however, is usually unharmed.
- Electromagnetic flux compression also is used to generate fields in excess of 200 T for experiments using a 1.5-MJ (10-kV) capacitor bank for the seed field and a 5-MJ (40-kV) bank for the drive field. Development efforts are underway to extend the peak field to 500 to 1,000 T, although to date fields have been limited to about 250 T.

The laboratory is well equipped with x-ray flash cameras, lasers, streak cameras, and fast data acquisition systems to permit precision transport and optical experiments to be carried out over a wide range of experimental conditions. The development of cryogenic techniques for low temperature experiments approaching 4 K and the use of fiber optic data links are particularly noteworthy.

The range of capabilities at ISSP gives the laboratory a unique status among high field laboratories. These capabilities are being used for a variety of solid state experiments including magneto-optical spectroscopy, cyclotron resonance, Faraday rotation, magnetic phase transitions, and magnetotransport. Topics of current interest include: field-induced electronic phase transitions in semimetals such as bismuth, graphite, and graphite intercalation compounds; electronic states and magneto-transport in two-dimensional electron systems as in semiconductor superlattices and quantum well structures; excitons in layer-type crystals; magnetic semiconductors; ferrimagnetic resonance; and high field magnetism and magnetic phase transitions. Figure 3 gives an example of pulsed-field measurements of the magnetoresistance of single crystal graphite in fields extending above 100 T. The transition at 40 T is believed to be a field-induced electronic phase transition that also has been observed at FBNML at lower fields and lower temperatures; the transition at 80 T has been tentatively identified as an electronic phase transition resulting from the crossing of Landau subbands.



(a) Temperatures in the range of 150 to 600 mK. These data were obtained at the Francis Bitter National Magnet Laboratory (FBNML) using steady-state fields. The breaks, indicated by arrows, are believed due to the onset of magnetic-field-induced electronic phase transitions (after Ref 20).



(b) Data at the higher fields and temperatures obtained using the electromagnetic flux compression facility at the Institute of Solid State Physics (ISSP). The break at 41 T is in line with the break observed at lower fields and temperatures at FBNML. The break at 71 T, observed at ISSP, was attributed to an electronic phase transition resulting from the crossing of Landau subbands (after Ref 21).

Figure 3. The measured values for the transverse magnetoresistance of single crystal graphite.

FUTURE OPPORTUNITIES

In the past, research in megagauss magnetic fields has been hampered by the lack of magnets that could provide reliable and convenient operation for research applications. The technologies required to construct research magnets for fields to 250 T are now well established. Less well established are the techniques and instrumentation required for experiments in the small volumes and on the short time scales available with the highest fields. Recent developments in advanced synthesis and microfabrication techniques as well as advances in instrumental systems for fast experiments on small-scale samples now make it possible to consider experiments not feasible a decade ago. The combined developments in magnet technology and experimental instrumentation provide significant new opportunities for research in the megagauss regime.

At present, the facilities for pulsed magnetic field research with the highest peak fields in given pulse-time regimes are located mainly outside the United States. Fields above 40 T, on shorter time scales, are attained with capacitor-driven coils constructed with strong conductors: 80 T with submillisecond duration at the University of Osaka using maraging steel polyheli-ces and 68 T with 5-ms duration at the Francis Bitter National Magnet Laboratory using Cu:Nb filamentary wire.

There is a strong demand for increased fields with pulse times of milliseconds and longer. Research on advanced semiconducting and metallic materials in dc fields to 30 T has revealed a variety of new phenomena in electronic systems of

reduced dimensionality that have threshold fields above 30 T. Similarly, new classes of magnetic and superconducting materials require higher fields to explore phase boundaries and to probe the interplay of magnetism and superconductivity in the ground-state properties. Ideally, large samples with long equilibration times are required for studies of ground-state properties. Hence, there is a strong existing experimental demand for higher fields with pulse times as long as possible.

The major impediments to development of higher field magnets, e.g., 60 T, with pulse times approaching 1 second are the costs of acquiring the power supply and the engineering development required to construct massive coils capable of withstanding the combined thermal and mechanical stresses generated at the higher fields. Estimates based on the feasibility calculations carried out at the University of Amsterdam for copper-beryllium reinforced copper wire indicate that such a magnet would require a 200-kg coil with a power supply capable of providing 15-MJ stored energy in the field plus resistive losses. Using controlled rectification, it is estimated that a peak power of 130 MW rms would be required.

The size of the power supply required for a magnet facility in the 1-second domain together with the extensive engineering development required for the magnet coils and cryogenic systems indicate that a project on the national scale would be needed to build and operate such a facility. If, however, parasitic access to a major power grid were possible, then such a magnet would be feasible to consider as a laboratory facility.

Scaling arguments and the experience of the existing pulsed-field laboratories indicate that it will be difficult or impossible to construct reusable magnets capable of producing peak fields higher than 80 to 100 T with pulse times longer than a millisecond. The generation of much higher fields, therefore, requires some form of inertial confinement of the flux as with single-turn coils or with flux compression devices using metal or plasma liners. Laboratory scale facilities have been built at the Institute of Solid State Physics in Tokyo that are capable of producing fields to 250 T suitable for small-scale experiments on microsecond time scales. Modest power supplies are needed; at the ISSP, a 100-kJ capacitor bank is used to drive single-turn coils with dimensions on the scale of centimeters. Somewhat higher fields, 500 to 1,000 T, should be possible with inertially stabilized coils, albeit with smaller volumes and shorter pulse times.

The exploitation of megagauss fields for laboratory experiments on solid state and condensed matter systems has been hampered by the short time scales and small volumes inherent to inertially established fields. However, the attainment of conveniently accessible fields an order-of-magnitude larger than dc fields opens a new regime to investigation that is relatively unexplored.

One area of application involves quasi-static experiments to measure the equilibrium electronic and magnetic properties of solid state systems that have threshold fields in the megagauss range. For such experiments, the short pulse times are an impediment. However, the adoption of advanced techniques and instrumentation

for microfabrication, fiber optics, fast data acquisition, pulsed lasers, and fast detectors can be expected to increase the number of possible experiments in megagauss fields. For example, incorporation of optical samples in fiber optic waveguides would allow experiments confined to transverse dimensions of a few microns. For such experiments, millimeter-sized magnet coils would be sufficient.

Another potential area of applications for small-scale megagauss magnets is in their use as pressure or shockwave transducers. Encapsulation of samples inside a conducting shell provides a way to generate megabar pressures within the sample with variability in the strain rate provided by the pulse time and shell configuration. Such transducers could have application to measurements of materials under combined conditions of high pressure and high strain rate that are not accessible by static pressure cells (diamond cell) or by standard shockwave techniques. Potential applications include measurements of high pressure equation-of-state of materials, synthesis of nonequilibrium materials, and processing of brittle materials.

The least explored and perhaps most interesting application of small-scale and short-pulse megagauss magnetic fields is in laser spectroscopy and photochemistry of atoms and molecules. Sample chambers are relatively unimportant, except to set initial conditions, since inertia is sufficient to confine gaseous or liquid samples in the beam for the duration of a single pulse. Thus such experiments should be feasible at much higher fields than may be possible for solid samples (500 to 1,000 T).

Present magnet technology provides the capability for construction of research magnets with peak fields of 250 T in centimeter volumes with microsecond pulse times. Such fields have only recently become available for experimentation on a routine basis. A natural question that arises whenever a new experimental capability becomes available is: what lies beyond? With dc and long-pulse magnets, factors-of-two increases in field are the most that may be expected. With inertially stabilized fields, the limits are not apparent.

The future development of research and research magnets in the megagauss regime appears to involve a conundrum in that increasing peak fields seem to require increasingly larger scale magnets. Static high pressure physics faced a similar conundrum that was partially resolved by adopting the philosophy "Think Small" (diamond cell). Perhaps high field research may benefit by the philosophy "Think Small-Measure Fast."

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REFERENCES

1. NRC Solid State Sciences Committee, *High-Magnetic Field Research and Facilities* (National Academy of Sciences, Washington, DC, 1979).
2. K. von Klitzing, G. Dorda, and M. Pepper, *Phys. Rev. Lett.* **45**, 494 (1980).
3. D.C. Tsui, H.L. Stormer, and A.C. Gossard, *Phys. Rev. Lett.* **48**, 1559 (1982).
4. S. Tanuma, Y. Onuki, R. Inada, A. Furakawa, O. Takahashi, and Y. Iye, *Physics in High Magnetic Fields*, edited by S. Chikazumi and N. Miura (Springer, New York, 1981), p. 316.
5. R.V. Coleman, G. Eiserman, M.P. Everson, A. Johnson, and L.M. Falicov, *Phys. Rev. Lett.* **55**, 863 (1985).
6. J.F. Kwak, J.E. Schirber, R.L. Greene, and E.M. Engeler, *Phys. Rev. Lett.* **46**, 1296 (1981).
7. G.R. Stewart, *Rev. Mod. Phys.* **56**, 755 (1984).
8. J.F. Herbst, J.J. Croat, F.E. Pinkerton, and W.B. Yelon, *Phys. Rev.* **B29**, 4176 (1984).

9. NRC Major Materials Facilities Committee, *Major Facilities for Materials Research and Related Disciplines* (National Academy of Sciences, Washington, DC, 1984).
 10. J.G. Bednorz and K.A. Muller, *Z. Phys.* **B64**, 189 (1986).
 11. C.W. Chu, P.H. Hox, R.L. Long, L. Gao, Z.J. Huang, and Y.O. Wang, *Phys. Rev. Lett.* **58**, 405 (1987); and R. Cava, R.B. vanDover, B. Batlogg, and E.A. Rietman, *Phys. Rev. Lett.* **58**, 408 (1987).
 12. S. Foner and H.H. Kolm, *Rev. Sci. Instrum.* **27**, 547 (1956).
 13. N.T. Olson, J. Baudas, and A.C. Kolb, *Megagauss Physics and Technology*: Proc. of the 2nd Internat. Conf. on Megagauss Magnetic Field Generation and Related Topics, Washington, DC, 1979 (Plenum Press, New York, 1980), p. 521.
 14. H.P. Furth and R.W. Waniek, *Rev. Sci. Instrum.* **22**, 195 (1956).
 15. C.M. Fowler, W.B. Garn, and R.S. Caird, *J. Appl. Phys.* **31**, 588 (1960).
 16. J.W. Shearer, *J. Phys.* **40**, 4490 (1969).
 17. R.B. Spielman, T.W. Hussey, and S.F. Lopez, Proc. of the 4th Internat. Conf. on Megagauss Magnetic Field Generation and Related Topics, Santa Fe, 14-17 July 1986. (In press)
 18. H. Daido, F. Miki, M. Fujita, K. Sawai, H. Fugita, Y. Kitagawa, S. Nakai, and C. Yamanaka, *Phys. Rev. Lett.* **56**, 846 (1986). [Also Institute of Laser Engineering Research Report OQD-86-7 (1986)]
 19. K. Okuda, S. Noguchi, M. Honda, K. Sugiyana, and M. Date, *High Field Magnetism*: Proc. of the Internat. Symposium on High Field Magnetism, Osaka (Japan), 1982, edited by M. Date (North-Holland, Amsterdam, 1983), p. 143.
 20. Y. Iye, L.E. McNeill, G. Dresselhaus, G.S. Boehinger, and P.M. Berglund, Proc. of the 17th Internat. Conf. on the Physics of Semiconductors, Kyoto, 1984 (Springer, New York, 1985), p. 981.
 21. N. Miura, T. Osada, and T. Goto, Proc. of the 17th Internat. Conf. on the Physics of Semiconductors, Kyoto, 1984, p. 973.
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SELF-ORGANIZING METHODS IN COMPUTER MODELING: RESEARCH AND APPLICATIONS IN JAPAN

Daniel O. Molnar

The Group Method of Data Handling (GMDH) algorithms are a form of artificial intelligence. This article describes the original GMDH algorithm, discusses the Japanese revision of GMDH, and compares the Japanese GMDH research with the efforts in the United States.

INTRODUCTION

Computer intelligence is a goal for Japan's next-generation computers. Artificial intelligence typically brings to mind exhaustive coding of an expert's decision logic. By contrast, what is of interest here is computer self-learning from some experiences (training data base). Given a set of data, regarded as a dependent variable, the task is to identify the independent variables upon which the data depend and to create a mathematical model of the dependence. Specifically, the Group Method of Data Handling (GMDH) (Ref 1 and 2) type algorithms and their derivatives are of interest; these algorithms are also in the category of artificial Neural network algorithms (Ref 3). The GMDH method of analysis without a model is versatile, easy to apply to different problems, and helpful for checking alternative hypotheses. Nonrelevant variables are automatically dropped from consideration.

Man can recognize clear patterns in two dimensions, and with difficulty sometimes in three dimensions. However, unlike man, the computer can recognize N-dimensional patterns. Frontiers of knowledge are becoming more complex because the more accessible areas have already been explored. These frontiers can be reached because the computer is the key that has unlocked a kit of new exploratory tools such as GMDH.

Why not use some existing modeling software package? Because existing packages cannot handle large numbers of independent variables and arbitrarily complex structures. The problem manifests itself as a large matrix inversion problem, which is avoided in the basic GMDH by repeatedly inverting matrices with dimension limited to 6×6 .

THE ORIGINAL GMDH ALGORITHM (Ref 1 and 2)

The basic GMDH algorithm was proposed by Ivakhenenko (Ref 1). GMDH identifies polynomial models based on data presented. The primary advantage of GMDH is that it self-selects the structure (degree of nonlinearity) of the model without prior information. Consider a set of N-observations of experiments with one dependent variable (y) and M-candidate independent variables ($X_i, i = 1, M$).

$$\begin{array}{ccccccc}
y_1 & x_{11} & x_{12} & \dots & x_{1m} \\
y_2 & x_{21} & x_{22} & \dots & x_{2m} \\
\vdots & \vdots & \vdots & \dots & \vdots \\
y_n & x_{n1} & x_{n2} & \dots & x_{nm}
\end{array}$$

These data are divided into two sets: a training set and a checking set. The basic building block of GMDH is an "elementary" polynomial in two variables (u,v):

$$\begin{aligned}
f(u,v) = & a_1 + a_2 * u + a_3 * v + \\
& a_4 * u * u + a_5 * v * v + \\
& a_6 * u * v
\end{aligned} \quad (1)$$

The initial input variables (X_i) are used in all pairwise combinations in a structure such as Equation 1. Least squares fit of the polynomial to the dependent variable y determines the six coefficients. A total of $M!/[2!(M-2)!]$ quadratic polynomials is obtained. The "best" outputs are selected for use in the next layer based on some heuristic selection criterion. Each "layer" of GMDH consists of a bank of such quadratic polynomial functions. Repeated layers of quadratic polynomials are developed until a predetermined stopping criterion is satisfied. The "complete" model is constructed in several layers of "partial" descriptions.

Layer #1 starts with independent variables (X_i); the best M -polynomials are selected from all possible pairwise combinations:

$$y_1 = f(x_1, x_2)$$

$$y_2 = f(x_1, x_3)$$

$$\dots$$

$$y_k = f(x_{m-1}, x_m)$$

Layer #2 uses the "best" outputs of the first layer (y_i) as input:

$$z_1 = f(y_1, y_2)$$

$$z_2 = f(y_1, y_2)$$

$$\dots$$

$$z_p = f(y_k, y_k)$$

where k and p denote the number of pairwise combinations selected.

The process continues until some stopping criterion is satisfied. The final estimate will use the best two outputs from the preceding layer:

$$y_{est} = f(z_1, z_1)$$

JAPANESE REVISION OF GMDH

(Tamura et al.; Ref 2, Chapter 12 and Ref 4)

Some of the GMDH development effort in Japan has concentrated on the removal of "heuristic" decisions present in the original algorithm. One of the methods used by Tamura et al. to remove the "heuristics" is described next:

- (h1) Simplifications of elementary polynomial (Equation 1) are made available for automatic selection based on Akaike criterion.
- (h2) Required division of the original data into two sets; training and checking sets are avoided. All the data are used for training since the use of Akaike's information criterion prevents overfitting.
- (h3) Predetermination of the number of intermediate variables selected in each layer is avoided by using all combinations permitted by computer memory restrictions in successive layers rather than limiting selection to a few of the best. The stopping rule for GMDH is when all the terms of the final layer have only linear terms, then all such terms are formed into a weighted sum.

A significant part of the Japanese GMDH effort cited in the open literature has been by or in association with Professor Hiroyuki Tamura of the Precision Engineering Department, Osaka University (Ref 4). Much of the work involved modeling of ecological systems, lakes, rivers, etc. The nonlinear polynomial models were successful in predicting quantities of interest. The philosophy of GMDH is to let the computer select the model based on the data.

COMPARISON OF JAPANESE GMDH WORK WITH THE EFFORTS IN THE UNITED STATES

In the United States, significant technical details on GMDH improvements do not seem as readily available. In the United States, the utility of Akaike's criterion is also recognized, which permits the use of all the data for training the algorithm (overfitting is prevented by the Akaike criterion). Selection of only the best models for the next layer is retained; however, when the GMDH is completed, a global adjustment of all the coefficients is implemented (Ref 5 and Ref 2, Chapter 2). The one principal user of GMDH type modeling is General Research Corp., who indicates that heuristic decisions are retained and tailored to specific problems being solved.

My research has found singular value decomposition (SVD) to be very useful in removing two problems with the basic GMDH algorithm. Consider a data set in which there are several candidate "independent" variables that contain nearly identical information and are good descriptors of the dependent variable. In this case the original GMDH algorithm would select all the nearly identical variables as inputs to the second layer. However, what is needed is a means of favoring independent data. The relative dependence of the data is available in the "conditioning number" resulting from the attempt of using two nearly dependent variables.

This information is also available in the complement of the nullspace resulting from the singular value decomposition process.

The second problem in which singular value decomposition is useful involves the global adjustment of all the variables. Consider that the basic GMDH process is completed and that a global adjustment (and simplification) of the model is desired. Such simultaneous adjustments of the variables tend to have stability problems (Ref 5). The stabilization of the estimation of poorly observable coefficient is accomplished by using SVD, setting the "small" singular values to zero. The tolerance used to determine which singular values are to be set to zero is based on the modeling residual.

GMDH type algorithms do not appear to be generally accepted by the statistical modeling community. Akaike indicated that he does not use GMDH and that it is used by engineers (Ref 6). Furthermore, an inquiry of a Computer Vision researcher (Ref 7) indicated lack of knowledge of GMDH (it can be used for pattern recognition). In the United States the interest is similarly restricted to an application-oriented group rather than a theoretical community.

MERGING OF FUZZY SET THEORY WITH GMDH

Recently, H. Tanaka and associates (Ref 8 and 9) merged Fuzzy Set theory with GMDH. Modeling errors considered are represented as uncertainty in the regression model coefficients rather than as measurement error. Fuzzy models are being used in robust control of trains, which also appear to provide faster computer execution.

GMDH often gives several candidate models of quality nearly equal to the best. One way to visualize the Fuzzy Set results as a merging of the various GMDH models into one (simpler) structure with coefficient uncertainty.

REFERENCES

1. A.G. Ivakhnenko, "Polynomial theory of complex systems," IEEE Trans. Syst. Man and Cybernetics, Vol **SMC 1**, No. 4, 364-78 (1971).
2. S.I. Farlow, Self-Organizing Methods in Modeling, GMDH Type Algorithms (Marcel Dekker, Inc., 1984); R.L. Barron, A.N. Mucciardi, F.J. Cook, J.N. Craig, and A.R. Barron, Chapter 2, "Adaptive learning networks: Development and application in the United States of algorithms related to GMDH"; S. Ikeda, Chapter 7, "Nonlinear prediction models for river flows and typhoon precipitation by self-organizing methods"; K. Ohashi, Chapter 10, "GMDH forecasting of U.S. interest rates"; J. Nomura, Chapter 11, "A method for predicting sales amount by the use of IWSM and GMDH"; H. Tamura and T. Kondo, Chapter 12, "On revised algorithms of GMDH with applications"; S. Fujita and H. Koi, Chapter 14, "Application of GMDH to environmental system modeling and management."
3. R. Hect-Nielsen, "Artificial Neural system design," UCSD Extension, 4-8 Aug 1986.
4. H. Tamura, Department of Precision Engineering, Osaka University, discussions on GMDH improvements, personal communications, 2 Sep 1987.

5. D. Molnar, "Modeling accuracy improvements for GMDH," Neural Net Conference, San Diego, Calif., 20-23 June 1987.

6. H. Akaike, Institute of Statistical Mathematics, personal communications.

7. M. Oshima, Chief, Computer Vision Section, Electrotechnical Laboratory, Ibaraki, personal communications.

8. I. Hayashi and H. Tanaka, "The Fuzzy GMDH algorithm by possibility models," Fuzzy Sets Conference, Tokyo, 20-25 July 1987.

9. H. Tanaka, Industrial Engineering Department, University of Osaka, personal communications, discussions on Fuzzy GMDH algorithms, 3 Sep 1987.

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THE 18TH INTERNATIONAL CONFERENCE ON LOW TEMPERATURE PHYSICS AND THE YAMADA CONFERENCE XVIII ON SUPERCONDUCTIVITY IN HIGHLY CORRELATED FERMION SYSTEMS

Wendy Fuller

High T_c superconductivity was the major topic at both conferences discussed in this article. The research results presented relating to high T_c include single crystal and critical field measurements, films, substitution of other rare earth elements, magnetism and superconductivity, thin films, and oxide superconductors.

EDITOR'S NOTE ON NOTATION

Limitations on typography in subscripts and superscripts have led us to use symbols other than those commonly found elsewhere. For the oxygen content we have substituted d for δ . For properties relative to the c -axis we use L for longitudinal and t for transverse.

18TH INTERNATIONAL CONFERENCE ON LOW TEMPERATURE PHYSICS

The 18th International Conference on Low Temperature Physics (LT18) was held in Kyoto, Japan, from 20-26 August 1987. The conference was very large, with about 1,600 attendees representing many countries. The overwhelming emphasis of the conference was on the new high T_c

superconductors. It is obvious that research in other areas of superconductivity has been pushed aside. Speakers who were supposed to discuss other topics in superconductivity (i.e., heavy fermion, etc.) only briefly discussed that topic before switching to high T_c . The media covered all the major sessions on high T_c , often to the distraction of the meeting attendees. Once the organizers limited the media coverage to the first couple of minutes of a talk the distraction was greatly reduced.

To paraphrase J.R. Schrieffer (University of California at Santa Barbara), trying to absorb all of the information, experimental and theoretical, presented on high T_c superconductors at LT18 was like trying to get a drink of water from a fire hose turned on full blast. There is no consensus among the theorists as to the mechanism for the high T_c in these materials. Many theorists have brushed off their favorite theory from other materials--organics, heavy fermion, etc.--and applied it to these new superconductors. At the moment there is some experimental evidence to support, as well as to detract from, each theory presented. A theory for these materials will have to wait until there are more data on clean single crystals and good films.

Single Crystal Measurements

Measurements are beginning to be performed on single crystals. This is important due to the anisotropy in these superconductors. Y. Hidaka (Electrical Communications Laboratories, Ibaraki, Japan) described single crystals of $(\text{La}_{1-x}\text{Sr}_x)\text{CuO}_4$ (8 by 8 by 2 mm³) and $\text{Ba}_2\text{YCu}_3\text{O}_7$ (1.5 by 1.5 by 0.1 mm³) grown from a melt. For the former material they found that H_{c2} in the ab plane is five to eight times as large as H_{c2} parallel to the c-axis. Thus these materials are anisotropic and measurements on sintered powder samples will result in some average values of a given property. B. Batlogg (AT&T Bell Laboratory, U.S.A.) reported values of $2\Delta/kT_c$ of 8.3 for Cu-O chains and 2.4 for the planes. The values were obtained from Cu nuclear relaxation rate measurements on single crystals of $\text{Ba}_2\text{YCu}_3\text{O}_7$. M. Sato (Tohoku University, Sendai, Japan) and U. Kawabe (Hitachi Central Research Laboratory) also discussed single crystals of the La-M-Cu-O (M = Sr, Ba).

Films

B. Zhao et al. (Academia Sinica, Beijing, China) described films of Sr-La-Cu-O and Ba-Y-Cu-O made by magnetron sputtering. The transition in the latter started in the range of 87 to 89.5 K but did not reach zero resistance until 20 K. H. Adachi et al. (Matsushita Central Research Laboratory) reported single crystal $(\text{La}_{0.9}\text{Sr}_{0.1})\text{CuO}_4$ films on SrTiO_3 substrates made by magnetron sputtering; they found an onset of 34 K. Other groups reporting films were H. Rogalla (Institut für Angewandte Physik, Giessen, FRG);

O. Meyer et al. (Kernforschungszentrum, Karlsruhe, FRG); H. Yamamoto et al. (Nihon University, Chiba, Japan); T. Ogushi et al. (Kagoshima University, Kagoshima, Japan); Y. Enomoto et al. (NTT Electrical Communications Laboratory, Ibaraki-ken, Japan); T. Moriwaki et al. (NTT Electrical Communications Laboratory, Ibaraki-ken, Japan); T. Geballe (Stanford University, Palo Alto, California, U.S.A.); and P. Chaudhari (IBM Watson Research Center, Yorktown Heights, New York, U.S.A.). IBM has made films in a variety of ways: electron beam evaporation, molecular beam epitaxy, sputtering, laser evaporation, ion beam deposition, and spray or plasma deposition. IBM has found that different substrates will give different results: Al_2O_3 --polycrystalline; MgO --polycrystalline, but orientated; SrTiO_3 and niobate--epitaxial films. In epitaxial films the best case for the 10- to 90-percent transition width is 1 K; however, 2 to 2.5 K is more typical. H_{c1} appears greater in films ~ 2.2 T than single crystals ~ 0.7 T. The anisotropy in the films is not as large as in the single crystals, $\xi_{||} = 4$ to 11 Å, $\xi_{\perp} = 1.5$ to 30 Å. The films have greatly improved critical currents over the ceramics. The ceramics of B. Batlogg have $J_c \geq 1,000$ A/cm² at 77 K rising to 10^5 A/cm² at 4.2 K. For epitaxial films with the c-axis in the plane, J_c is routinely $> 5 \times 10^4$ A/cm² at 77 K and IBM has seen $J_c > 10^5$ A/cm² at 77 K. Yamamoto has reported $J_c > 10^6$ A/cm² at 77 K. Stanford uses three targets (sources) and directs O_2 at the substrate during deposition of the film. Stanford reports a $J_c > 6 \times 10^5$ A/cm² at 78 K and 1×10^7 A/cm² at 4.2 K. Moriwaki found that on their films a B-field of 1 T reduces J_c by > 50 percent in the temperature range 70 to 87 K.

Critical Field Measurements

K. Okuda et al. (University of Osaka, Japan) were able to trace out the largest portion of the H_{c2} versus T curve. They used pulsed magnetic fields up to 70 T. They found, on sintered ceramic samples, $H_{c2}(0) \approx 40$ T and $dH_{c2}/dT_c \approx 1.69$ T/K for $\text{La}_{1.85}\text{Sr}_{0.15}\text{CuO}_{4-d}$ and $dH_{c2}/dT = 1.54$ and 2.35 T/K with $H_{c2}(0) = 90$ and 148 T for $\text{Y}_{0.4}\text{Ba}_{0.6}\text{CuO}_y$ and $\text{YBa}_2\text{Cu}_3\text{O}_{7-d}$, respectively. For the latter material they found that at 4.2 K a field of 54 T did not restore more than 10 percent of the normal resistance. It is obvious that very high field facilities will be needed to characterize these materials.

Substitution

In trying to understand the high T_c superconductors several research groups have been substituting other elements in the $\text{YBa}_2\text{Cu}_3\text{O}_{7-d}$ material. Y can be replaced by many rare earth elements and one still obtains a high T_c material. P. Chu (University of Houston, U.S.A.) reported success with La, Dy, Lu, Yb, Nd, Sm, Eu, Gd, Ho, Er, Tm, Ce, Tb, and Zr. Other groups also reported success with a variety of lanthanide substitutions: S. Tanaka (University of Tokyo, Japan); F. Mueller et al. (Los Alamos National Laboratory, New Mexico, U.S.A.); M.B. Maple (University of California at San Diego, U.S.A.); T. Yamada (NTT, Tokyo, Japan); S. Kagoshima (University of Tokyo, Japan); H. Takagi (University of Tokyo, Japan); and M. Sato (Tohoku University, Sendai, Japan). Resistive measurements as well as magnetization, critical magnetic field, and specific heat measurements were

described. In general, the materials were very similar to $\text{YBa}_2\text{Cu}_3\text{O}_{7-d}$, which is surprising since some of the elements are magnetic. Tanaka pointed out that since the magnetic moment of the rare earth ion is almost the same as in the pure rare earth there is little electron interaction with the rare earth elements in these superconductors. B. Batlogg (AT&T) reported on the rapid decrease in T_c as one moves away from Cu in the series Fe, Co, Ni, Cu, Zn, Ga.

Oxygen Planes Versus Chains

The role of the oxygen planes versus the chains in obtaining the high T_c was a question of much discussion and it was not resolved. As mentioned earlier, the Cu nuclear relaxation rate gives a different value for $2\Delta/kT_c$ for chains (8.3) and planes (2.4). J. Jorgensen (Argonne National Laboratory, U.S.A.) reported that T_c was highest for samples with chain ordering; thus, he felt a one-dimensional chain on the Cu-O sublattice was needed. L. Greene (Bellcore Laboratory, U.S.A.) found that when the central plane in $\text{YBa}_2\text{Cu}_3\text{O}_{7-d}$ is empty, the sample is not superconducting and has a tetragonal structure. She also found two orthorhombic structures: (1) $T_c = 90$ K, central plane one-half full; and (2) $T_c \approx 55$ K, central plane one-quarter full. M. Ishikawa (Tokyo University) found the same crystal structures and T_c 's. He correlated the structures with d . Orthogonal I has $d \approx 0$; in orthogonal II $d \approx 0.5$. He found two tetragonal phases, neither of which is superconducting. Tetragonal I has $d < 0$, while tetragonal II has $d \approx 1$. Tetragonal II has $\rho \approx \exp[(1/\tau)^{1/3}]$ between 1.7 and 70 K.

Magnetism and Superconductivity

The interplay between magnetism and superconductivity in the oxide superconductors was another topic of much interest. Antiferromagnetism and superconductivity in the $(\text{La}_{1-x}\text{Ba}_x)\text{Cu}_2\text{O}_{4-d}$ system were described by several groups: B. Dunlop (Argonne National Laboratory, U.S.A.); K. Asayama (Osaka University, Japan); T. Fujita (Hiroshima University, Japan); and K. Kumagai (Hokkaido University, Japan). These groups found that for $x \leq 0.01$ the system orders antiferromagnetically and is in the orthorhombic structure. For $x \geq 0.02$ the system is a superconductor with T_c independent of x for $x > 0.04$. N. Nishida (Tokyo Institute of Technology, Japan) reported similar results for $\text{YBa}_2\text{Cu}_3\text{O}_x$. He found that for $x \approx 6.9$ the material is superconducting at 90 K, and when $T < 200$ K there is only the nuclear magnetic dipole field of the Cu ions. For $x \approx 6.4$, $T_c \approx 60$ K and the high temperature magnetic behavior is similar to that for $x = 6.9$; however, at $T < 10$ K there may be disordered magnetism on the Cu atoms. For $x = 6.2$ the material is a tetragonal insulator and there is long-range antiferromagnetic order connected with the Cu(2) atoms. The ordering temperature is roughly 300 K. Currently it appears that different sublattices are involved in the magnetic order and superconductivity according to Dunlop.

Superconductivity Criteria

There were the usual claims of super high T_c that have become common recently. There were also words of warning, i.e., what should be the criteria for calling a material superconducting. Along this line, P. Chu (University of Houston, U.S.A.) gave four:

- Meissner effect
- High stability for the material
- Zero resistance
- High reproducibility among other laboratories

S. Wolf (Naval Research Laboratory, U.S.A.) added another: state the sensitivity of your instruments for zero resistance and plot the data as $\log R$.

Applications

Work towards applications was described by several labs. Y. Enomoto (NTT Electrical Communications Laboratory, Ibaraki-ken, Japan) reported on a cryogenic far infrared detector using a polycrystalline film of $\text{BaPb}_{0.7}\text{Bi}_{0.3}\text{O}_3$. The film was patterned with a meander line and contained many Josephson junctions connected through the grain boundaries. The optical responsivity was 10^4 V/W and signals from 1- μm to 1-mm waves were detected. To reduce noise the detector was operated in the 4- to 6-K range. Two groups presented research on superconducting wires of $\text{YBa}_2\text{Cu}_3\text{O}_{7-d}$: Y. Yamada et al. (Toshiba Research and Development Center, Kawasaki, Japan) and K. Ohmatsu et al. (Sumitomo Electric Industries, Osaka, Japan). The Toshiba group described several methods for making wires, some sheathed in Ag. The nonsheathed material has a T_c of 87 K with $J_c(77\text{ K}) = 725\text{ A/cm}^2$. When it was in a Ag sheath $T_c = 88$ K and $J_c(77\text{ K}) = 560\text{ A/cm}^2$. If this sheathed wire was made into a coil $T_c = 85$ K and $J_c(77\text{ K}) = 120\text{ A/cm}^2$. The Sumitomo group reported $J_c(77\text{ K}) = 1,240\text{ A/cm}^2$ for

a Ag-sheathed wire. Thus progress is beginning to be made in obtaining wires of the high T_c material.

Thin Films of Conventional Superconductors

M.R. Beasley (Stanford University, U.S.A.) was concerned with the case of two-dimensional superconductors, i.e., thin films. This is an important consideration for device applications where very thin films are needed. Films can be divided into three groups: (1) homogeneous or microscopically disordered, such as amorphous Mo; (2) very finely granular, $\ell_d \approx \xi(0)$, such as Al/Al-oxide films; and (3) coarsely granular or macroscopically disordered, $\ell_d < \xi(0)$, as in NbN. In all cases the transition temperature is lowered due to the disorder, but the reduction is different in each group. In the microscopically disordered case the $T_c(R=0)$ is close to the mean-field T_c . Here T_c decreases as the disorder increases. In the macroscopically disordered regime, $T_c(R=0) < T_c^{mf}$; here T_c^{mf} stays roughly constant while T_c decreases with increasing disorder. Martinoli showed how it is possible to study the critical behavior of a system under a variety of conditions--frustration, size, etc.--by using an array of 10^4 Josephson junctions. Modern microfabrication techniques permit such a system to be made. By studying the frequency dependence of parameters one can effectively study the size dependence since the scattering length is related to the frequency.

Organic Superconductors

Organic superconductors, although of low T_c , are still of interest. I.F. Shchegolev (Institute of Solid State

Physics, Chernogolovka, U.S.S.R.) reported on the current status of this field. He reported that Riboska has found a new organic superconductor, $(ET)_4Hg_{2.88}Br$, where $ET = BEDT-TTF$. This material is highly anisotropic, $\approx 10^3$, as determined by the room temperature resistivity. It is basically a layered material where ρ_c is larger. Another compound, $\beta-(ET)_2I_3$, has two phases, one of high T_c and another with low T_c . There is a difference in the superstructures, but the reason for the difference in T_c is an unanswered question.

Miscellaneous

Two papers outside of the field of superconductivity generated interest. One was the observation of phase slips in spin supercurrents in $^3He-\beta$ (A.S. Borovik-Romanov et al., Institute for Physical Problems, Moscow, U.S.S.R.). The supercurrent or magnetization flow in superfluid 3He is driven by a gradient in the phase of the order parameter. This phenomenon, the equivalent to the ac Josephson effect in superconductors, was predicted in 1975. Another interesting paper concerned cryogenic techniques. A compact dilution refrigerator that needs no mechanical pumps was reported by P.R. Roach et al. (Argonne National Laboratory, Illinois, U.S.A.). This is a one-shot 3He - 4He dilution refrigerator that cools to 13 mK and runs for 10 hours. Charcoal pumps are used. The operation of the system is controlled by heaters on the pumps and it is possible to automate. The system is immersed in a 4He bath. The advantages are the lack of vibration and noise since there are no continuously running mechanical pumps.

Summary

In summary, high T_c superconductivity overshadowed all other topics at LT18. Many groups from around the world are working in this field, some of whom are newcomers to the field of superconductivity. The various intrinsic parameters are beginning to be sorted out now that good films and single crystals are being made. Much more work is needed on the theory of these materials. In spite of the domination of the high T_c materials some work is still continuing in other aspects of superconductivity: thin films--especially disordered ones--and organic and heavy fermion superconductors. Outside of superconductivity there is interest in quantum fluctuations, narrow wires, a Josephson current in ^3He , and ways of reaching very low temperatures. The very low temperatures are needed to investigate quantum fluctuations.

YAMADA CONFERENCE XVIII ON SUPERCONDUCTIVITY

The Yamada Conference XVIII on Superconductivity in Highly Correlated Fermion Systems was held in Sendai, Japan, from 31 August through 3 September 1987. It was very well organized considering there were 400 attendees when the original plans had called for about 150. The greater number was obviously due to the interest in the new high T_c superconductors that dominated the conference. Over half of the attendees came from Japan with the rest spread among 21 other countries.

Many topics in superconductivity were covered in Sendai. In many ways the conference was a repetition but also a continuation of the superconductivity sessions at LT18. In Sendai the speakers tended to

stay with their advertised talk better than at LT18. Results in the high T_c field were expanded upon in Sendai. The media was covering the conference but not to the extent it did in Kyoto. The meeting could be divided into five major topics: oxide superconductors, heavy fermion, organic superconductors, ternary superconductivity, and artificial structures. As previously mentioned the oxide superconductors dominated the conference. However, the other topics or subfields had interesting results and questions to resolve as well.

Organic Superconductors

In organic superconductors there is still a question as to whether the superconductivity is due to singlet or triplet pairing. K. Murata of the Electrotechnical Laboratory in Ibaraki, Japan, presented results on H_{c2} of $\beta\text{-(BEDT-TTF)}_2\text{I}_2$ that suggest singlet pairing. L. Gorkov (L.D. Landau Institute for Theoretical Physics, Moscow, U.S.S.R.) addressed the theoretical aspects and said that in a clean crystalline form of the superconductors one expects a very high H_{c2} for H parallel to the b -axis if the pairing is singlet.

Ternary Superconductors

The major result for ternary superconductors was the existence of both superconductivity and ferromagnetism in HoMo_2S_8 . M. Giroud et al. (Centre de Recherches sur les Très Basses Températures, Grenoble, France) induced superconductivity in the ferromagnetic state of HoMo_2S_8 by applying a magnetic field. Others working in this area are Y. Koike (Tohoku University, Sendai, Japan) and P. Burlet (Centre d'Études Nucléaires, Grenoble, France).

Heavy Fermions

It is clear from the results presented that it is hard to determine the pair function from experiment and harder still to determine the pairing interaction. The competition between and coexistence of superconductivity and magnetism were addressed in these materials as well. $(U_{1-x}Th_x)Pt_3$ is antiferromagnetic at 5 K. In $(U_{1-x}Th_x)Be_{13}$ it is questionable as to whether there is magnetic order while there is competition and coexistence of magnetism and superconductivity in URu_2Si_2 . In the case of coexistence of magnetic order and superconductivity the question remains as to whether the same electrons are responsible for both phenomena.

Artificial Structures

It is becoming technologically possible to fabricate the structure one wishes to study almost down to the atomic level. I. Schuller (Argonne National Laboratory, Illinois, U.S.A.) showed that one has considerable control in obtaining two-dimensional versus three-dimensional structure in fabricating superlattices. It is now possible to make superconducting networks with varying degrees of periodicity. Thus superconductivity in periodic, quasi-periodic, and random networks or arrays can be studied at will. Results on various networks were reported by P. Chaikin (University of Pennsylvania, U.S.A.) and A. Goldman (University of Minnesota, U.S.A.).

Oxide Superconductors

The oxide superconductors dominated the conference two out of the four days. There are many groups from many

countries working in this field. In general, the same research groups presented results in Sendai as in Kyoto. It became increasingly clear that good control in sample preparation and monitoring of the site occupancy are important to understanding a variety of results. The role of the chains versus the planes of Cu-O was addressed here as in Kyoto. M. Ishikawa (University of Tokyo, Japan) reported on the possibility of two orthorhombic phases of $Ba_2YCu_3O_{7-\delta}$, one with $T_c \approx 90$ K and the other with $T_c \approx 60$ K. K. Mueller (IBM Zurich, Switzerland) described a glassy state in the high T_c materials. The origin of the granular behavior was under question; one possibility was in the twin boundaries of the CuO planes. He emphasized that any analysis of electrical or magnetic properties should take the glassy nature into account.

The competition between superconductivity and magnetism was discussed in relation to the oxide superconductors. Many groups have made (rare earth) $Ba_2Cu_3O_{7-\delta}$. From measurements of these materials there appears to be a complete decoupling between the superconducting electrons and the 4f moments. The T_c is not changed much by using different rare earths in place of the yttrium. Both Argonne National Laboratory and Hiroshima University have been partially substituting other elements for the Cu in $YBa_2Cu_3O_{7-\delta}$. Y. Aoki at Hiroshima has found that at a 5-percent concentration of Fe or Al there is an orthorhombic to tetragonal transition. Up to this concentration both Al and Fe decrease the T_c at about the same rate, 6 K/atomic percent. For higher concentrations the T_c appears to stop changing for Al substitution but it continues to decrease for Fe, at least up to 10 percent substitution. Questions remain as to whether the Fe magnetically orders at some

concentration. The magnetism of Cu itself is another area of research. In LaCuO_4 a spin density wave (SDW) state has been found from magnetic susceptibility and neutron diffraction studies (H. Sato et al., University of Tokyo, Japan). J. Thoulence (Centre de Recherches sur les Très Basses Températures, Grenoble, France) reported that this material is superconducting. There is perhaps antiferromagnetic ordering at 400 K. In discussions Nishida's results on muon scattering in $\text{YBa}_2\text{Cu}_3\text{O}_6$, which were reported in Kyoto, were mentioned as evidence for magnetism of Cu in that compound. None of the superconducting materials show a Curie-Weiss term in the susceptibility.

As in Kyoto a number of theories for the nature of the superconductivity in the oxide superconductor were presented. No consensus was reached for the mechanism; phonons, spins (resonating valence bonds), and charges (excitons or plasmons) were all suggested as possibilities.

In Sendai there were all the usual claims of higher transition temperature materials. However, none were presented that had substantial evidence and reproducibility. The general feeling was that the highest confirmed T_c remained at 93 K for $\text{YBa}_2\text{Cu}_3\text{O}_{7.4}$.

Single Crystals and Thin Films of High T_c Superconductors

There is rough agreement between the results of the various groups who have made single crystals or films of the Cu-oxide

superconductors. The anisotropy in the critical field $H_{c2}/H_{c2}^a \approx 3$ to 6 with coherence lengths $\xi_c \approx 5$ to 7 Å and $\xi_L \approx 20$ to 30 Å. R. Shelton (University of California, Davis) reported a very anisotropic J_c that increases close to T_c . Anisotropy results on thin films are in agreement with single crystals if the films are grown on SrTiO_3 . M. Beasley (Stanford University, U.S.A.) found fluctuations in epitaxial films of $\text{YBa}_2\text{Cu}_3\text{O}_{7.4}$ grown with the c-axis perpendicular to the film. He found a two-dimensional behavior far from T_c crossing over to a three-dimensional behavior closer to T_c . From the data, the coherence length was found to be 2 Å. R. Phillips (Lawrence Berkeley Laboratory, U.S.A.) reported on the specific heat of $\text{YBa}_2\text{Cu}_3\text{O}_{7.4}$. He found that even in $H=0$ there is a linear term in C_p . The question was whether this is intrinsic or is it due to incomplete (inhomogeneous) superconductivity. Another unusual feature is that C_p shows a cusp at T_c and not a discontinuity. Again questions arise: Is it intrinsic? Is it due to incomplete superconductivity? Can it be explained by the glass model? The results could be explained by inhomogeneous samples, so more experiments are needed on good, homogeneous samples to answer these questions.

SUMMARY

In summary, there is a continued challenge experimentally and theoretically to understand the high T_c oxide superconductors. This will be met by continuing to improve the control in the fabrication of the

materials. Single domain, clean, single crystals are needed as are epitaxially grown films. The systematics of both the normal state and superconducting properties of the material will continue to provide researchers a challenge for some time. This, perhaps, will lead to higher T_c materials. When higher temperature anomalies are observed it is necessary to have the results reproduced in other laboratories; in addition, all the standard checks for superconductivity must be performed before claims can be made.

Wendy Fuller received a B.S. in physics from the University of Maryland, College Park, in 1975 and an M.S. and Ph.D. in physics from the University of California, Los Angeles, in 1976 and 1980, respectively. Since 1980 she has been a research physicist at the Naval Research Laboratory. Dr. Fuller is a member of the American Physical Society, American Association of Science, Sigma Xi, and Women in Science and Engineering. Her current research interests are in dc and ac properties of two-dimensional granular superconductors, high T_c superconductors, and quasi-one-dimensional materials.

INTERNATIONAL MEETINGS IN THE FAR EAST 1988-1994

Compiled by Yuko Ushino

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The Australian Academy of Science, the Japan Convention Bureau, and the Science Council of Japan 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.

1988			
Date	Title/Attendance	Site	Contact for Information
August 1-5	The 10th Congress of the International Ergonomics Association	Sydney, Australia	Secretariat IEA88 IEA88 PO Box 380 Spit Junction, NSW 2088, Australia
August 1-6	The IUPAC 32nd International Symposium on Macromolecules 50-F500-J1,300	Kyoto, Japan	The Society of Polymer Science, Japan Honshu Building, 5-12-8 Ginza Chuo-ku, Tokyo 104
August 2-9	The 9th World Conference on Earthquake Engineering 57-F800-J1,200	Tokyo, Japan	Secretariat: The 9th SCEE Steering Committee c/o Japan Convention Service, Inc. Nippon Press Center Building 2-2-1 Uchisaiwai-cho Chiyoda-ku, Tokyo 100
August 14-13	The 10th International Congress on Rheology	Sydney, Australia	R. I. Tanner Department of Mechanical Engineering University of Sydney NSW 2006
August 15-17	International Federation of Automatic Control Symposium	Melbourne, Australia	Conference Manager The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
August 15-17	Electrical IFAC Conference	Melbourne, Australia	Conference Manager The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
August 15-19	The 3rd International Phyco logical Congress	Melbourne, Australia	Dr. M. N. Clayton Botany Department Monash University Clayton, Victoria 3168

*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

1988

Date	Title/Attendance	Site	Contact for Information
August 16-19	The 7th International IUPAC Symposium on Mycotoxins and Phycotoxins 40-F150-J250	Tokyo, Japan	Organizing Committee 7th International IUPAC Symposium on Mycotoxins and Phycotoxins c/o Inter Group Corporation Akasaka Yamakatsu Building 8-5-32 Akasaka, Minato-ku, Tokyo 107
August 21-26	International Geographical Congress	Sydney, Australia	Secretariat: Australian Academy of Science GPO Box 783, Canberra, ACT 2601
August 22-24	The 4th International Conference on Liquid Atomization and Spray Systems 15-F100-J200	Sendai, Japan	Fuel Society of Japan Kairaku Building 6-5-4 Soto-kanda, Chiyoda-ku, Tokyo 101
August 22-26	The 5th Australia-New Zealand Conference on Geomechanics	Sydney, Australia	Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, ACT 2600
August 24-28	The 7th Asian Conference for Radiographers and Radiological Technologists (7th ACRT) and 1988 National Scientific Congress of Radiologic Technologists 14-F100-J2,000	Miyazaki, Japan	Japan Association of Radiologic Technologists 1-26-7 Shinkawa, Chuo-ku, Tokyo 104
August 29- September 1	The 5th International Conference on Molecular Beam Epitaxy 20-F150-J250	Sapporo, Japan	Japan Society of Applied Physics c/o Department of Electrical and Electronic Engineering Tokyo Institute of Technology 2-12-1, Oh-okayama Meguro-ku, Tokyo 152
August 29- September 2	The 3rd International Conference on Synchrotron Radiation Instrumentation (SRI-88)	Tsukuba, Japan	Katsuki Kobayashi Photon Factory Synchrotron Radiation Research Facility National Laboratory for High Energy Physics 1-1 Uehara, Oho-machi Tsukuba-gun, Ibaraki 305
September 4-8	The 1st International Conference on Computational Methods in Flow Analysis 24-F110-J250	Okayama, Japan	Department for International Affairs Okayama University of Science 1-1 Ridaicho, Okayama 700
September 19-22	The 29th International Conference on the Biochemistry of Lipids (ICBL) 39-F100-J200	Tokyo, Japan	Secretariat: The 29th International Conference on the Biochemistry of Lipids c/o Department of Psychological Chemistry and Nutrition Faculty of Medicine University of Tokyo 7-3-1 Hongo, Bunkyo-ku, Tokyo 113
September 20-22	The 4th Japanese-German Joint Seminar on Non- destructive Evaluation and Structural Strength of Nuclear Power Plant 2-F30-J70	Kanazawa, Japan	Japan Atomic Energy Research Institute Tokai Establishment Tokai-mura, Naka-gun, Ibaraki 319-11

1988			
Date	Title/Attendance	Site	Contact for Information
October 11-14	The 4th International Workshop on Electro- luminescence	Tottori, Japan	Dr. Hiroshi Kobayashi Department of Electronics Faculty of Engineering Tottori University Koyama, Tottori 680
October 17-20	The 9th International Conference on Pattern Recognition	Beijing, People's Republic of China	9 ICPR Secretariat Chinese Association of Automation P.O. Box 2728 Beijing
October 19-22	BIDEC International Bio-Fair/ Tokyo '88 Symposium 19-F120-J800	Tokyo, Japan	Secretariat of BIO FAIR TOKYO '88 Symposium c/o Japan Convention Services, Inc. Nippon Press Center Building 2-2-1 Uchisaiwai-cho, Chiyoda-ku, Tokyo 100
October 24-25	The 1st International Conference New Diamond Forum 20-F150-J250	Tokyo, Japan	Secretariat: International Communications Inc. Kasho Building 2-14-9 Nihonbashi, Chuo-ku, Tokyo 103
October 24-28	The 3rd International Conference on Surface Engineering	Tokyo, Japan	Cotec Corporation Sankochi Building 5-17-14 Shinjuku Shinjuku-ku, Tokyo 160
October 25-28	International Conference on Materials and Process Characterization for VLSI (ICMP '88)	Shanghai, People's Republic of China	Zhu Ye Institute of Materials Science Fudan University, Shanghai
November 2-5	International High- Performance Vehicle Conference	Shanghai, People's Republic of China	Ship Design Committee CSNAME P.O. Box 3053 Shanghai
November 5-8	The 1st International Conference on the Metallurgy and Materials of Tungsten, Titanium, Rare Earths, and Antimony	Changsha, People's Republic of China	Secretariat of W-Ti-R-E-Sb '88 The Nonferrous Metals Society of China 9 Xizhang Hutong, Sizhimennei Dajie Beijing
November 9-12	The 2nd International Conference on Formulation of Semiconductor Interface (ICFSI-88)	Takarazuka, Japan	Tsunemasa Taguchi Faculty of Engineering Osaka University 2-1 Yamadaoka Fukita-shi, Osaka 565
November 11-14	International Symposium on Geothermal Energy, 1988 30-F50-J200	Kumamoto and Beppu, Japan	Geothermal Research Society of Japan c/o Geological Survey of Japan 1-1-3 Higashi, Tsukuba, Ibaraki 305
November 14-17	The 3rd International Topical Meeting on Nuclear Power Plant Thermal Hydraulics and Operations	Seoul, Korea	Dr. Jong Hee Cha P.O. Box 7 Daeduk-Danji Cheong-Nam, Korea 300-31
November 14-18	1988 Annual Meeting of the International Society for Interferon Research 28-F300-J500	Kyoto, Japan	Organizing Committee of ISIR '88 c/o Inter Group Corporation Shohaku Building 6-23 Chayamachi, Kita-ku, Osaka 530

1988			
Date	Title/Attendance	Site	Contact for Information
November 16-18	Techno-Ocean '88 International Symposium 5-F50-J250	Kobe, Japan	World Import Mart Co., Ltd. World Import Mart Building 3-1-3 Higashi-Ikebukuro Toshima-ku, Tokyo 170
November 19-26	The 13th International Diabetes Federation Congress 20-F80-J120	Sydney, Australia	Professor J. R. Turtle, Professor of Medicine Department of Endocrinology University of Sydney NSW 2006
November 28- December 2	International Conference on Fifth Generation Computer Systems 1988 39-F500-J1,200	Tokyo, Japan	Institute for New Generation Computer Technology 21F Mita-Kokusai Building 1-4-28 Mita, Minato-ku, Tokyo 108
1989			
Date	Title/Attendance	Site	Contact for Information
April 3-5	International Symposium for Electromachining 16-F100-J300	Nagoya, Japan	Institute of Industrial Science University of Tokyo 7-22-1 Roppongi, Minato-ku, Tokyo 106
April 10-13	The International Symposium for Electromachining 15-F100-J300	Undecided	The Institute of Electrical Engineers of Japan Gakkai Center Building 2-4-16 Yayoi, Bunkyo-ku, Tokyo 113
April 11-14	International Symposium on Ship Resistance and Powering Performance (ISRP)	Shanghai, People's Republic of China	International Symposium on Ship Resistance and Powering Performance Department of Naval Architecture and Ocean Engineering Shanghai Jiao Tong University Shanghai
April 18-21	The 2nd Asian Fisheries Forum 30-F150-J150	Tokyo, Japan	Secretariat: The 2nd Asian Fisheries Forum c/o Faculty of Agriculture Tokyo University 1-1-1 Yayoi, Bunkyo-ku, Tokyo 113
May 14-18	The 3rd World Conference on Neutron Radiography	Osaka, Japan	Research Reactor Institute, Kyoto University Kumatoricho, Sennan-gun, Osaka 590-04
May 29- June 2	The 2nd International Near Infrared Spectroscopy Conference	Tsukuba, Japan	Dr. Sumio Kawano National Food Research Institute Kannondai, Tsukuba 305
July 2-7	XXVII International Conference on Coordination Chemistry	Brisbane, Australia	Professor Clifford J. Hawkins Department of Chemistry University of Queensland Saint Lucia, Brisbane, Queensland 4067
July 9-14	The 4th International Conference on Scanning Tunneling Microscopy/ Spectroscopy (ICSTM/STS)	Oharai, Japan	Professor Osamu Faculty of Science Tokyo Institute of Technology 2-12-1 Ohokayama, Meguro-ku, Tokyo 152
July 10-14	The 4th International Symposium of Plant Biosystematics (IOPB) 30-F80-J200	Kyoto, Japan	IOPB Symposium c/o Department of Botany Faculty of Science, Kyoto University Kitashirakawa Oiwake-cho Sakyo-ku, Kyoto 606

1989			
Date	Title/Attendance	Site	Contact for Information
July 24-26	The 2nd Microoptics Conference/The 9th Topical Meeting on Gradient-Index Imaging Systems (MOC/GRIN '89)	Tokyo, Japan	Mr. Yasuhiko Noguchi Secretariat: MOC/GRIN '89 Banda Building 1-35-5 Yoyogi, Shibuya-ku, Tokyo 151
August 13-18	Solar Energy Congress Tokyo 1989 40-F600-J400	Tokyo, Japan	Japanese Section of International Solar Energy Society 322 San Patio, 3-1-5 Takada-no-baba Shinjuku-ku, Tokyo 160
August 20-25	The 9th International Conference on Crystal Growth (ICCG) 48-F250-J550	Sendai, Japan	Secretariat: 9th International Conference on Crystal Growth c/o Inter Group Corp. 8-5-32 Akasaka, Minato-ku, Tokyo 107
August 21-26	The 14th International Conference on High Energy Accelerators	Tsukuba, Japan	Mr. Kitagawa National Laboratory for High Energy Physics 1-1 Ooho, Tsukuba-shi, Ibaraki 305
August 27- September 1	The 5th International Symposium on Microbial Ecology (5th ISME) 73-F600-J600	Kyoto, Japan	Organizing Committee of 5th International Symposium on Microbial Ecology c/o Inter Group Corporation 8-5-32 Akasaka, Minato-ku, Tokyo 107
August 28-31	International Symposium on Computational Fluid Dynamics-- Nagoya, 1989	Nagoya, Japan	Professor Michiru Yasuhara Department of Aerospace Engineering Nagoya University Furo-cho, Chikusa-ku, Nagoya 464
September 4-8	The 7th International Conference on Liquid and Amorphous 30-F120-J280	Kyoto, Japan	Department of Physics, Faculty of Science, Kyoto University Oiwake-cho, Kita-Shirakawa Sakyo-ku, Kyoto 606
September 4-8	ISES Solar World Congress 1989 Kobe 65-F400-J400	Kobe, Japan	Secretariat: ISES Solar World Congress 1989 c/o International Communications, Inc. Kasho Building, 2-14-9 Nihonbashi Chuo-ku, Tokyo 103
September 5-7	International Conference on Zinc and Zinc Alloy Coated Steel Sheet 20-F50-J150	Tokyo, Japan	Secretariat of GALVATECH '89 Iron and Steel Institute of Japan 1-9-4 Otemachi, Chiyoda-ku, Tokyo 100
September 8-10	1989 International Symposium on Electromagnetic Compatibility 26-F170-J400	Nagoya, Japan	Secretariat: International Symposium on Electromagnetic Compatibility c/o Department of Information and Computer Sciences, Toyohashi University of Technology 1-1 Tenpaku-cho, Aza-Hibarigaoka, Toyohashi, Aichi 440
September 17-22	International Conference on the Science and Technology of Defect Control in Semiconductors	Yokohama, Japan	IC-STDOS c/o Lab. Physics of Crystal Defects Institute for Materials Research Tohoku University 2-1-1 Katahira, Sendai 980

1989			
Date	Title/Attendance	Site	Contact for Information
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
September 25-28	The 5th International Conference on Numerical Ship Hydrodynamics N.A.-F-J200	Hiroshima, Japan	Shipbuilding Research Association of Japan c/o Faculty of Engineering Hiroshima University Shitami Saiji-cho, Higashi-Hiroshima 724
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 5-39 Showa-machi, Maebashi 371
October 26-28	ACEANCUPS Polymer Symposium 10-F30-J30	Osaka, Japan	Institute of Scientific and Industrial Research, Osaka University 8-1 Mihogaoka, Ibaraki-City, Osaka 567
October (tentative)	Specialty Electric Conference	Sydney, Australia	Conference Manager The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
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
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
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
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
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

1990			
Date	Title/Attendance	Site	Contact for Information
August 23-30	V International Congress of Ecology 62-F900-J1,060	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
September 16-22	IUMS Congress: Bacteriology and Mycology - Osaka, Japan - 1990 71-F2,000-J600	Osaka, Japan	Preliminary Committee of International Congress of Microbiology c/o JTB Creative Inc. Daiko Building 3-2-14 Umeda, Kita-ku, Osaka 530
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
1990 (tentative)	The 6th International Conference on the Science & Technology of Iron and Steel 50-F300-J500	Japan (undecided)	International Conference Secretariat and Editorial Department Iron and Steel Institute of Japan 3F, Keidanren Kaikan, 1-9-4 Otemachi, 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
August (tentative)	International Congress on Medical Physics 45-F600-J900	Kyoto, Japan	National Institute of Radiological Science 4-9-1 Anagawa, Chiba 260
August (tentative)	The 16th International Conference on Medical and Biological Engineering (ICMBE) 45-F600-J900	Kyoto, Japan (tentative)	Japan Society of Medical Electronics and Biological Engineering 2-4-16 Yoyogi, Bunkyo-ku, Tokyo 113
1992			
Date	Title/Attendance	Site	Contact for Information
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
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 Department of Electronic Chemistry Tokyo Institute of Technology at Nagatsuta 4259 Nagatsuta-cho, Midori-ku Yokohama 227

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