JPRS-JST-87-027
23 SEPTEMBER 1987

FOREIGN BROADCAST INFORMATION SERVICE

JPRS Report

Science & Technology

Japan

JPRS-JST-87-027
23 SEPTEMBER 1987

SCIENCE & TECHNOLOGY

JAPAN

CONTENTS

DEFENSE INDUSTRIES

ENERGY

LASERS, SENSORS, OPTICS

TELECOMMUNICATIONS

/9987

HITACHI DEVELOPS CERAMIC SUPERCONDUCTING DEVICE

OW111017 Tokyo KYODO in English 1003 GMT 11 Aug 87

[Text] Tokyo, 11 August KYODO--Hitachi Ltd. said Tuesday it has test-manufactured a ceramic superconducting quantum interference device (squid) that it made into the form of a fine film by applying its semiconductor fine process technology.

The new squid, which reached its superconducting temperature through cooling with cheap liquid nitrogen at minus 196 C, can detect faint magnetic fields with a strength only a 10 millionth that of the earth's magnetic field.

This means that the new squid can be incorporated into medical diagnostic equipment intended for diagnosing brain and heart disorders by catching changes in the extremely weak magnetic fields these organs generate, the company said.

Hitachi's new squid is made using a high-frequency sputtering process to form a thin film of yttrium-barium-copper oxide onto a substrate of magnesium oxide, which is then heat-treated in an oxygen environment.

The resulting superconducting film is one to two microns thick (a micron equals 1/1,000th of a millimeter) and superconducts at minus 187 C, at which temperature it has a maximum current density in excess of 6,000 amperes per square centimeter.

Optical exposure and chemical etching processes are then used to make a hole in the middle of the film, after which two Josephson junctions are connected to both of the hold to form a squid.

International Business Machines Corp. announced a thin-film ceramic squid similar to the Hitachi squid in April. However, the IBM squid has to be cooled to minus 205 C, and is not as sensitive as the hitachi squid.

Hitachi said it plans to officially announce its new squid at the international superconducting electronics conference, which will be held in Tokyo 28-29 August.

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RECENT TRENDS IN SUPERCONDUCTOR DEVELOPMENT DISCUSSED

Tokyo SHIN KINZOKU KOGYO in Japanese Summer 1986 pp 1-8

[Article by Hideo Ihara, Electrotechnical Laboratory: "Recent Developments in New High-Field Superconductors"]

[Text] 1. Introduction

Broad new fields of application for superconductors are opening up in the forms of superconducting magnets, power storage, power transmission, etc., as well as transformations in medical treatment and the manufacturing industry. In the electronics fields, also, the future for new materials is bright with regard to Josephson elements and Fluxon elements. in addition to the conventional superconductors Nb, NbTi, Nb_3Sn, and V_3Ga, such new materials as Nb_3Al, Nb_3Ge, NbN, and $PbMo_6S_8$ have been added, with considerable interest focused on their application. A new phase was also ushered in with the availability of such new materials as the superconductors MoN and UBe_{13}, the compound function superconductor $BaPb_{1-x}Bi_xO_3$, the artificial lattice superconductor Au/Cr, and the organic superconductor $(BEDT\text{-}TTF)_2I_3$.

Topics for superconductor development fall into the following six categories:

(1) Development of high critical temperature (T_c) materials

(2) Development of higher critical magnetic field (H_{C2}) and high critical electric current density (J_c) materials

(3) Development of materials for high-performance Josephson elements and Fluxon elements

(4) Development of superconductors with new functions

(6) Development of superconductors with new materials

Development objectives for these categories are summarized along with related materials in Table 1.

The need for high-T materials mentioned in (1), in a word, lies in escape from the restrictions imposed by liquid He. This becomes quite obvious when we consider both the technological and economic burdens of the refrigeration

Table 1. Areas of Superconductor Development

Area of development	Developmental objective	Material system
(1) High-T_c materials	At present 30K, next 100K, finally 300K	Nb_3Si, Nb_3C, MoN, RuN
(2) High-H_c and high-J_c materials	Wire making of present materials 100T, finally 1000T	$Nb_3AlN(Al,Ge)Nb_3Ge$, NbN $PbMo_6S_8$, application of f electrons
(3) High-performance J element and f element materials	High speed, high reliability, high durability	Nb, NbN, Nb_3Ge, Nb_3Al
(4) New-mechanism superconductors	Superconductors with exciton and plasmon mechanism, T_c approximately 1000 K	CuCl(?) CdS(?) Artificial lattices, low-dimensional materials
(5) New-function superconductors	Superconductors of light and magnetism linking	$BaPb_{1-x}Bi_xBi_xO_3$, $Li_xTi_{2-x}O_3$
(6) New-material superconductors	Moving toward high T_c for organic conductors	$(BEDT\text{-}TTF)_2I_3$

required for liquid He, and also the instability of future He supplies. For these reasons, and as can also be seen from Figure 1, development of superconductors with T_c of 30-35 K is needed. If a closed cycle cooling system is possible, then superconductor technology will require only a power source for use any time, any place. This can be expected to hasten popularization. The use of liquid hydrogen and liquid Ne is also meaningful in consideration of reduced refrigeration cost and freedom from problems of raw resources availability.

Developmental objective (2) is now the formation into wire of previously available superconductors Nb_3Al, $Nb_3(Al_{0.7}Ge_{0.3})Nb_3Ge$, and $PbMo_6S_8$. For the long term, there is the need for research to increase the high-T_c properties of heavy fermion superconductors which have a good probability of showing high T_{c2}.

With regard to (3), Nb and NbN will be basic materials in the near future, with Nb_3Ge and the A15 compound Nb_3Al the subjects of special applications. Because of the poor durability and reliability of Pb alloys, it seems certain that they will be replaced by materials of the Nb family.

Objective (4) is the implementation of high-T superconductors with new superconductor structuring by means of (plasmons) (quanta of collective

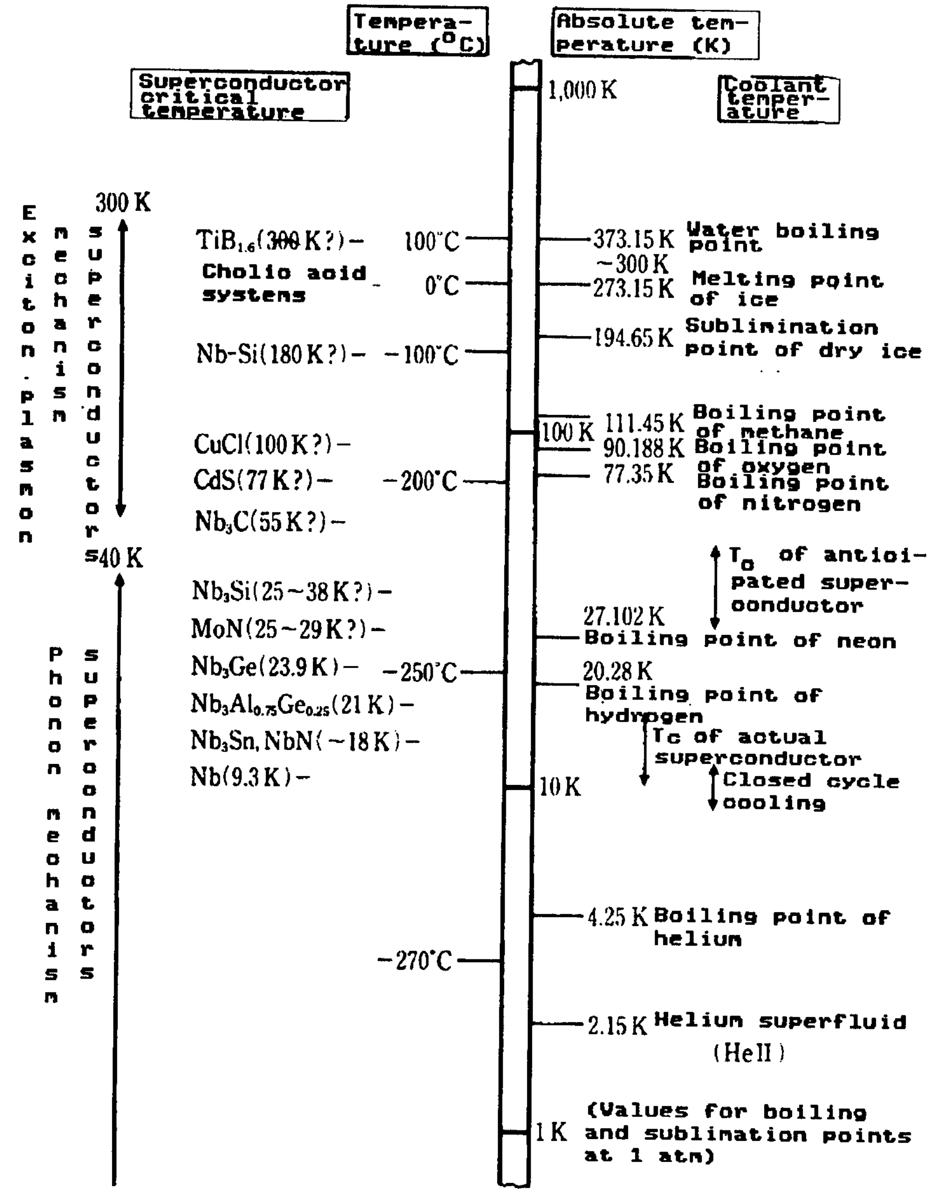

Figure 1. Critical Temperature (T_c) and Coolant Temperature for Superconductors

excited state electrons) and (excitons) (quanta of electrons and positive holes bonded together by static force), which will replace current superconductor structuring by means of phonons (lattice vibration). There are also methods which use a position shift in phase-completing electron density waves, without creating these sorts of electron pairs.

(5) is designed to link superconductors with characteristics of light, electricity, magnetism, heat, force, radiation, etc., to obtain new functions from these superconductors. Examples include such photosensitive materials as $BaPb_{1-x}Bi_xO_3$ and such magnetic superconductors as $ErRh_4B_4$ and $HoPb_6S_8$.

(6) involves superconductors which use as constituents materials other than ordinary inorganic metals, including organic materials and oxides. These materials can be included in any of the functional categories (1)-(5), but in terms of the growth of new materials, they should receive special consideration as an independent category.

Directions of development for superconductor wire and material for Josephson elements were explained previously by Tachikawa and Mikoshiba in this publication, and will not be duplicated here. Instead, we will emphasize the developmental directions for new superconductors beyond those. Materials discussed here will be new high-T_c superconductors, oxide superconductors having optical sensor functions, heavy fermion superconductors having a good probability of giving rise to high H_{c2} superconductors, and organic superconductors having some probability of becoming new material superconductors.

2. New High-T_c Materials

Categories of high-T_c materials vary depending on the developmental objectives of T_c. At present, normally those materials are considered which have a T_c of 15 K or above but less than 20 as shown in Table 2. However, the objects of future practical research will probably show higher T_cs than such materials currently in use, including Nb_3Sn wire (18.4 K) and NbN Josephson elements (17.3 K). In the area of wire development, materials having a high T_c include Nb_3Ga (20.3 K), $Nb_3(Al_{0.7}Ge_{0.3})$ (20.7 K) and Nb_3Ge (23.9 K). In the electronics field, this category includes materials of A15-type structure, including Nb_3Sn. The reader should refer to footnoted documents (2) and (3) for more information on these materials.

From the point of view of developing new high-T_c materials, there are previously popular materials which presently have a low T_c but demonstrate the possibility of rasing the maximum T_c value (23.9 K). These include such materials as Nb_3Si, Nb_3C and V_3C, which have the A15-type structure, and MoN, RuN, and RhN, which have the B1-type structure. These materials having a high-T_c are substances not present in equilibrium phase diagrams, and are extremely difficult to synthesize. The cause of this difficulty in synthesis turns out to be the cause of the high T. In other words, research and development regarding high-T_c materials becomes R&D on the technology of nonequilibrium materials synthesis itself. It seems apparent that both the difficulties and the points of interest in future R&D on these high-T_c materials will lie in this area.

Why, then, do the A15-form Nb_3Si and Nb_3C yield high T_cs? The answer is provided by empirical rule, from a lattice constant and T_c. When an A15-type compound of the Nb family is graphed and plotted as shown in Figure 2, with the lattice constant on the horizontal axis and T_c on the vertical axis, then T_c can be predicted for Nb_3Si of 30 K, and for Nb_3C, with a lattice constant of 4.08 A, of over 77 K. A separate empirical rule form Dew-Hughes predicts values for Nb_3Si and Nb_3C of 38 K and 55 K, respectively. A15-type Nb_3X compounds can be stabilized in a state of equilibrium when the atomic radius ratio lies in the range of $0.97 < r_X/r_{Nb} < 1.065$. Since $r_S/r_N = 0.88$ and $r_C/r_{Nb} = 0.51$, the production of Nb_3Si and, in particular that of Nb_3C,

Table 2. Characteristics of High-T_c Superconductors (T_c > 15 K)

State		Symmetry	Structure	Superconductor	T_c(K)	H_{c_2}(T) (4.2K)	Gap energy $\Delta(0)$(meV)	Coherence length $\xi(0)$(nm)	Magnetic interstitial length $\lambda(0)$(nm)
Compound	(Two components) system	Cubic crystal	A15	Nb_3Ge	23.9	37	3.9	~3	130
			〃	$Nb_3(Al_{0.7}Ge_{0.3})$	20.7	42			
			〃	Nb_3Ga	20.3	34			
			〃	Nb_3Al	18.9	32.5	3.5	~3	(150)
			〃	Nb_3Sn	18.5	28	3.4	~3	170
			〃	V_3Si	16.9	25	2.5	~3	(150)
			〃	V_3Ga	16.8	27			
			〃	Mo_3Re	15				
			B1	NbN	17.3	43	2.5	~3	200
			〃	$NbC_{0.2}N_{0.8}$	17.9	17			
			$D5_c$	$(Y_{0.7}Th_{0.3})_2C_3$	17.0				
			L12	Nb_3Ru_3	16.0				
		Tetragonal crystal	$D8_b$	Mo_3Tc_7	15.8				
		Hexagonal crystal		MoN	16.3				
	three comp. system	Rhombus crystal		$PbMo_6S_6$	15.2	50	2.4		
Alloys	three comp. system	Cubic crystal	B1(fcc)	PdCuH	16.6				
			〃	PdAgH	15.6				
	two comp. system	Cubic crystal	A2(bcc)	MoTc	16.0				

becomes difficult. This is because on each face of the body-centered cubic lattice formed by Si or C, two Nb atoms must be skewered like dumplings on a stick, with negative effects for the atomic radius ratio. Thus, the very cause of a raise in T_c also causes an increase in the difficulty of synthesis. At present, a T of 19 K can be implemented for NbSi through application of 1 M bar (one million atmospheres) through explosion compression. With Nb_3Ge, up to the present, only values of 13 K and below have been obtained using such methods as CVD, simultaneous vapor deposition, and the sputter method achieving 2.3 K and above. In the future, it will be necessary to develop synthesizing processes using negative ions and plasma to increase the ion radius of Si and C.

For such B1-type compounds as MoN and RuN, as shown through empirical rules in Figure 3, the relationship between the lattice constant and T_c predicts a T_c of approximately 30 K for MoN, TcN, RuN, and RhN. Also, in addition to the nitrides, the relationship between the electron state density $N(E_F)$ and T_c predicts a T_c of approximately 23-32 K for Tc, Ru, and Rh. When easily generated lattice vibration irregularities and instability in covalent bonding are added to substances having these high electron state densities, even

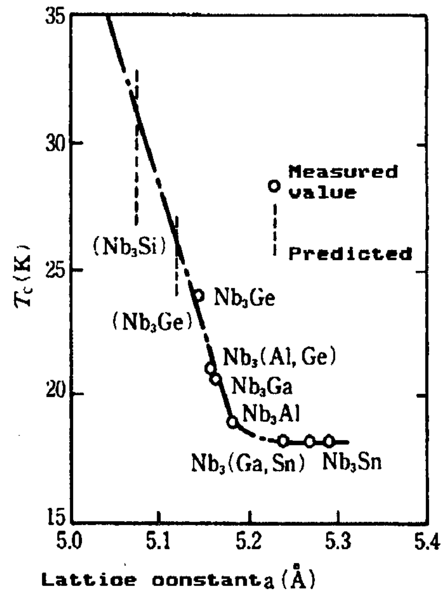

Figure 2. Relationship Between Lattice Constant and T_c for A15-Type Nb Based Compounds

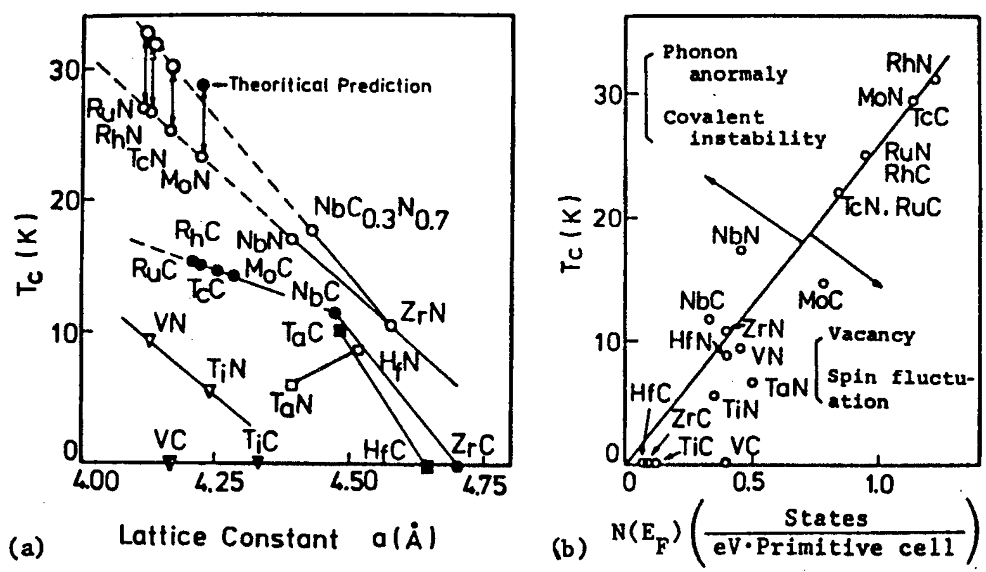

Figure 3. Relationship Between T_c for B1-Type Transition Metal Nitrides and Carbides, and Lattice Constant (a) and Electron State Density (b)

higher T_c can be expected. The above are based on empirical rules, but for MoN we have precise T_c calculations based on band calculations, form which a T of 29.3 K can be estimated. The authors have also confirmed the accuracy of these band calculations, and consider these estimates to be highly accurate.

Synthesis of B1-MoN has been attempted in the United States, Japan, and Germany, with theoretical estimates by the NRl group in the United States of 9 K, by the authors of 13 K, and by Linker and associates in Germany of 6 K. Actually, more than 10 other groups have also attempted synthesis using the sputter and high pressure methods, but their results have been far from the target T_c.

The causes of low T_c lie in the presence of large quantities of unbonded N and of N space lattices within the B1-MoN crystals. This incomplete Mo and N bonding is caused by the fact that a large part of the electron structure of B1-MoN is in antibonding status, making bonds unstable. In order to raise the T_c for the B1-type transition metal compounds it is necessary to increase the electron state density and thus increase the number of valence electrons. Then the proportion of antibonding orbits will increase and bonds will become destabilized. Even here, the principle, which causes T_c elevation, makes production difficult. Such methods as the use of active electron state nitrogen and atomic ions, catalytic effects, the optical atomic level epitaxial method and high-pressure high-temperature processing are thought to be effective in overcoming this problem, and are being widely tested.

We will discuss one method of high-pressure synthesis. This method was chosen for testing because, although there is hex-Mon in the B1-MoN combined phase, the packed density of electrons in the B1 phase is higher, so that there is more possibility of improved crystallization and hex--B1 phase transition with high-pressure high-temperature treatment. When B1-MoN crystals were processed under 6 GPa of pressure at a temperature range of 700-1,400°C, phase transition was observed from the B1 phase to the hex phase for all but a small portion of the sample. The maximum T_c was 16.3 K which, as Table 1 shows, is the highest T_c obtained for presently available superconductors consisting of other than cubic crystal materials. This is of great importance, since actual experience to date has normally shown higher T_c values for cubic crystals than for hexagonal ones. As Figure 4 shows, it is known that when crystals of the same composition are changed from hexagonal to cubic there is an increase in T_c of 5-10 K. From this, too, we can estimate a T_c of 21-26 K for B1-MoN if perfect crystals could be obtained. In addition, a T_c for perfect B1-MoN crystals of approximately 25 K can be estimated from the N space lattice concentration for B1-MoN and the electron state density ratio for hex MoN and B1-MoN. It is only a question of time until the T_c for B1-MoN exceeds the T_c for NbN and reaches 20 K or above.

A T_c of 30 K is also estimated for B1-RuN, and at present production is being attempted. Production of this substance is difficult, since the antibonding orbit specific gravity is greater than that for MoN. At present, B1-RuN crystals have not been successfully obtained in perfect form, but a T_c of 10 K or above has been obtained for systems having a low nitrogen content. This T_c is still low, but since relatively high T_c values have been obtained so simply, it appears that Ru-N systems will provide superconductors having high T_c properties. Although there is some hope for the future, implementation will be difficult since at present Ru is among the precious metals, with only approximately 8 tons produced annually worldwide. Reserves should be confirmed. There are also expectations for TcN and RhN, but these face similar difficulties with regard to resources.

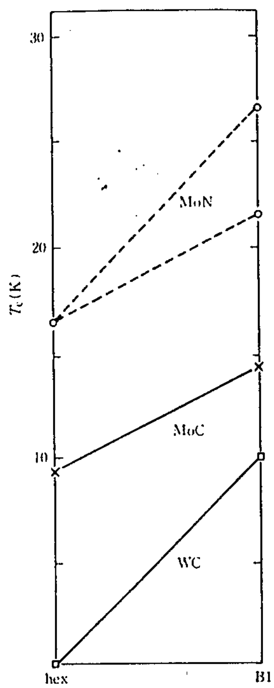

Figure 4. Relation Between Crystal Structure and T_c for Transition Metal Compounds

Other high-T_c materials research has taken the form of investigating new crystal forms other than A15-type and B1-type compounds. This research does not involve the expansion of already existing materials, so the linear estimates used up to this point do not hold. Instead, a qualitative leap in materials design methods is required. Presenting results only for the sake of documentary convenience, such cubic crystals as Y-Mo-B, Y-Nb-B, Y-Nb-P and Y-Mo-P are powerful candidates. Y and Mo, and Y and Nb, show nonsolid-solubility, and do not react, while through B or P both can be bonded. Such action by B or P is termed the "Gorota Ishi" [small-stone] effect. These physical systems are also in a disequilibrium phase. It seems likely that the new physical systems resulting from such combinations with nonsolid-soluble elements will provide a direction for future investigations into high-T_c materials.

3. Oxide Superconductor Materials

Attention has been focused on oxide superconductors in particular because they are expected to provide superconductor materials with a surprisingly high T_c for oxides and with a high degree of optical permeability and good optical performance due to the low carrier concentration. Oxides with T_cs of 4.2 K or above include Li_{1+x} $Ti_{2-x}O_4$ (13.7 K), $BaPbP_{-x}Bi_xO_3$) (13 K), Rb_xWO (7.3 K0 and Cs_xWO_3 (6.2 K). The characteristics of the first three are shown in Table 3. Of particular interest is $BaPb_{1-x}Bi_xO_3$. This material shows a high T_c even though its carrier concentration is one order of magnitude lower than that for ordinary superconductors. Because of the low carrier concentration, it resembles the semiconductors in optical permeability and structural

Table 3. Characteristics of Typical Oxide Superconductors

Characteristics \ Oxide	$BaPb_{1-x}Bi_xO_3$	$Li_{1+x}Ti_{2-x}O_4$	Rb_xWO_3
Crystal form	Tetragonal crystal	Cubic crystal · spinel	Hexagonal crystal · perovskite
T_C(K)	13	13.7	7.2
H_{C_2}(T)	5.5	18.5	
Electron specific heat coefficient (mJ/mol·K^2)	1.6	20	~1
Carrier concentration ($10^{21}cm^{-3}$)	2~3	13.5	(~2.0)
Electron state density $N(E_F)$ $\left(\frac{\text{states}}{\text{eV}\cdot\text{spin}\cdot\text{atom}}\right)$	0.03	0.97	
Resistance rate ρ($\mu\Omega$ cm)	545	20000	(1000)
Effective mass (m^*/m)	0.5	9.4	
Reflective rate R(%) $\lambda = 1\ \mu m$	3		
Absorption coefficient (cm^{-1}) $\lambda = 1\ \mu m$	10^5		

sensitivity. This material is also of interest because it shows the highest T_c of the materials with superconductor electrons made up only of sp electrons, and because of its particularly high degree of electron/lattice interaction.

$BaPb_{1-x}B_xO_3$ is a solid solution of $BaPbO_3$ and $BaBiO_3$, taking on a Perovskite structure. The superconductor consists of tetragonal crystals in a range of 0.05 < 0.3, with T_c maximized when x is approximately 0.25. The material shows good optical permeability due to its low carrier concentration; at a thickness of 300 nm, the backing is visible. The substance shows considerable mutual interaction with infrared rays, having actual optical characteristics of 0.6 µm of 10 percent reflectivity and absorbance coefficient 10^4 cm^{-1} at wavelengths of 0.6 µm, and 3 percent reflectivity and absorbance coefficient of 10^5 cm^{-1} at wavelengths of 1 µm.

The optical detection mechanism of superconductors uses transition across an energy gap, and in this point superficially resembles the use of band gap transition by semiconductor sensors. However, the content is quite different. In principle, a light beam activates the superconductor electron pairs, while decreases the energy gap, and shows a nonequalibrium superconductor effect. This makes it possible to utilize changes in the characteristic Josephson junction I-V gap voltage corresponding with the amount of illumination. This point differs from the photoelectric effect found in semiconductors, in which the current varies with the amount of illumination.

When using $BaPb_{1-x}Bi_xO_3$ in a sensor, one method involves using the particle boundaries which occur in sputter membranes as Josephson junction barriers. For sputter membranes of approximately 200 nm in thickness, aggregates of crystals having approximate diameters of 250 nm are formed. When these are heat-treated in an oxidizing atmosphere at 600°C, lead oxides are volatilized from the highly flawed particle boundaries, and the particle boundaries are converted to insulators. In this way, using the particle boundaries as a barrier, the crystals form Josephson junctions. If 10-unit particle boundaries are separated and a voltage bias is applied, then 10 elements are linked in series, a voltage of 10 times the initial magnitude is generated, and sensitivity is increased by that amount.

The importance for optical sensor materials of low carrier concentration in oxide superconductors lies in the fact that illumination-caused changes in the energy gap $\delta\Delta$ are inversely proportional to the electron state density $N(E_F)$, in other words the carrier concentration. For this reason, $BaPb_{1-x}Bi_xO_3$ shows a sensitivity 10 times greater than that of ordinary superconductors. In the case of $Li_{1+x}Ti_{2-x}O_4$, the d electrons participate, so that the carrier concentration increases, making this substance unsuitable for photosensor material. Future development is needed of materials having higher T_c and lower carrier concentration.

4. Heavy Fermion Superconductors

Normally, the coefficient γ for electron specific heat ($C = \gamma T$) is approximately 1 $mJ/mole.K^2$. However, there are compounds of the lanthanum (4f) and actinium (5f) series, including such superconductors as UBe_{13}, UPt_3, and $CeCu_2Si_2$ in which the F electrons are valence electrons, which show such abnormally large values for γ as 1,000 $mJ/mole.K^2$ or above. Because γ is proportional to the effective electron mass (y-m^*), these are called heavy electron system or heavy Fermion system superconductors. Because the corresponding upper critical magnetic field H_{C2} increases in proportion to the increase in this γ, as Table 4 shows, H_{C2} is exceedingly large despite the low T. If the T_c could be increased, there is a possibility of obtaining a significantly higher H_{C2}.

Table 4. Characteristics of Heavy Fermion Superconductors

Characteristics \ Compound	UBe_{13}	UPt_3	$CeCu_2Si_2$
Crystal form	Cubic	Hexagonal	Tetragonal
Distance between f items (Å)	5.13	4.1	4.1
γ ($J/mole\ K^2$)	1.1	0.45	~1
m^*/me	192		
T_C(K)	0.85	0.5	0.67
H_{C_2}(0K)(T)	>6.0	~2.3	~2.0
Specific heat $C(T<T_C)$	T^3		$\sim T^3$

An unusually large effective mass is thought to be due to the relationship between γ values and the distance between f electrons, as shown in Figure 5, and also to the resulting narrowing of the f band, which occurs as the mutual interaction among f electrons decreases along with reductions in the above-mentioned distance. The spin fluctuation effect and the many-body effect are also considered of major importance. In addition, there is the possibility of superconductors having p waves from the parallel spins of superconductor electron pairs. (In normal superconductors, the spins of electron pairs are antiparallel, with spin sum of zero, and are termed s waves.) Experimental evidence has been reported regarding these p-wave superconducting structures, including specific heat and ultrasonic wave absorption. Spins are parallel for p-wave superconductors, so a shielding effect can be anticipated for the external magnetic field, with the possibility of producing a high-H_{C2} superconductor. The mechanism of this heavy Fermion superconductor is not yet clear, but further study of the application of these materials as new materials can be expected both because of the possibility of high-H_{C2} materials occurring in general and also because of the possibility of high-T_c materials occurring if the electron state density can be increased using the f electrons.

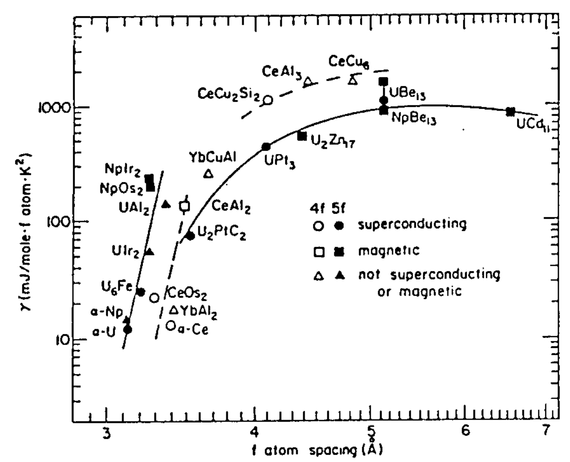

Figure 5. Interrelationship Between Electron Specific Heat Coefficient and Distance f Atoms for f Electron Materials

5. Organic Superconductors

The motivation for development of organic superconductors was the formation of one-dimensional organic superconductors of exciton structure with high T_cs as proposed by Little. This structure makes it possible to form electron pairs among the conducting electrons in the main chains by means of side chain electronic polarization (exciton), yielding a high T_c (approximately 1000 K). However, the first organic conductor substance, $(TMTSF)_2PF_6$ (shown in Figure 6), was not in the direction of the exciton structure organic superconductor proposed by Little, but instead was discovered as an extension of highly conductive ordinary charge transfer complex single-dimension organic metals. One-dimensional organic conductors, including TTF TCNQ and TMTSF TCNQ, which were organic metals with electric conductivity of 10^3-10^4 ($\Omega^{-1}\cdot cm^{-1}$), were

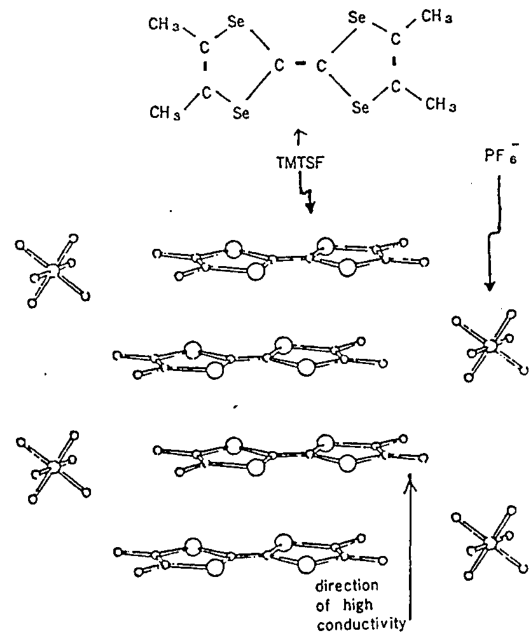

Figure 6. $(TMTSF)_2$ Molecules and Their Crystal Structures

discovered earlier. However, the lattice instability characteristic of one-dimensional metals was generated at low temperatures, with metal-insulator transitions (termed Peierls transitions by the author of proposal) such as CDW (charge density wave) transition occurring and resulting in demetalizing of the material. A superconductor phase could be expected if the one-dimensionality were encouraged through horizontal mutual interaction, the metal-insulator transition temperature (T_{MI}) lowered as far as possible, and the metal phase continued down to extremely low temperatures. A number of tests have been performed concerning donor-acceptor recombination for charge transfer complexes, high-pressure experiments, and chemical modification methods.

In the midst of all this, in 1980 such materials as $(TMTSF)_2PF_6$ and $(TMTSF)_2AsF_6$ synthesized by Bechgaard and associates were discovered to have a T_{MI} of 20 K or less. Jorome and Bechgaard then used the T_{MI} reduction effect based on the strengthening of mutual interactions in the horizontal direction through compression confirmed by a TMTSF-DMTCNQ system (TMTSF molecules are flat, as shown in Figure 4; the stack forms a one-dimensional column). This was used to show that superconductor transitions occurred in $(TMSTSF)_2PF_6$. Undeniably, there are points in this announcement which were developed from Little's organic superconductor proposal for exciton structure. However, it does not follow that earlier proposal since both the structure and mechanism are completely different. Certainly the framework of discoveries in this field is based on the earlier pursuit of organic materials having high conductivity, which led to the production of organic metals, and the ability to maintain this metal phase even at low temperatures gave rise to the discovery of superconductive properties. Of course, with $(TMTSF)F_6$ it is necessary to use compression to suppress the transition to the SDW (spin density wave) phase, which is the insulating phase, but that is not the

Table 5. T_c(K) for Organic Superconductors: Pressure (Kbar) in Parentheses

Cation / Anion (x)	$(TMTSF)_2X$		$(BEDT\text{-}TTF)_2X$	
PF_6	1.4	(6.5)		
AsF_6	1.4	(9.5)		
SbF_6	0.38	(10.5)		
TaF_6	1.35	(11)		
ClO_4	1.4			
ReO_4	1.2	(9.5)	~2	(74)
FSO_3	3	(5)		
I_3			2.5 8	 (1.3)
AuI_3			5.0	
$I\ Br_2$			4.2	

essential point. In actuality, substances showing superconductivity have been found in the subsequent seven categories in the $(TMTSF)_2X$ series as shown in Table 5, and $(TMTSF)_2ClO_4$, with the molecular volume of X reduced and mutual interaction (within the column) increased, shows superconductivity at normal pressure.

Based on this idea, four categories of another organic superconductor series, the $(BEDT\text{-}TTF)_2X$ series as shown in Table 5, have been created using the suppression of the Peierls transition through dimensionality increased by the chemical modification method. In particular, $(BEDT\text{-}TTF)_2I$ shows a T_c of 1.3 K for formed crystals, but after compression processing at 1.3 K bar, a T of 8 K was discovered even when the pressure was released. AuI_2 shows point symmetry and has a molecular length shorter than that of I_3; because of the increase in mutual interaction between the columns $(BEDT\text{-}TTF)_2AuI_2$ shows a measured T_c of 5 K even at normal pressure.

Organic compound superconductors and inorganic compound superconductors differ on a number of points, the former characterized as follows.

(1) They are composed of such commonly available elements as C, H, O, Se, I, and Cl, thus easing problems with resources.

(2) They can be made the object of molecular design for easy improvement of characteristics.

(3) They are configured as molecules, so there is room to build in functions in addition to superconductivity.

(4) Because they are organic, processing and forming properties are good.

Some of these points are not particularly appropriate at this time, but the essence is that materials possessing these characteristics are possible. If materials with high T_cs become available, they will be strong rivals to today's inorganic superconductors. The annual change in the organic superconductor's T_c is now similar to that of the inorganic superconductors before 1970. Whether this T_c continues to rise in accordance with the present trend, or whether it follows the path of the inorganic systems, depends on the capabilities of researchers in material design.

6. Conclusion

In this review we have discussed the possibilities for new superconductors. For information on magnetic superconductors and multimembrane superconductors, readers should refer to references (4) and (27) in the bibliography.

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20136/9365
CSO: 4306/3669

MATERIAL DESIGN OF HIGH PERFORMANCE GLASSES DISCUSSED

Tokyo KINO ZAIRYO in Japanese Feb 87 pp 42-52

[Text] 1. Introduction

High-grade materials are necessary for building a highly advanced system. This is the reason new and up-to-date materials attract attention. In the field of glass, a material called the new glass is attracting attention as an up-to-date material. In view of this situation, I wish to make a survey of the functions the new glass has as a glass and relate in what manner such a functional glass can be designed.

2. Definition of New Glass

In the first place, new glass can be defined as a highly technical and high-performance glass. However, let us think a little more concretely on its definition. Glass is a material used by mankind for more than 5,000 years. A material with such a long history ought to have some valuable characteristics worthy of its history. The characteristics of glass follow:

1) Possesses transparency and optical characteristics.

2) The continuous change of composition is possible. Therefore, the fine adjustment of physical properties is possible.

3) Practically all elements can be taken into the glass as a solid solvent.

4) Shapes from fibrous to flat plate can be freely processed. Highly-precise processing is also possible.

5) Possesses comparatively high strength and hardness, and it is chemically stable.

6) Secondary processing such as crystallization, phase splitting, and ion exchange are possible.

7) Various physical properties such as chemical and biological characteristics, electrical characteristics, and thermal characteristics can be provided.

Table 1. New Glass Classified by Characteristics

Type of glass	Characteristics 1	2	3	4	5	6	7
Refractive index distribution glass	0	0		0		0	
Quartz system optical fiber	0	0		0	0		
Laser glass	0		0	0	0		
Photochromic glass	0		0	0		0	
Delay line glass	0			0	0		0
Substrate glass	0			0	0		
Faraday rotation glass	0			0			0
Porous glass				0		0	
Biological glass				0	0	0	0
Chemical tempered glass				0	0	0	
Machinable crystallized glass				0	0	0	
Chemical cutting photosensitive glass	0			0		0	0
Radioactive waste treatment glass					0		0
Low expansion crystallized glass					0	0	0

Characteristics:
1 Transparency, optical characteristics
2 Continuous change of position possible; continuous change of physical properties
3 Characteristics as a solid solvent
4 Shape freedom and workability height
5 Comparatively high hardness and strength
6 Secondary processing of crystallization, phase-split and ion exchange possible
7 Possesses various physical properties such as chemical and biological characteristics, electrical and thermal characteristics

Table 1 shows which of these characteristics are present in glass presently manufactured using the new glass. By using optical fiber, which plays the leading role in optical communication, as the example, let us study what functions have been used. First of all, transparency is a proper function for the optical fiber. In addition to being simply transparent, there is an engineering value in that the loss value of 0.2 dB/km which is the theoretical value of the SiO_2 glass has been realized. By utilizing the freedom of changing the composition mentioned in item two, an optical waveguide has been formed by forming a core with a slightly high refractive index and a slightly low class in a concentric circle. Fibers extending several tens of kilometers can be prepared because of the workability mentioned in item four. The strength and hardness mentioned in item five are extremely important for use in utility materials.

When considered in such a way, the following definition of new glass is easier to understand. New glass is a material that has made the best and fullest use of the many characteristics of glass.

3. Itemized Discussion on New Glass

An outline will be given here on glass that is presently considered "new glass," and on what sort of new glasses, made of up-to-date materials, will be used in various devices in the future.

3.1. New Glass Utilizing the Optical Characteristics

(1) Refractive index distribution glass

In parallel with the progress of information transmission technology by optical fiber and optical electronics, optical circuit parts to perform optical branching, optical coupling, and waveform matching have become necessary. The refractive index distribution glass realizes such functions. There are various forms of this new glass such as the rod lens type, the flat plate type, and optical waveguide lens.

1) Rod lens

The rod lens is rod-shaped with a high refractive index in the central part, and a reduced refractive index in a parabolic condition towards the periphery. Its diameter is about 1 mm. It is used as a microlens in an optical disk pickup for converging the laser beam on the disk and for receiving light and condensing on the diode. Moreover, the arrangement of many rod lenses providing an equal magnification erecting image is called the lens array and it has contributed to the compacting, weight reduction, and cost reduction of facsimile machines and copying machines. How this lens is used is shown in Figure 1 and example (3) in Figure 1 shows the coupling system of the optical circuit.

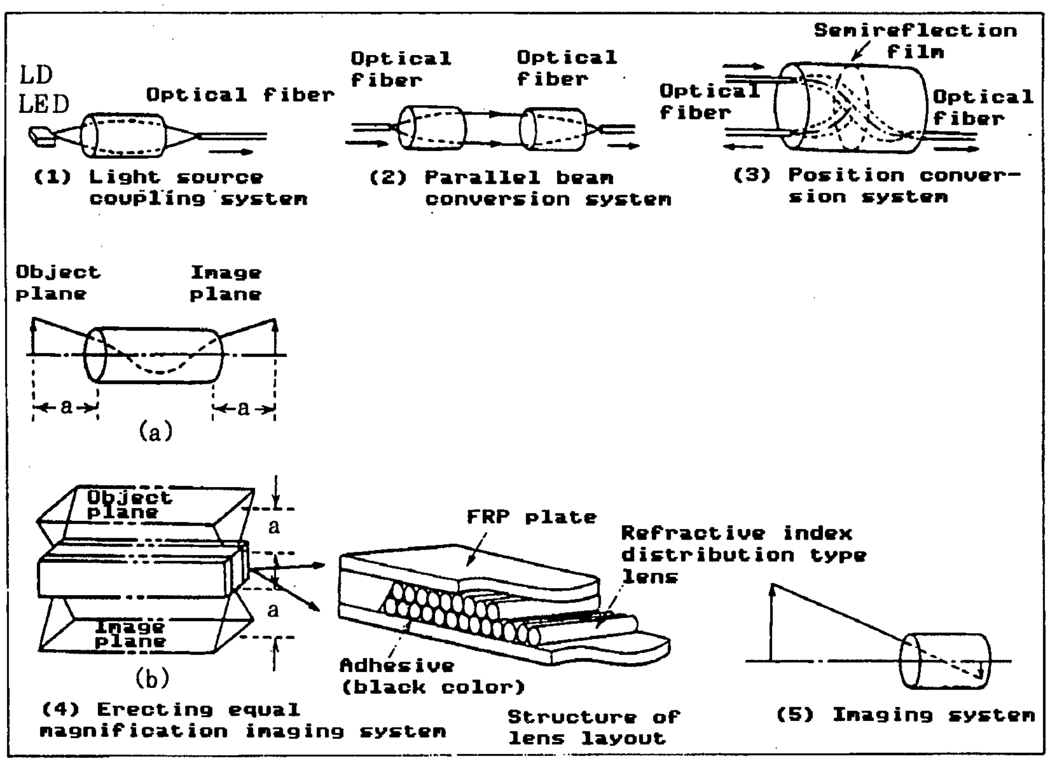

Figure 1. Application Examples of Refractive Index Distribution Lenses

In general, this lens is prepared by the ion-exchange method. In other words, a glass rod containing an ion with a high polarizability and capable of causing an easy ion exchange (a univalent cation generally and to be concrete, Tl^+, Cs^+) is prepared, this is treated in a molten salt of $NaNO_3$, KNO_3, and ion exchange occurs. As a result, a concentration gradient could be prepared so that ions such as Na, etc., are present close to the surface and ions such as Tl, etc., are present in abundance close to the center. The refractive index would be a similar shape.

2) Flat plate microlens

This lens is prepared by arranging many lenses in an array in a flat plate. Compared with the rod lens, it is better suited for mass production because it is flat and dielectric multilayers, filters, and diaphragms can be provided by surface treatment. It has characteristics such as being capable of composing an optical circuit by lamination, etc.

The flat plate microlens is prepared by the ion exchange method as is the rod lens, however, a method for impressing the electric field and expediting the intrusion speed of the ion has been adopted. In other words, after attaching a thin titanium film with the thickness of 1μ to 2μ on one side of a substrate glass by the sputter method, patterning is made on the part introducing the ion by the photolithography method and a circled window is prepared. This is maintained in molten salt, an ion raising its refractive index according to the electric field is introduced and the functions of a lens are provided.

Besides the above method, there is also the method of stacking, thin films with a high refractive index in order on a glass substrate that has a hemispheric hole by using the plasma CVD.

3) Optical waveguide lens

The optical waveguide prepares the functions of optical distribution, optical coupling, etc., on a flat substrate. Types of optical waveguides are shown in Figure 2.

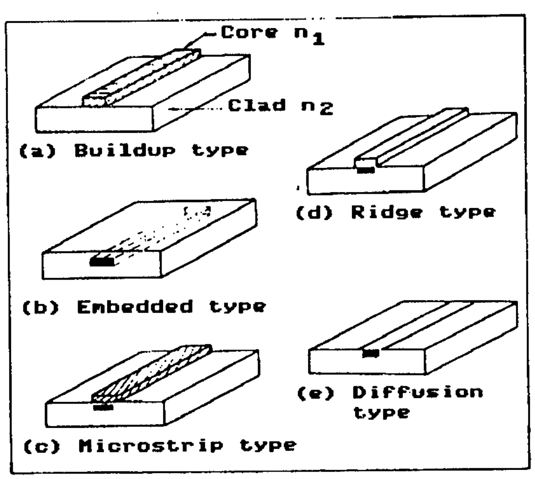

Figure 2. Types of Thin Film Three-Dimensional Optical Waveguides

(2) Energy of light transmission

Quartz glass, high-purity multicomponent glass, halogenide glass, chalcogenide glass, and heavy-metal oxide glass can be selected according to the transmitted optical wavelength for materials that are used for transmission such as those that are used for communication and transmit light over a long distance, and those that are used for a laser knife and laser material processing machines and transmit a high-energy laser beam.

1) Quartz system glass

This glass system has already been put to use in optical communication. The low transmission loss of 0.2 dB/km has been realized for light with a wavelength of 1.5 μm. This is also the theoretical value. Therefore, the future theme may be to offer a further low-priced fiber without any loss in capacity. For achieving this purpose, the problem of what process should be used for minimizing the OH group, which causes the transmission loss, may become an important technical theme.

2) High-purity multicomponent system glass

Because a refractive index difference between the core and clad can be larger in this glass than in the quartz system glass, a fiber with a high numerical aperture can be prepared and it excels in optical coupling with the light source. However, the transmission loss is several dB/km to 30 dB/km and it is used for the data link between equipment at a distance of 1- to 2-km. Although there is a possibility it may compete with plastic fiber in the future, the high-purity multicomponent glass presently possesses characteristics excelling the plastic fiber in the degree of more than one digit.

3) Infrared transmission glass

When trying to obtain a fiber with a lower transmission loss than the quartz system fiber, it is necessary to use the wavelength range decreasing the transmission loss by Rayleigh scattering. In other words, the method of using infrared radiation rays is the only solution. Because the transmittable wavelength range is up to 2 μm in the quartz system fiber, a material capable of transmitting longer wavelength infrared radiation rays should be selected. Three types of glass are candidates for an infrared light transmitting fiber: heavy metal oxide glass, fluoride glass, and chalcogenide glass. A minimum transmission loss of a value one to three digits lower than the quartz system glass can be expected. However, the actual transmission loss of the fiber still falls short of that for the quartz system glass. (Note; The same performance has been obtained for extremely short ones.) The reason is that the concentration of impurities is still high; microcrystals are generated in the glass and cause scattering. In other words, the basic problem is that it lacks stability compared with the quartz system glass and a breakthrough is required for future development.

(3) Laser glass

Because glass excels in workability and can be made into all sizes from large to fibrous types, the application field will widen when a high=efficiency glass laser is developed. Glass containing rare earth ions such as Nd, Yb, Ho, Er, and Tm as active ions has been confirmed showing a laser oscillation. However, the active ions maintained in the glass reflect the disordered structure of the glass, the width of the oscillation spectacle is wide and the oscillation efficiency is low. Besides the oxide system glasses such as the silicate glass and phosphate glass, the fluoride and chalcogenide glass are being studied as hosts. The phosphate glass, compared with other oxide system glasses, has the characteristic of the sectional area of induction emission being high, and in the fluoride phosphate glass the nonlinear refractive index coefficient is small.

The laser nuclear fusion has been studied as an application of the glass laser and has become an important theme of the gigantic chemistry.

(4) Photochromic glass

The phenomenon of changing the light transmittance by optical irradiation is called photochromism. A glass showing such a phenomenon has been prepared and put to use. There is the type in which the structural defects in the matrix of the glass are centered around coloring and the type that contains silver halide as the photosensitive crystal. An explanation of the latter type will be given as it has already been put to use.

Glass matrices of various compositions can be used. When glass containing silver and halogen is melted, silver and halogen are melted in ion condition in the glass. When the glass is heat treated at an intermediate temperature between the transition point and softening point of the glass, microcrystals of silver halide are deposited. The transparency of the glass can be maintained when the size of the crystal lattice is around 10 nm and the distance between the crystal lattices is 60- to 100-nm. When ultraviolet radiation rays or visible light rays are irradiated on crystal lattices, the silver halide undergoes a light oxidation-reduction reaction, decomposes, and becomes colored as an atomic silver is generated. Because coloring and decoloring necessitate a mechanism for stabilization by means of the structural recombination at the atomic level, those that stipulate the coloring and decoloring speeds are those that take part in the transport phenomenon such as the alkali ion in the glass and those that take part in the oxidation-=reduction reaction such as copper.

The photochromic glass is presently sued in spectacles. Other applications such as functional materials for optical memory of information storage, switching elements, and display devices can be expected. For this purpose, it is necessary that characteristics such as the coloring and decoloring speeds, etc., be improved.

(5) Optical integrated circuit

The optical integrated circuit prepares a part with a high-refractive index (optical waveguide) on a single substrate and integrates optical devices such as the luminescent and light-receiving elements, optical modulator, optical switch, optical separator, and optical filter on this substrate and is capable of performing functions by light that had been performed up to now by semiconductors.

The concept on the optical integrated circuit is one that has been advocated since the latter part of the 1960s and research has been active on this concept because expectations were held for compacting, high upgrading, and stabilization. With the optical fiber put to practical use and importance increasing on the optical transmission technology, research has been promoted as a replacement for the conventional integrated circuits.

The optical integrated circuit basically consists of three elements: a light source, various functional devices (waveguide, etc.), and a photodetecting element. They can be classified into either the hybrid type or monolithic type according to their form of integration.

The roles performed by glass in composing an optical integrated circuit include forming an optical waveguide, forming the part connecting with the fiber, and forming the passive parts of micro-optics (refractive index distribution lens, etc.). When the monolithic integrated circuit becomes the mainstream, GaAs, etc., may also become the mainstream.

(6) Optical memory

The optical and photomagnetic disks are being developed as devices capable of accumulating a large volume of information. The chalcogenide glass has been used as the memory film for the optical disk.

There are two types of optical disks, the postscript type and the rewritable type. The postscript disk irradiates by laser on the chalcogenide glass film, forms a hole by melting and evaporating the glass by the irradiated energy and performs recording by this hole. The rewritable disk crystallizes the thin noncrystalline layer by the laser ray and records using the change of he refractive index. Heating is made by a laser with a wavelength and strength different form the laser ray used in writing, and the record is erased by noncrystallizing it.

Films of Te, Te-Se, Te-Ge, Te-C, Te-Se-As, Te-Se-Pb, Sb-Se, and Te-Se-Sn have been used for recording films with excellent results.

3.2 New Glass Using the Electromagnetic Characteristics

(1) Electrochromic glass

The amorphous WO_3 has been studied as the functional film for display or for the dimmer glass. When an ultraviolet ion such as H^+ or Li^+ is injected into WO_3, W is reduced, it becomes of pentavalence and is colored into blue.

Differing from the liquid crystal display, it remains colored by the memory effect once it has been colored. Therefore, its application as window glass, etc. is possible. The structure of a dimmer glass is shown in Figure 3.

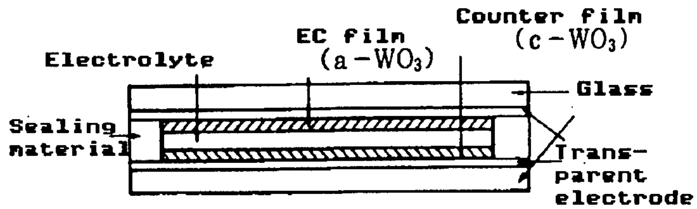

Figure 3. Example of Dimmer Glass Structure

The vacuum vapor deposition method, RF sputter method, anode oxidation method, spraying method, thermal decomposition method of organic tungsten, etc., are used for forming the amorphous WO_3 film, however, the electron beam vacuum vapor deposition method is generally used.

These glasses are still in the development stage and there are many problems that must be solved. Particularly, the development on the production technology of a large area cell will become important when these glasses are used for automobile and house windows. Moreover, since the amorphous WO_3 has the photochromic characteristic of coloring by light, the basic research on how it should be held down will become important.

(2) Faraday rotation glass

The Faraday effect is a phenomenon in which the polarizing direction of the linearly polarized light progressing in a solid rotates by the magnetic field. In other words, the following equation is obtained when the angle of rotation is made θ, the material length is made 1, and the magnetic field strength is made H:

$$\theta = V \cdot \ell \cdot H$$

V in the above equation is the Verdet's constant and is a physical constant peculiar to the material. In the Faraday rotation glass, a big V and a small absorption coefficient are demanded. There are many types of glass containing earth elements (Ce, Pr, Tb, Dy, etc.) with a large Verdet's constant.

The Faraday rotation glass has been applied to ammeters and optical isolators in the laser optical system, i.e, elements passing light in only one direction. Utilization as an optical switch in the optical communication and optical measurement fields are considered future markets. The device is capable of turning on and off the light by the electric current and the concept drawing is shown in Figure 4.

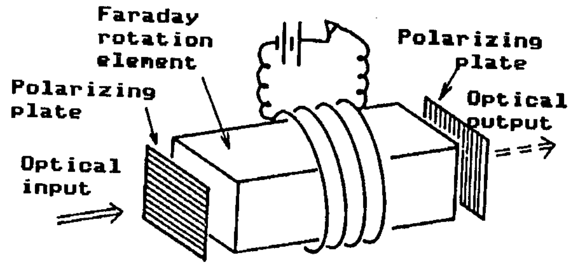

Figure 4. Concept Drawing of Optical Switch

(3) Glass substrate

There are presently five glass substrates for electronic devices. They are: 1. Glass substrate for amorphous solar cell; 2. Glass substrate for flat display; 3. Glass substrate for the optical, photomagnetic, and magnetic disks; 4. Glass substrate for the photomask; and 5. Glass substrate for the hybrid IC. The qualities needed for each application differ considerably. The substrate for the magnetic disk will probably become competitive with existing substrates such as aluminum, etc. Moreover, because transparency is demanded in an optical disk, optical disks may become competitive with plastics.

3.3 New Glass Using the Mechanical, Chemical, and Thermal Characteristics

(a) Ceramic reinforced glass

Ceramic reinforced glass lacks toughness. This is a defect when it is used in mechanical applications. Research is being done on tempered glass compounded with ceramic fiber, etc., to correct this defect. A high modulus of elasticity and high strength are preferable for reinforcing fibers. Therefore, carbon fiber, alumina fiber, SiC fiber, or whiskers, are used as the reinforcing fiber. Conditions such as not reacting greatly with the fiber and the suitable coefficient of thermal expansion are necessary for glass to become the matrix, therefore, crystallized glasses of the Li_2O-Al_2O_3-SiO_2 system, borosilicate system, and high-silicate glass are used. Compound materials capable of being machined are available by selecting the reinforcing fiber and matrix.

This material is still in the research stage and has not been put to practical use. Since it is lightweight and excels in high strength, high toughness, and heat resistance, development for uses in high-temperature precision machines, artificial bones, etc., are now underway.

(2) Oxy-nitride glass

This glass has substituted a portion of the oxygen ions in an oxide glass with nitrogen ions and as three coordination anions exist in the glass structure, a glass with high strength and excelling in heat resistance can be manufactured. The following are the production methods:

(1) Method of blowing ammonia gas into melted glass.
(2) Method of treating porous glass in ammonia gas.
(3) Method of using nitrogen compound materials (Si_3N_4m AlN), etc.

Uses for reinforcing glass fibers, etc., can be considered, however, there are many research problems such as the difficulty of making the glass into a fiber, etc.

(3) Chemical reinforced glass

This glass is strengthened by generating a compressive stress on the surface layer. This is done by treating the glass in molten salt containing alkali metal elements and replacing the alkali ions with larger alkali ions that originally were in the glass. A glass with a higher strength than the wind-cooled tempered glass, which is an ordinary tempered glass, is available by this treatment method. The strength of a chemical reinforced glass depends upon the glass composition and treatment temperature. Glasses well suited for chemical reinforcement are those in which the mutual diffusion coefficient of alkali ions is great and those with a small amount of noncross-linking oxygen. Therefore, a glass with Al_2O_3, TiO_2, and ZrO_2 added to the silicate system glass has been selected.

The chemical reinforced glass has been used for spectacle lenses, watch covers, etc. In the future, new uses such as for optical memory-related substrate glass, large-sized display glass, etc., may be developed.

(4) Chemical cutting glass

When ultraviolet radiation rays are irradiated on the Li_2O-Al_2O_3-SiO_2 system glass containing silver ion, the exposure to light generates a silver colloid. When heat treatment follows, the silver colloid becomes the crystal core and crystals of lithium metasilicate are deposited. Because these crystals greatly lack in chemical durability, compared with the parent glass, and dissolve in diluted hydrofluoric acid, only the crystallized portion can be removed. The production process for such a glass is shown in Figure 5. The chemical cutting glass is used for the printer wire guide, the substrate for thin-film magnetic head, and as the head for the ink jet printer.

3.4 New Glass Using Biological, Biochemical Characteristics

(1) Biochemical porous glass

A porous glass has fine continuous holes of 1- to 100-nm. The porous glass developed by the Corning Glass Works in the United States was the first of its kind in the world. It has been commercialized in Japan.

The porous glass is prepared by utilizing the phase splitting phenomenon of glass. When a borosilicate glass of a suitable composition is dissolved under a normal method and reheated after the molding, the glass undergoes phase splitting and separates into a part rich in SiO_2 and a part rich in B_3. Because the B_2O_3-rich part dissolves when treated with acid, a porous glass, as shown in Figure 6, results.

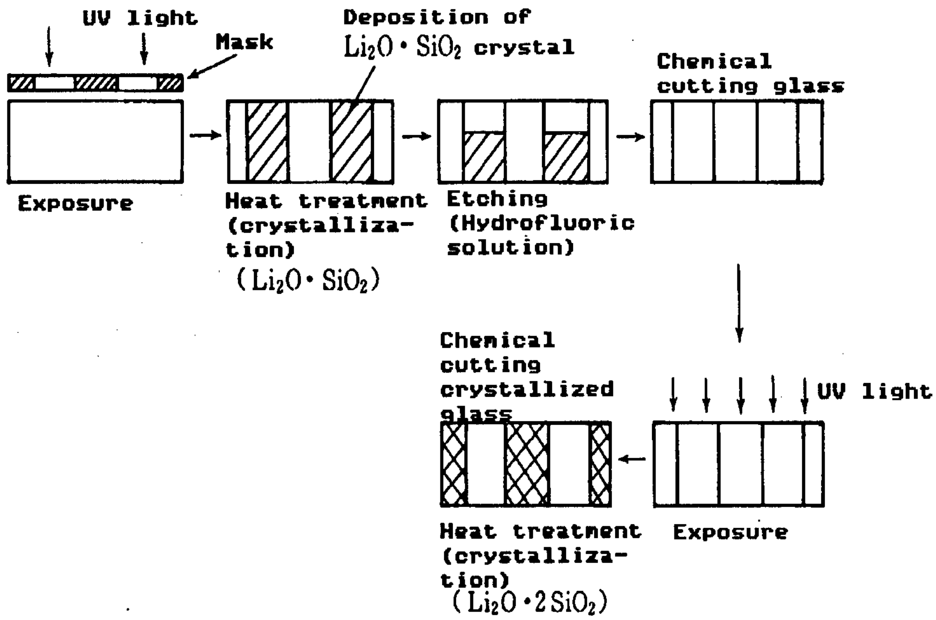

Figure 5. Manufacturing Process of Chemical Cutting Photosensitive Crystallized Glass

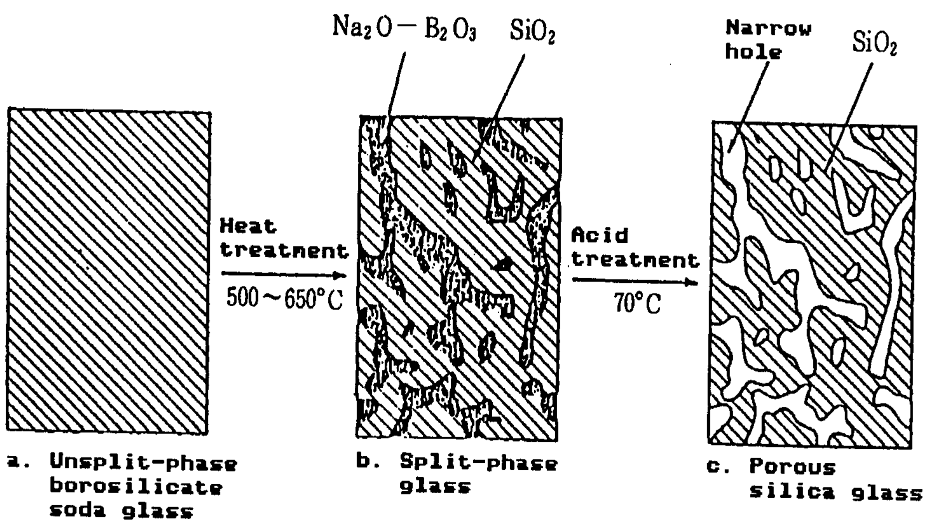

Figure 6. Preparation of Porous Silica Glass

The biochemical uses of this glass include the segregation and purification of microorganisms and biochemical matters, and the immobilization of microorganisms. For example, a column of porous glass can segregate and purify different size viruses. The use of porous glass as an immobilized enzyme carrier will probably be put to practical use on a larger scale.

Generally, enzymes are expensive and it is said that recovery is difficult when once used and the enzymatic activity often declines. If the enzyme can be immobilized on the surface of some material and the decline in activity can be prevented, it will answer the need for reducing the cost of using enzymes. The organic polymer and porous glass are promising candidates for carriers.

(2) Biological hard-structure glass

Hopes are placed on glass and crystallized glass as materials for artificial bones and artificial tooth roots. Metals have been mainly used up to now as hard-structure materials. However, metals do not have a biological affinity and they are used with the expectation that they will be extracted. Ceramics such as alumina, etc., are also without a biological affinity, however, they are warrantable, even when left within a living body, because they are free from toxicity. However, materials without a biological affinity have the defect of generating a gap between the peripheral structures and it is considered that materials with an affinity will become the mainstream.

The biological glass has an SiO_2-P_2O_5-CaO-Na_2O system base and a biological affinity as it resembles the constitutive elements of bones. However, the strength of the glass is low and it is difficult to put it to practical use. Therefore, crystallized glass and compounded crystallized glass are being studied. Crystallized glass with a crystal phase similar to the apatite in bone and with increased strength due to crystallization, and glass that has crystals growing in a single direction under stress and provided with the same structure as fiber-reinforced materials have been developed.

As stated, the biological hard-structure glass is to be used for artificial tooth roots and artificial bones, and, at present, the only biological glass that has been put to use is the aural small bone implant. All others are still in the clinical stage.

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20158/9365
CSO: 4306/7555

BRIEFS

SUPERCONDUCTING MATERIAL DEVELOPMENT--Tokyo, 4 August KYODO--The Ministry of International Trade and Industry's Electrotechnical Laboratory said Tuesday it has developed a new superconducting compound that showed a transition to a zero-resistance state at 65 C, or 338 Degrees Kelvin. The new superconducting material, which is an oxide based on strontium, barium, yttrium, and copper, continued in the zero-resistance state similar to superconductivity for 10 days at room temperature in the air, the laboratory said. The Electrotechnical Laboratory also noted that measurements of the new material allowed it to observe a nonlinear characteristic curve between current and voltage at 65 C, which is another indication of superconductivity. The research results of the laboratory's experiments with the new superconducting material will be published in the August edition of the JAPANESE JOURNAL OF APPLIED PHYSICS. [Text] [Tokyo KYODO in English 1113 GMT 4 Aug 87 OW] /12232

CSO: 4306/0523

COUNTRY PLANS THREE-AXIS WEATHER SATELLITE

Tokyo AEROSPACE JAPAN-WEEKLY in English 3 Aug 87 pp 5,6

[Text]

The Meteorological Agency and the National Space Development Agency of Japan (NASDA) plan to replace the spin-stabilization system now used in the "Himawari" series weather satellites with the three-axis stabilization system beginning with the fifth weather satellite which is scheduled for launch in 1993.

The planned new satellite will be supplied by either Ford Aerospace of the U.S. or Aerospatiale of France. It will be equipped with two infrared-ray cameras to improve observation capabilities.

The currently operational "Himawari-3" weather satellite is basically the same as the U.S.' GOES (Geostationary Operational Environmental Satellite) developed by Hughes Aircraft. It is a spin-stabilization satellite.

Japan plans to launch another spin-stabilization weather satellite or the "Himawari-4" in August 1989. The planned three-axis stabilization satellite will be launched in 1993 as the "Himawari-5." Launching cost is estimated at ¥30 billion compared with ¥22 billion now required for the conventional spin-stabilization satellite.

/8309
CSO: 4307/033

MOS-1 TO BE LAUNCHED IN JANUARY 1988

Tokyo AEROSPACE JAPAN-WEEKLY in English 3 Aug 87 pp 6, 7

[Text]

The National Space Development Agency of Japan (NASDA) has announced that it would launch Japan's first remote sensing satellite called MOS-1 marine observation satellite on January 23, 1988, from the Tanegashima Space Center in Kagoshima Prefecture.

The satellite will be equipped with three different sensors for practical observations of the earth (primarily the oceans). The sensors include a multispectrum electronic self-scanning radiometer, a visible and thermal infrared radiometer and a microwave scanning radiometer.

It will be used to observe water vapor in the atmosphere, ocean currents, the water surface temperature, the water-content of clouds, the distribution of ice floes and of chlorophyl, the generation of red tides, the detection of mineral and energy resources, crop inventories and so on.

The observation data will be provided to organizations cooperating in this evaluation and to overseas earth observation stations.

The satellite will weigh about 740 kilograms and will be launched into a sun-synchronous orbit at an altitude of about 900 kilometers by a two-stage N-II rocket. Its mission life is two years.

/8309
CSO: 4307/033

H-11 TO BE POWERED BY NEW ENGINE

Tokyo AEROSPACE JAPAN-WEEKLY in English 3 Aug 87 p 7

[Text]

The National Space Development Agency of Japan (NASDA) has decided to adopt the LE5A new liquid oxygen/liquid hydrogen engine for the second stage of the H-II next-generation large-capacity rocket which will be used in the 1990s.

The new engine is modified from the LE5 engine to be used in the present H-I rocket. With the enhanced-thrust engine, the H-II's launching capacity will be increased by 10%. It will be capable of launching a 2.2-ton satellite into a geostationary orbit 36,000 kilometers above the earth.

The LE5 is now being developed by NASDA in cooperation with Mitsubishi Heavy Industries, Ltd. (MHI) and Ishikawajima-Harima Heavy Industries Co., Ltd. (IHI).

NASDA plans to use the H-II rocket not only to launch large-capacity applications satellites but also to deliver supplies to the space station which will be built jointly by the U.S., Europe, Canada and Japan.

/8309
CSO: 4307/033

DEVELOPMENT, FEATURES OF ROLLER ROCKER ARM REPORTED

Tokyo NAINEI KIKAN in Japanese Jun 87 pp 47-52

[Excerpts] 1. Foreword

In the industrial world recently there has been dynamic progress in lowering engine friction. There is a high frequency of automobiel use by passenger vehicle drivers at low and medium engine speeds, and particular attention has been paid to the fact that the percentage of total engine friction accounted for by valve train friction is very large in the areas of such numbers of revolutions. Rollerizing the cam follower is extremely effective as one method of greatly reducing valve train friction, and the number of places taking this up as a main theme of development have increased.

Rollerizing the valve train is not a particularly new technology, and it has been employed in some automobile engines for 20 or 30 years, mainly for the purpose of dealing with wear on the valve train. Since then, operation of automobile engines at high speed revolutions has advanced, and with the accompanying lightening of the valve train and progress in wear-resistant materials, such technology has disappeared from use.

Mitsubishi Motor Corporation planned a reexamination of this technology and with full use of both the newest valve train planning technologies and technology related to complex structures fostered by many years of experience with aluminum rocker arms, they possess the world's first structure formed from needle rollers and aluminum rocker arms. Moreover, they successfully developed a needle roller system rocker arm, which has the same level of high speed following characteristics of valve trains currently in use, and used it in the V6 engine with the Debonair model supercharger which went on sale this spring.

In this article we introduce the special features and structure of the needle roller arm system rocker arm, and the effect of its use, from the point of engine friction.

7. Results.

7.1 Practical improvement in fuel consumption.

Figure 13 [not reproduced] shows one example, and at 10 mode fuel consumption there is an improvement of 3 to 5 percent. For fuel consumption at fixed [teichi Nenhi], especially at low speeds, the effect is large and there is a big improvement of from 2 to 8 percent. In idle fuel consumption there are also cases not linked to improvement in fuel consumption where the percentage of friction lowered is unchanged due to deterioration in combustion because of choking off fuel and increased pumping loss due to closing the open throttel, etc. This point also confirms that it will be advantageous in diesel engines which do not have throttle valves.

Besides this, using a cam with smaller overlap on the valve timing and also combining that with engine modifications such as lowering the number of idle revolutions, results in a multiplication effect and a further large increase in 10 mode fuel consumption becomes possible.

7.2 Improvement in passing acceleration performance.

Engine full open performance is increased by friction reduction due to the needle roller system rocker arm, and generally low and medium speed torque increases from 1 to 3 percent. In terms of the effect on running efficiency of the vehicle, this is especially manifest in an improvement of passing acceleration.

Figure 15 [not reproduced] shows examples of improvement in passing acceleration, and the improvement is from 3 to 5 percent, and on the practical side, this is a big effect. The feeling is a light, pleasant sensation like being lofted up. Furthermore, that this sensation can be most strongly felt when racing is extremely natural, because as shown in Figure 8 [not reproduced] the reduction rate of engine friction is linked to the load reduction rate.

7.3 Improvement in valve train wear resistance.

In spite of the fact that the contact surface pressure between the cam rollers increases, wear resistance increases dramatically due to rolling contact in the needle rocker system and thus contributes to longer engine life. The results of simulated accelerated wear experiments are shown in Figure 16 [not reproduced] for a gasoline engine and in Figure 17 [not reproduced] for a diesel engine and we see that they surpass by far even those for the ceramic chip which we developed earlier. This accelerated wear experiment is one method where we can discern clearly the anti-scuffing qualities of the slipper system, and in the needle roller system which changed from sliding contact to rolling contact, we need not worry about this point, and the results were forecast from the start. However, with the needle roller system, because full validation of pitching resistance is required especially, we also carried out anti-wear characteristics confirmation experiments in the high revolutions zone too. Representatively, at 6,000 rpms which is an approved number of revolutions for the engine, even in lengthy experiments of 1,500 hours we confirmed no problems in roller revolutions whatsoever.

7.4 Other effects.

Reducing valve train friction has many other merits in addition to improving performance and fuel consumption. For example, vibration of the timing belt due to the resonance of the belt is an abnormal sound and this occurs when the actual tension of the belt is fairly high, but since valve train working torque is reduced by rollerization, actual working tension is reduced by this amount and it is harder for these sounds to occur. Accordingly, the degree of freedom to set tension range in assembly is increased.

Furthermore, cranking torque declines when starting the engine, and improvement in startability was also confirmed with diesel engines.

Besides these we want to add also that at the same running resistance, because engine load declines, waste gases (especially NOx) and lowering of combustion noises also result.

12964/9274
CSO: 4306/6073

JAPAN, U.S. AGREE ON SDI RESEARCH

Tokyo AEROSPACE JAPAN-WEEKLY in English 3 Aug 87 p 5

[Text] Japan and the U.S. reached agreements July 22 on the framework for Japanese participation in the U.S. Strategic Defense Initiative (SDI) Research Program. The agreements were signed by U.S. Defense Secretary Caspar Weinberger and Japanese Ambassador Nobuo Matsunaga at the U.S. Department of Defense.

The agreement consists of two documents. The Japanese government, however, released the basic conditions of the Japanese participation only and refused to release the rest which features an undisclosed arrangements for implementing the framework agreement.

According to the government, Japanese corporations and other entities participating in the SDI research will be allowed to incorporate the research results in their own products royalty-free even though the patents will generally belong to the U.S. government.

However, utilization of the new technology and information classified for military reasons will be restricted. And such classified technology and information will be designated by the U.S.

Under the agreement, Japanese entities--corporations and governmental research bodies--will be treated on equal terms with U.S. competitors in the bidding for contracts. Japanese corporations will be eligible to bid directly on contracts supplied by the Pentagon or its prime contractors.

Japanese participants, however, will be required to protect military technologies developed through the research in accordance with existing Japanese laws as well as the present Mutual Defense Assistance Agreement between the two countries.

Japan is the fifth country which signed a government-level agreement on SDI participation, following the U.K., West Germany, Israel and Italy. France, Belgium, the Netherlands and Canada will participate on a commercial basis.

/8309
CSO: 4307/033

XSSM-1 PROVING EXCELLENT PERFORMACE IN U.S.

Tokyo AEROSPACE JAPAN-WEEKLY in English 3 Aug 87 pp 4, 5

[Text] The XSSM-1 surface-to-ship missile developed by the Technical R&D Institute (TRDI) for the Ground Self-Defense Force (GSDF) is now proving its excellent performance in the United States.

The missile has been undergoing operational tests since late June at a test range in the United States. According to the Defense Agency (JDA), the missile succeeded 100% in hitting the target in all tests made so far, including the maximum-range test and an ECM (electronic countermeasure) test.

The XSSM-1 is now highly evaluated by U.S. military officials concerned as one of the best missiles in the world.

The XSSM-1 is a derivative of the Model 80 ASM-1 air-to-ship missile. The missile development is underway with a view to deployment at operational units in FY 1988. Mitsubishi Heavy Industries, Ltd. (MHI) has been promoting the development program as the prime contractor in cooperation with other electronics manufacturers.

The missile is powered by a solid rocket motor combined with a small jet engine. Its guidance system is a combination of the inertial guidance at the initial stage of the flight and active radar homing at the last stage.

It is five meters in overall length, 0.35 meters in diameter and it weighs 660 kilograms. Development cost is estimated at ¥24 billion. GSDF plans to procure the XSSM-1 missiles for 3.5 squadrons or 56 launchers under the current FY 1986-90 Medium-Term Defense Buildup Program.

/8309
CSO: 4307/034

DEFENSE AGENCY OFFICIALS DIVIDED ON FSX PLAN

OW151351 Tokyo KYODO in English 0917 GMT 15 Aug 87

[Text] Tokyo, 15 August KYODO--A plan to jointly remodel an existing U.S. fighter with a U.S. company for Japan's next generation support fighter, known as the FSX, has a strong possibility of being adopted, defense agency sources said Saturday.

But the air staff office of the Air Self-Defense Force, which calls for domestic development of the FSX, opposes the remodelling plan, according to the sources.

McDonnell Douglas' F-15J, the ASDF's mainstay interceptor fighter, which is being licence-built in Japan with Mitsubishi heavy industries as the prime contractor, is the most likely candidate, the sources said.

The Defense Agency will begin development of the FSX from fiscal 1988, starting next April, and will appropriate about 70 billion yen for the development cost of the FSX during the five-year defense buildup program which started in fiscal 1986, the sources said. The Defense Agency will make a final decision on the selection of the FSX after a prototype test flight in seven or eight year's time, they said. The Defense Agency is considering whether the FSX should be developed domestically or jointly with the U.S. aerospace industry, or imported.

General Dynamics' F-16 and McDonnell Douglas' F-18, as well as the F-15, are also among the candidates.

Meanwhile, a Japanese consortium, led by Mitsubishi, has called for domestic development of the FSX, to be the successor to the F-1 support fighter, which is to be phased out in the 1990s.

U.S. Secretary of Defense Caspar Weinberger proposed on a visit to Japan in June should buy an American warplane or remodel a U.S. aircraft in line with Japanese technology in selecting the FSX.

The U.S. Senate adopted a resolution in July which urges the U.S. Government to press for a commitment from Japan to procure a U.S. fighter for the FSX.

Senator John Danforth, a proposer of the resolution and a Republican from Missouri, where both McDonnell Douglas and General Dynamics are located, said "if the Japanese proceed to develop and build their own jet fighter, it will belie all Japanese claims that they wish to rectify the current trade imbalance."

/12913
CSO: 4307/032

FS-X EXPECTED NOT TO BE UPSET BY SENATE RESOLUTION

Tokyo AEROSPACE JAPAN-WEEKLY in English 3 Aug 87 pp 1, 2

[Text]

The U.S. Senate, acting on an omnibus trade bill, passed on July 21 a resolution under which the U.S. government is required to press for a commitment from Japan to purchase American aircraft as the FS-X next support fighter of the Air Self-Defense Force (ASDF).

The resolution which was passed unanimously by 97 Senators has no bidding force but it was added as an amendment to the trade bill which was voted and passed by the Senate on July 22.

The resolution was proposed by Democratic Leader Robert Byrd and Sen. John Danforth. It calls for continuously pressing Japan to purchase American aircraft. The U.S. Department of Defense is also required to report to the Congress on the FS-X negotiations with the Japanese government.

Commenting on the Senate resolution, the Japanese Defense Agency (JDA) officials said, "Japan would make its own decision on the FS-X. This is a major premise."

They stressed that the aircraft selection would be pursued based on the three principles worked out by JDA Director General Yuko Kurihara, which call for: 1) selecting the best aircraft from purely a military point of view; 2) gaining consensus of the Pentagon on the basis of the importance of the Japan-U.S. Security Treaty; and 3) ignoring pressure from the defense industries of both countries.

The Japanese industries concerned expect the FS-X to be a domestic development effort whether or not the omnibus trade bill should be passed. They strongly expect the

Japanese government to select an indigenous aircraft because Japan's future aircraft development capabilities would stall if American aircraft should be selected.

Mitsubishi Heavy Industries, Ltd. (MHI), Japan's leading defense contractor, refrained from commenting on the Senate resolution on the FS-X. But MHI have reiterated its view that Japan ought to defend itself with its own weapons.

Quite a few engineers involved in the FS-X development will retire under the age limit. If research and development activities of domestic aircraft should be interrupted as a result of introduction of U.S. aircraft, there would be no engineers who take over the accumulated technology, according to MHI.

The Japanese aircraft industry insists that the Japanese government should not be swayed by the Senate resolution in making the FS-X decision.

/8309
CSO: 4307/034

PROSPECTS FOR CEILING ON DEFENSE BUDGET PROPOSAL

Tokyo AEROSPACE JAPAN-WEEKLY in English 3 Aug 87 pp 2, 3

[Text]

The budgetary ceiling on the FY 1988 defense budget proposal will be somewhere between 6.5% and 7.0% in terms of a growth rate from the current fiscal year's budget, according to the negotiations between the Defense Agency (JDA) and the Ministry of Finance.

JDA wants a 7.3% or at least 7.0% increase in the defense spendings for FY 1988 in order to stably implement its FY 1986-90 Medium-Term Defense Buildup Program (MDBP).

However, the value of yen against dollar remains stronger compared with the yen value when the FY 1987 budget was compiled. In addition, the amount of money earmarked for sales tax in the FY 1987 budget is unnecessary in the FY 1988 budget. Because of such restraining factors, a final decision on the ceiling will be made through ministerial negotiations between JDA Director Yuko Kurihara and Finance Minister Kiichi Miyazawa.

Negotiations for the budgetary ceilings on the FY 1988 budget proposals got into upswing after the supplementary budget bill passed the Diet on July 24. The Cabinet is expected to decide on the ceilings by July 31 at the latest.

JDA has insisted on a 7.3% increase in defense budget before full-scale negotiations begin because it has to assure at least 5.4% real growth every year in order to carry out the current MDBP which calls for spending a total of ¥18,400 billion.

According to an economic survey, the deflator for FY 1988 is estimated at 1.9. So, to assure a 5.4% real growth rate, JDA needs a 7.3% increase in consideration of the deflator. The increase is equivalent to addition of over ¥250 billion to the initial defense budget (¥3,517.4 billion) for FY 1987.

In addition to those macroeconomic figures, JDA is aware of other restraining factors. One is strong yen. When the FY 1987 budget was compiled, the amount of military equipment imports were converted into dollars at an exchange rate of ¥163 per dollar.

Though recent exchange rates of yen are heading a little downward, the yen value still remains higher than ¥163 per dollar. No decision has been made on a new exchange rate to work out the ceiling on the FY 1988 budget proposal.

But it will certainly be higher than ¥163. As a result, the amount of equipment imports in yen would be smaller, restraining an overall growth rate of the budget.

The growth rate will also be lowered because no funds are necessary for sales tax in FY 1988. When the FY 1987 defense budget proposal was compiled, some ¥9.3 billion was set aside for the sales tax. If the sales tax was introduced as the government had planned, the FY 1988 budget was to include ¥50 billion for the sales tax.

Since no decision has been made yet on any indirect taxes, JDA cannot appropriate any funds for such taxes instead of the sales tax. So, the budget will have to be scaled down in this respect too.

JDA was allowed to ask for a 6.3% increase in its budget proposal under the FY 1987 budgetary ceiling. As the government will relax the ceilings on budget proposals in general with a view to expanding domestic demand, the ceiling on the FY 1988 defense budget proposal will likely be higher than 6.3%

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CSO: 4307/034

ASDF TO SELECT AFIS IN AUGUST

Tokyo AEROSPACE JAPAN-WEEKLY in English 3 Aug 87 pp 3, 4

[Text]

The Air Self-Defense Force (ASDF) plans to introduce an automatic flight inspection system with about ¥900 million authorized under the FY 1987 budget for installation on the YS-11 flight checker.

Selection of the system is now underway with proposal received from C. Itoh & Co., Ltd. (representing Litton Systems Canada), Nozaki & Co., Ltd. (Sierra Research), Nissho Iwai Corp. (Gull) and Furuno Electric Co., Ltd. A final decision on the selection is expected to be made in August this year.

ASDF plans to modify two of the eight YS-11 transport aircraft into flight checkers. In addition to a YS-11 flight checker now in service, the two aircraft will also be equipped with AFIS.

The first of the two aircraft will be modified in FY 1987-89. Following the authorization of the funds for AFIS, ASDF will ask for the aircraft modification funds under the FY 1988 budget.

/8309
CSO: 4307/034

BRIEFS

ASTRONOMERS OPPOSE SDI--Tokyo, 13 August KYODO--A group of noted Japanese astronomers Thursday issued a joint statement opposing the U.S. strategic defense initiative (SDI) project. The statement said the project restricts the launching of scientific observation satellites and classifies technology and data obtained from research for military reasons. The SDI project not only betrays the wish for peaceful utilization of space, but hampers progress in astronomical studies, it said. The statement also said 510 astronomers who signed it would not participate in any research related to the project. The astronomers, at 70 organizations across Japan, account for three-fourths of scholars in this field in this country, the promoters said. The 29 promoters, including director Yoshihide Kozai and professors Masaki Morimoto and Jun Jugaku at the Tokyo astronomical observatory, said the signatures were collected since last March. Jugaku emphasized the SDI project runs counter to international cooperation vital for astronomical progress. Moritomo said he and his group members would appeal to researchers abroad for support for their cause. [Text] [Tokyo KYODO in English 1256 GMT 13 Aug 87 OW] /12913

CSO: 4307/032

SYNCHROTRON RADIATION DEVELOPMENT STATUS REPORTED

Tokyo TOSHI KEIZAI in Japanese Nov 86 pp 46-47

[Article by Yuuta Sagara, scientific journalist, "Synchrotron Radiation"]

[Text] Applicable in Various Academic Fields

Synchrotron radiation (SR) is indispensable for developing next-generation high-technology such as ultra-large-scale integrated circuit (ULSI), etc., and has come into the limelight as a new scientific and technical advocator.

SR is electromagnetic radiation generated when positive electrons or electrons with a velocity close to the velocity of light pass through a magnetic field. This light possesses the following excellent features: 1) it has a continuous spectrum extending from far infrared rays to X-rays, 2) it is extremely strong, 3) it is highly directive, and 4) it has a repeated pulse light with a short width. There is no light source which can be compared with SR, particularly in extreme wavelength areas with short waves.

For these reasons, SR is used academically in various fields such as semiconductor engineering, metallic engineering, industrial chemistry, global science, medicine, and life science as well as basic physics and chemistry.

It is anticipated that SR will be used in Japan's favorite semiconductor industrial fields, such as analysis of very small amounts of light elements, photochemical reactions, surface and interfacial analysis, ultra-fine processing work, etc. The number of researchers in SR science has increased sharply.

The United States, West Germany, France, and other countries, are enthusiastically developing SR facilities. In Japan, the National Laboratory for High Energy Physics (NLHEP) of the Ministry of Education, Culture, and Science, the Electrotechnical Laboratory of MITI's Agency of Industrial Science and Technology (AIST) Nippon Telegraph and Telephone Corporation (NTT) Atsugi Laboratories, and the Science and Technology Agency (STA) are developing or are planning to develop such SR facilities. Also, Sumitomo Electric Industries, Ltd., Mitsubishi Electric Corporation (MEC), Toshiba Corporation, Shimadzu Seisakusho, Ltd., and the Japan Steel Works, Ltd. are conducting private research and development of SR facilities with cooperation from the Ministry of Education, Culture, and Science and MITI.

In Japan, the only SR facility with a capacity of 2.5 billion eV is presently being operated full scale at NLHEP, at Tsukuba in Ibaraki Prefecture. In the beginning this SR facility had a poor image, being used in research on physical properties in which an electron accelerator is needed, but it now has more than 8,000 users annually and is being worked to capacity.

Accordingly, in the next fiscal year, NLHEP will begin development of the world's most intensive SR light source by using an accumulating ring (AR), "Incident Storage Ring" of a macro-particle accelerator, "Tristan (electron and positive electron collision type accelerator)." The Tristan is currently under construction in NLHEP. NLHEP will carry out this development work so it can begin conducting experiments on the SR light source in 1989. The development cost is approximately Y1 billion.

The Tristan consists of a 400 m long linear accelerator, an AR with a diameter of approximately 100 m, and a main ring with a diameter of approximately 1 km. The AR is a linear accelerator, and further accelerates electrons and positive electrons accelerated up to 2.5 billion eV, stores them, and sends them to the main ring.

World's Highest Technology and Large-Scale Optical Plant Is Constructed

SR is radiated when electrons and positive electrons go round the AR. This type of SR is used in the NLHEP project. When an AR is used, electrons and positive electrons can be accelerated to the world's most intensive level, which 6 to 8 billion eV.

SR emitted when using the AR is light from ultraviolet rays to gamma-rays; X-rays with a wavelength of 1 to 0.5 angstrom (1 angstrom is one-hundred millionth of a centimeter) is the most intensive in such an SR. It is said that the brightness will be 1,000 to 10,000 times that of the SR facility with a capacity of 2.5 billion eV.

SR is an important, indispensable weapon in the development of next-generation high technology for the 21st century. Accordingly, the STA will construct a large-scale optical plant in the Kansai district. This plant consists chiefly of an SR facility which can emit X-rays with a short wavelength of 0.1 angstrom, which is the highest level in the world.

According to this plan, the STA will construct a ring shaped-accelerator at a cost of about Y60 billion, with a completion date in 1994. This accelerator has a diameter of approximately 400 meters, and can emit an energy of 6 billion eV.

Unlike NLHEP's AR, STA's accelerator has great power. On the other hand, NLHEP's AR is capable of being used for multiple purposes, and will play a role as a "connection" until the completion of STA's optical plant. Results obtained form this AR will be fully utilized in the construction of the optical plant.

In the optical plant the SR can easily be changed from the wavelength of ultraviolet rays to X-rays. In addition, it can emit light which is 10,000 to

1 million times brighter than that of X-ray is generated for medical examinations.

The shorter the X-ray wavelength, the more possible it is to closely investigate physical phenomena to carry out super-fine processing work. it will be possible to use SR in various fields, such as to catch the movement of electrons acting in crystals, clarification of changes of movement of molecules in the muscles of animals, development of new semiconductor processing technologies, and so on.

The STA intends to construct not only the world's highest level SR facility, but also research facilities which will employ laser light, etc., in the optical plant. The STA also wants to develop the optical plant as a mecca for worldwide optical science, and is planning to promote basic research work for the 21st century through joint use among industry, government, universities, and international cooperation.

Powerful for Development of VLSI

The scale of facilities will inevitably be large, because the STA's optical plant and the NLHEP's AR will be used for multiple purposes on a large scale.

In addition, the Electrotechnical Laboratory at Tsukuba is presently developing a small SR unit to be used industrially even in the clean rooms of semiconductor plants in the future.

The Electrotechnical Laboratory has already succeeded in accumulating electrons from a small test ring, and has confirmed synchrotron orbit radiation (SRO). However, in order to make a small industrial SOR unit, it is necessary to research and develop well-balanced elemental technologies. For example, it is necessary not only to miniaturize the electron accumulating ring, but also to miniaturize electron incident equipment, to enhance the efficiency of this equipment, to miniaturize beam lines employing SOR, and so on.

For this reason, the Electrotechnical Laboratory is conducting research on the small SR in collaboration with Sumitomo Electric Industries, Ltd., MEC, Toshiba Corporation, and Shimadzu Seisakusho Ltd.

It is expected that a small industrial SR will be fully utilized specifically to develop ULSIs with an integration degree of more than 64 megabits. In order to develop such ULSIs, it is necessary to reduce the minimum line width of circuits transferred to semiconductor wafers to less than 0.5 micron (1 micron is one-thousandth mm). This is because X-ray lithography employing a small SR unit is indispensable for achieving this superfine processing technology.

NTT Atsugi Laboratories are also carrying out the same research and development work as that mentioned above.

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CEO: 4306/2534

DEVELOPMENTS IN OPTICAL SENSOR TECHNOLOGIES DESCRIBED

Tokyo OPTRONICS in Japanese Dec 86 pp 74-80

[Article by Tatehiko Hidaka, High Frequency Research Office, Electrotechnical Laboratory: "Development of Hollow Optical Fibers; Establishment of Micropower Precision Measuring Technology"]

[Text] As lasers diffused, microgas analysis technology utilizing their excellence in spectral purity and coherence has been developed in recent years. The current project also tackled the development of high sensitivity gas analysis technology utilizing so-called hollow fibers in the infrared and the ultraviolet soft X-ray areas. Initially, hollow fibers for the medium infrared area 910 μm band) and then experiments of hollow fibers for soft X-rays (25-75 Å) were made. Since sensor technologies need precision measuring technology for micropower, the current project has studied and established precision light attenuation measuring technology using an acousto-optic element. These technologies are likely to be integrated to contribute to the progress in new optical sensor technologies in the future.

Introduction

Along with improved functions and reduced prices of various lasers, especially semiconductor lasers, the development of new sensor technologies combining them with optical fibers has become active. The current project has also developed every sort of sensor technology for use in oil refineries. The Electrotechnical Laboratory has decided to start research into optical sensor technologies combining an optical fiber and laser as well.

The first theme of the optical sensor technology development by the Laboratory is the gas analysis technology using a hollow optical fiber. A laser is an extremely suitable illuminant for detection and determination of a trace of a gas molecule due to its intensity and monochromaticity. As for its monochromaticity, for example, it is not impossible to obtain a high-purity illuminant with a bandwidth of 1 KHz. The gas molecule detection technology using such illuminants is very likely to be an epoch-making detection technology whose detection limit exceeds that in the conventional gas detection technology by several digits.

On the other hand, the Electrotechnical Laboratory has so far pointed out the potential of the hollow optical fiber based on an entirely new principle; a certain type of glass (quartz, etc.) allows the real part nr of its refractive index to be smaller than 1 in the infrared area (wavelengths of 9-10 µm) and soft X-ray area, so that a refractive index of the glass part (clad) of a hollow waveguide made of such a material, when its hollow part is regarded as its core, becomes smaller than that of the core, and thus electromagnetic waves existing at the core will be transmitted without appreciable loss. If a gas containing objective gas molecules flows into such a hollow optical fiber and, at the same time, such a laser beam as absorbed by the molecules is guided and its transmission factor is largely affected by the presence of gas molecules, thereby permitting molecules to be detected. Based on this concept, the Laboratory decided to initially start with research into test manufacturing and characteristic evaluation of a hollow optical fiber in the infrared and the soft X-ray areas.

In addition, the second theme of the optical sensor technology development is the development of a precision measuring technology for microoptical power needed for the test and evaluation of fundamental characteristics of optical sensors. The research aims at precise measurement of micropower of below µW, using a method to measure the power ratio with existing laser small power measured values as its standard. Measurement by this method requires measuring precise power ratios (attenuation) and an optical attenuator to materialize laser beams with the power ratios measured. This article describes the development of two types of methods effectively utilizing characteristics of the acousto-optic modulator for the former and, for the latter, test manufacturing and a study of a precision optical attenuator using a deflecting plate permitting correct theoretical values to be obtained.

Development of Hollow Optical Fibers

Infrared-Area Hollow Fiber

Transmission wavelengths of conventional quartz (SiO_2) optical fibers roughly range from 0.3 µm to 2 µm. Transmitting laser beams with outside wavelengths of them necessitates a newly devised transmission guide made of materials other than SiO_2 or having different structure based on an entirely new principle. Of them, optical fibers made of new materials, notably KRS-5, etc., have been studied as core materials for infrared transmission, research and development going on in the current large project as well.

Generally speaking, a refractive index of solids (including glass) is likely to become smaller than the value of vacuum or air (1.0) in the infrared and the vacuum ultraviolet soft X-ray areas. Figure 1 shows typical complex indexes of refraction of a solid in from the infrared to the vacuum ultraviolet areas. The real part of a complex index of refraction becomes smaller than 1 in the infrared area due to the resonance to lattice vibration of a solid and in the vacuum ultraviolet area due to plasma vibration of electrons inside of the solid. If a solid with a refractive index smaller than 1 (glass with a smooth surface is preferable) is available, a step index type optical fiber can be configured by using material such as a clad material. A core is a hollow part (vacuum or air). This article reports a hollow waveguide for infrared light (especially 10.6-µm (CO_2 gas laser beam).

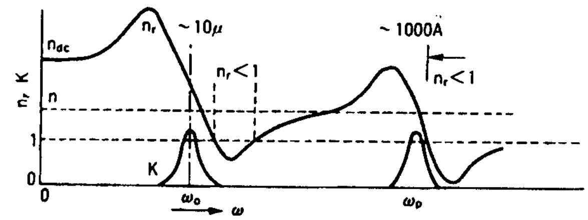

Figure 1. Solid Complex Indexes of Refraction; n_r-iK
In the infrared and the vacuum ultraviolet
(soft X-ray) area, n_r can be smaller than 1.

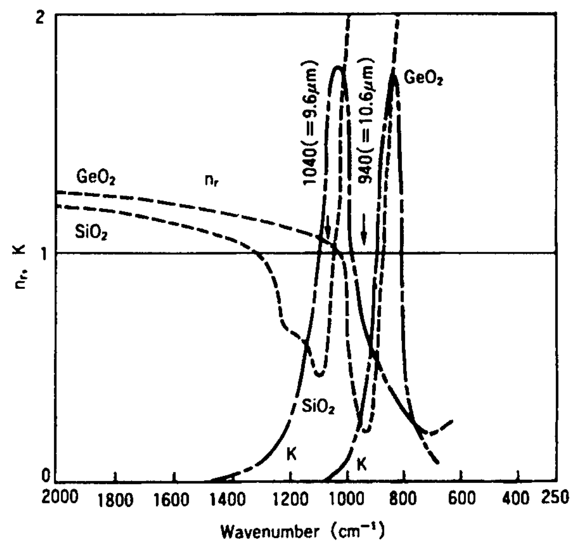

Figure 2. n_r-iK of Quartz (SiO_2) and GeO_2 in the Infrared
Area (adjacent to 1,000 cm^{-1} = 10 μm)
With GeO^2, n_r falls to 0.3 at 940 cm^{-1}.

Figure 2 shows complex indexes of refraction n_r-iK (n_r and K representing a real and an imaginary part, respectively) of SiO_2 (quartz) and GeO_2, a similar glass material, which are the most fundamental as glass materials. In the drawing, GeO_2 glass shows its n_r being smaller than 1 at 940 cm^{-1} (10.6 μm). As against this, with SiO_2, n_r becomes smaller than 1 only within the range of 1030-1300 cm- 1, showing no effect to a CO_2 gas laser beam (940 cm^{-1} = 10.6 μm). For this reason, it was decided to start with GeO_2 for an optical fiber material for CO_2 gas lasers.

Figure 3 shows contents of K_2O and ZnO and then optical characteristics (minimum loss wave numbers of a hollow optical fiber and then loss values). Loss of 0.05 dB/m can be expected with a 1-mm-aperture linear fiber. Figure 4 shows loss characteristics when a CO_2 gas laser beam is actually transmitted. Transmission loss actually obtained is about one digit less compared with a theoretical value, which was presumably caused by an imperfect internal surface of the hollow fiber or the core-clad interface. It was proven that in manufacturing the hollow fiber, a microcrystal of GeO_2 grew with ZnO as its core to aggravate its characteristics. A study of its improvement including material composition, is underway at present.

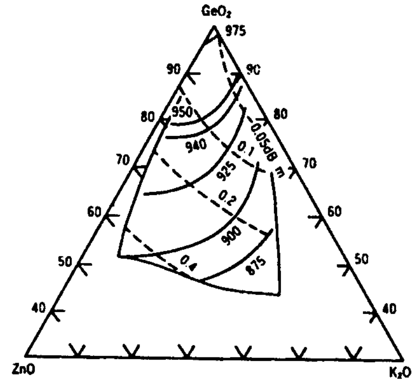

Figure 3. Transmission Characteristic (Theoretical Value) of GeO_2-K_2O-ZnO Glass Hollow Fiber
Values to 1-mm aperture-HE_1 mode
Numerics on either side of the triangle represent mol concentrations of GeO_2. One division of the horizontal axis corresponds to 10 mol concentration of ZnO and K_2O, those closer to the right side show higher K_2O concentrations. Solid lines show wave numbers indicating minimum loss, while dotted lines show then loss (db/m).

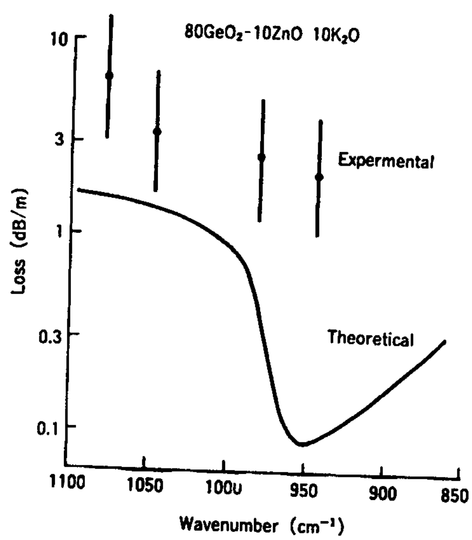

Figure 4. Transmission Characteristics of $80GeO_2$-$10K_2O$-10ZnO Glass Hollow Optical Fiber
Experimental values and theoretical estimated values

X-Ray Transmission Fiber

In general, with a solid the real part n_r of its refractive index becomes smaller than 1 in the vacuum ultraviolet X-ray area (wavelength of below 1,000 Å). In frequencies much higher than plasma vibration (wavelength of about 1,000 Å) of electrons inside of a solid, n_r and K can be supported by

$$n_r = 1 - \frac{1}{2}(\omega_p/\omega)^2$$

$$K = \frac{1}{2}(\omega_p/\omega)^3 \cdot 1/(\omega_p \tau)$$

where ωp and τ represent electron plasma frequency and its relaxation time, respectively. Figure 5 shows n_r-iK, complex indexes of refraction of quartz (SiO_2) in the soft X-ray area (100-10 Å). The n_r value is, for example, 0.99 at 50 Å, a value usable as a clad material for hollow optical fibers. However, the value of loss term being too great to override mainly contributes to increased loss against fiber bending. In Figure 5, the peak and n_r curve seen at 23 Å are caused by the absorption of inner electrons by the oxygen atom.

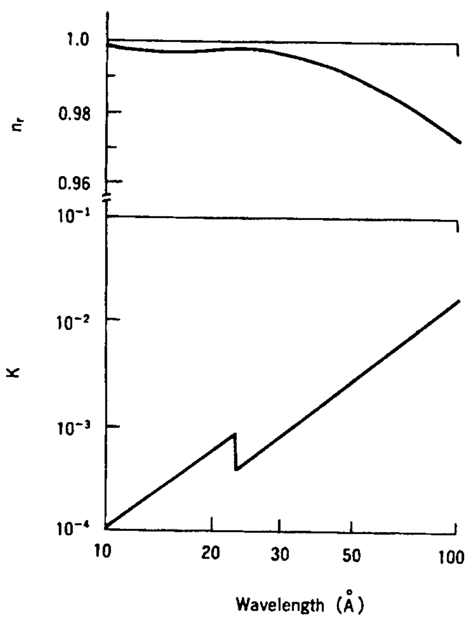

Figure 5. n_r and K of Quartz (SiO_2) in the Soft X-ray Area

The X-ray transmission fiber efficiency may be evaluated as follows: Suppose a case where X-ray's advance direction is curved 90 degrees; 45 degrees incidence using a quartz plate results in a reflectance of 10^{-4} percent, proving no practicability. As against this, a quartz hollow fiber theoretically shows that its transmission efficiency can exceed 1 percent. Thus, expectations are placed on a hollow optical fiber for its excellent efficiency 10^4 times that of a plane reflecting mirror in 90-degree curving.

Soft X-ray transmission characteristics of a quartz hollow fiber were obtained as follows: A block diagram of the experiment is shown in Figure 6. The illuminant was an SOR facility installed by the Electrotechnical Laboratory, which was made monochromatic by the oblique incident diffraction grating spectroscope. For improved spectral purity, a proper filter was used. A soft X-ray made monochromatic is let into the quartz hollow fiber with an internal diameter of 0.2 mmϕ and total length of 230 mm to be transmitted. An outgoing X-ray is detected by the ceramic channel thoron. Electric generating power from the channel thoron is amplified, processed by the multichannel analyzer, and then followed by data processing. The fiber input terminal is fixed and it is parallel to an incident beam. The outgoing terminal, together with the detector, rotates up to 90 degrees against the incident direction, when the fiber draws a uniform arc of circle through the total length. Figure 7 shows an example of transmission efficiency thus obtained. The characteristics qualitatively tend to be in accordance with their theoretical values, but the efficiency as a whole is one digit poorer. This means to steam from the fiber direction at the input terminal being slightly deflected from the X-ray beam direction. Angle fitting at the incident part is so severe as to be within 0.2 degrees. Considering that angular (sysmach) of the incident part is subtracted, transmission efficiency roughly accords with its theoretical value.

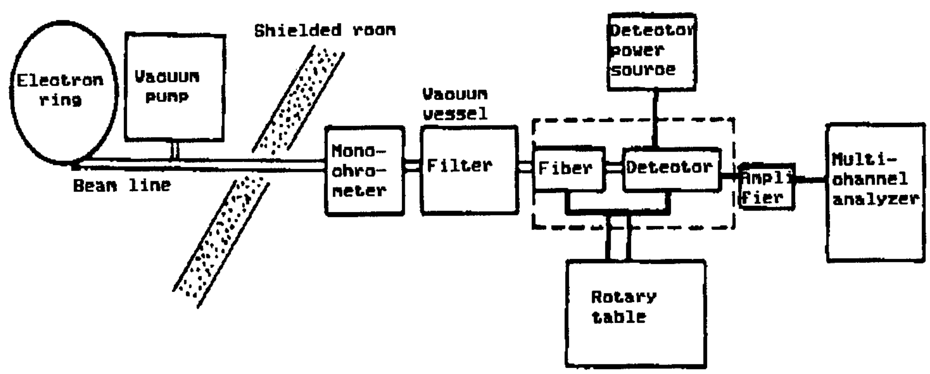

Figure 6. Block Diagram for Soft X-ray Transmission Characteristic Measurement

Figure 8 shows wavelength dependency of transmission efficiency when the angle is made constant. Although fine ripples are present, appreciable wavelength dependency cannot be found as a whole. Loss is great for wavelengths shorter than 25 Å, which is attributable to the absorption (K absorption) of oxygen inner-shell electrons in SiO_2. Also, the weak peaks adjacent to 40 Å are presumably ascribed to the influence by the absorption (43.5 Å) of inner-shell electrons of carbon C on the internal surface of the hollow fiber.

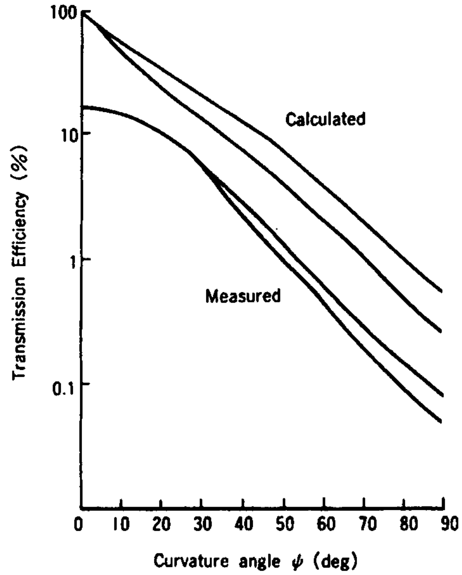

Figure 7. Angular Dependency of Transmission Efficiency
The upper results are for 32 Å and the lower for 68 Å.

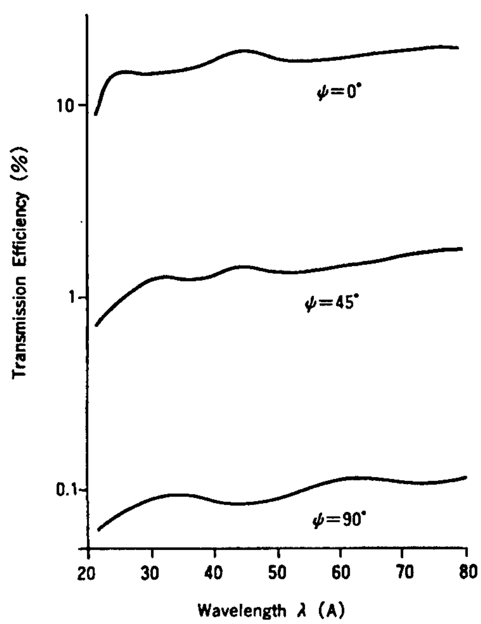

Figure 8. Wavelength Dependency of Transmission Efficiency

Micropower Precision Measuring Technology

Power Ratio Measuring Method Utilizing Acousto-Optic Modulator

For the measurement of laser beam power ratios and attenuation, a method involving utilizing photodiodes and pyro-electricity elements is available, substituting the power ratios, etc. for voltage ratios of dc and audio frequencies, and thereby permitting their measurement. For the measurement of relatively great power ratios, however, two types of methods have been newly developed which utilize typical modulation characteristics such as frequency deflection and spatial modulation of an acousto-optic modulator. Both of them use a 30 MHz attenuation measuring device already developed.

Modulated Power Substitution Method

1. Principle: AOM's linear modulation characteristics are utilized. In AOM driven by a sine wave is ample diffracted light, while I_1, the intensities of the primary diffracted light in the Raman's area and the Bragg area can be expressed respectively as follows:

$$I_1 = J_1^2(h\Delta n) = \frac{1}{4}(h\Delta n)^2 - \frac{1}{16}(h\Delta n)^4 + \qquad (1)$$

$$I_1 = \sin^2(h'\Delta n) = (h'\Delta n)^2 - \frac{1}{3}(h'\Delta n)^4 + \qquad (2)$$

where J_1, h and h' and Δn represent a primary Bessel function, constants and variations of the refractive index. When (h n) is small enough compared with 1, I_1 is proportional to $(\Delta n)^2$. When $LiNbO_3$ is used as an electro-acoustic sensing element for AOM, n is proportional to ac modulated voltage E, so that I_1 is proportional to E^2 or modulated power. Therefore, variation ratios of I_1, a laser beam intensity, can be substituted for modulated power.

2. Experience: Figure 9 shows the circuit for the experiments. A laser beam (He-Ne, 633 nm) goes into AOM driven by 30 MHz modulated power controlled by the high frequency attenuator, and its primary diffracted light is received by the photo detector through the photo attenuator. Thirty MHz is chopped by 1 KHz to facilitate detecting laser beams, while the intensity of a received beam corresponds to the magnitude of a 1 KHz signal of the photo detector's output, thereby permitting the magnitude to be observed by the synchronism detector. When the attenuation of the photo attenuator changes, changes in the output beam intensity are measured by regulating AOM modulated power by the high frequency attenuator so as to constantly maintain the same indication of the synchronism detector and by reading a then variation ratio of modulated power by the 30 Mhz attenuation measuring device.

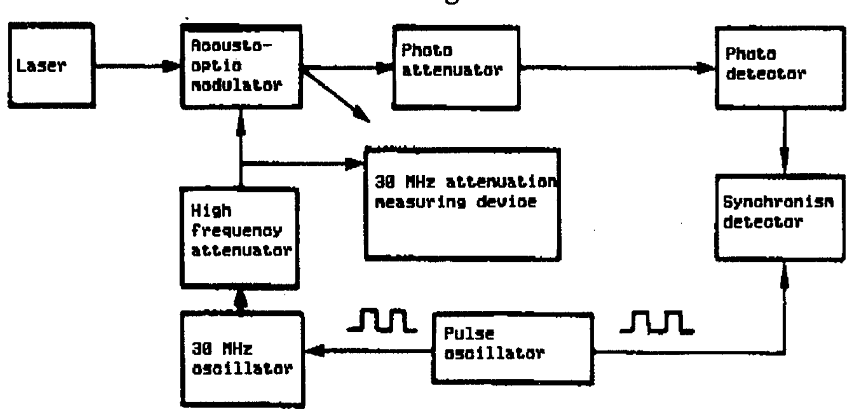

Figure 9. Laser Beam Power Ratio Measuring Circuit by Modulated Power Substitution Method

To know the proportional relation between I_1 and E^2, a comparison was made by measuring the same attenuation with various AOM drive voltages with the result shown in Figure 10. The experiment used AOM for use in the Raman's area, while the calculated value was obtained by the expression (1). A range of about 50 dB was obtained for the deviation of ±0.1 dB.

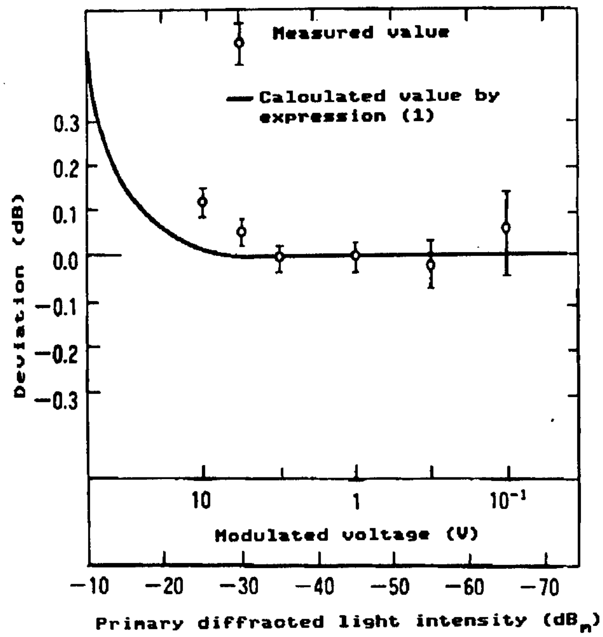

Figure 10. Experiment on I_1-E^2 Relation

Intermediate Frequency Substitution Method

1. Principle: This method was used in microwave bands, etc. but had not been developed in the optical area. It includes the serial and the parallel methods. Figure 11 shows the serial method. With the use of AOM's frequency deflection characteristics, a required difference frequency laser is made. Laser output is divided into a local and a measuring channel, with the former modulated by AOM driven by sine wave modulated voltage. The primary diffracted light is output at an angle of $_1$ with its frequency deviating by 30 Mhz. This beam is synthesized with a local channel beam with the original frequency through the photo attenuator. The synthesized beam is detected by the photo detector and then by the intermediate frequency detector to fetch intermediate frequency of 30 MHz. At this time, the transmission factor of intermediate frequency signal power and that of the photo attenuator are proportional to each other in the scope where the beam intensity of the measuring channel is proper. Intermediate frequency signals go into the intermediate frequency level meter through the intermediate frequency amplifier and the standard attenuator. Photo attenuation can be measured by regulating the standard attenuator to enable this level meter instruction to be constant. With the parallel method, noise effects by the photo detector, etc., can be controlled with the use of a switch by inputting photo detection output and the standard attenuator output alternately into the intermediate frequency amplifier to detect synchronism.

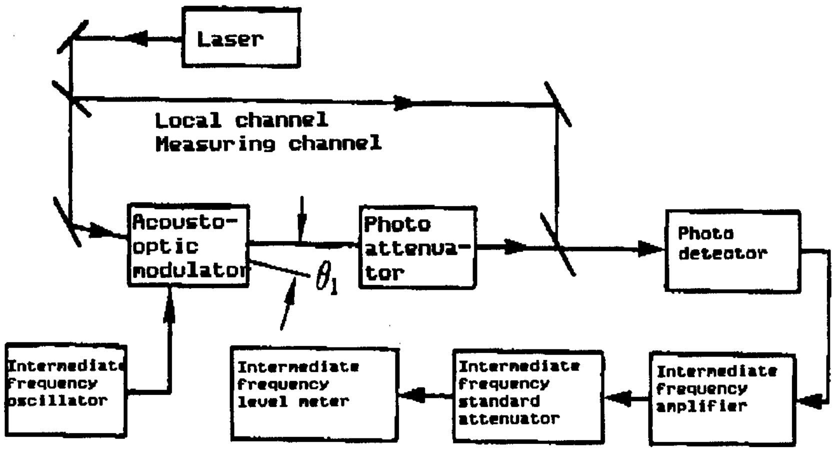

Figure 11. Laser Beam Attenuation Measuring Circuit by Serial Type Intermediate Frequency Substitution Method

2. Experiments: Experiments were made using an He-Ne laser (5 mW, 633 nm) with AOM driven at 30 MHz. An ND filter (transmission factor, 0.1) was used for the photo attenuator and PIN diode with an impedance transducer added to it was utilized for the photo detector. To know a dynamic range of the measuring device, measurement was made using the same attenuator (about 1.00 for various laser level inputs. Figure 12 shows the results of experiments on the serial and the parallel method. In the serial method, lasers at low levels were susceptible to the influence of noises, resulting in a range of about 50 dB for the deviation of ±0.15 dB. In the parallel method, the range was expanded to about 70 dB.

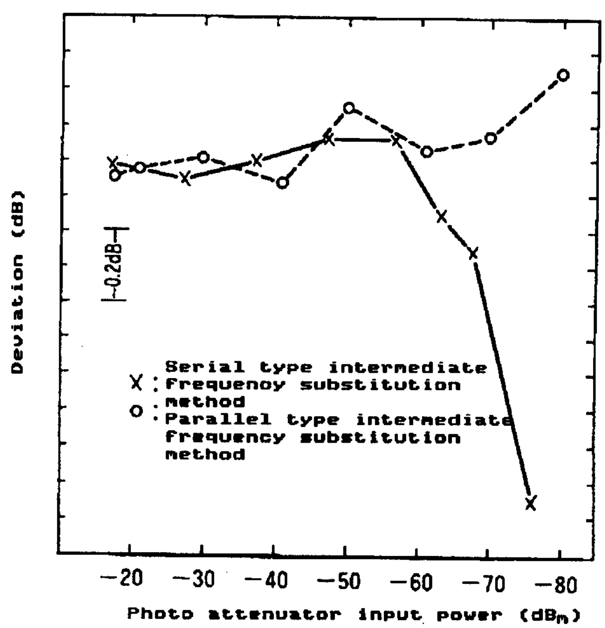

Figure 12. Linearity of Intermediate Frequency Substitution Circuit

Precision Photo Attenuator

An attenuator capable of comparing theoretical values with measured ones are advantageous since precision can be confirmed. For this reason, a rotary type attenuator combining two deflecting plates was adopted to be test manufactured. To minimize I/) optical axis fluctuations, Grantompson prisms were used for the deflecting plates. The read resolution for angles of rotation is 1/40 degree.

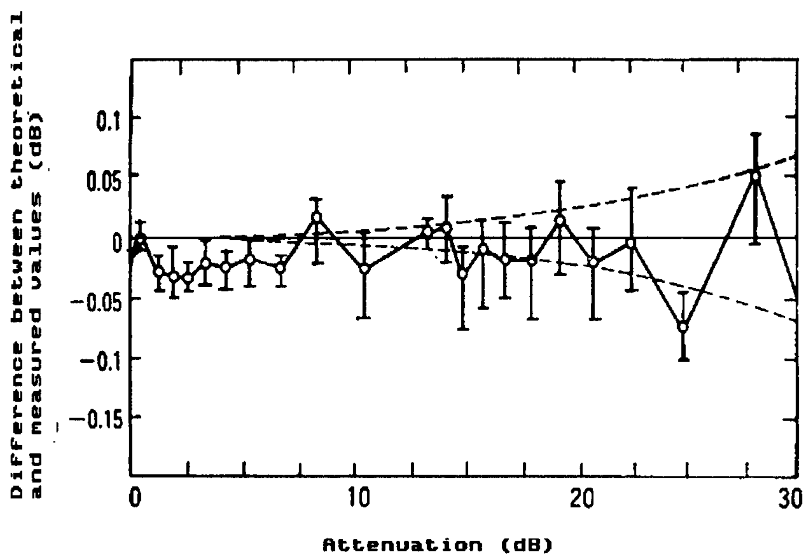

Figure 13. Difference Between Theoretical and Measured Values of Deflecting Plate Type Photo Attenuator

Figure 13 shows a difference between the theoretical values and the calculated ones. The maximum difference is within a range of ±0.07 dB. Incidentally, dotted lines show an attenuation error corresponding to a rotation angle read error of 0.04 degrees.

Consideration

In the modulated substitution method, the dynamic range is around 50 dB, limited by nonlinearity in high levels and by noises in low levels. The method is free from the influence of turbulence on the plane of polarization compared with the intermediate frequency substitution method.

In the intermediate frequency substitution method, as to ranges with good linearity and usable for measurement, 50 dB and 70 dB were obtained by the serial type and parallel type, respectively. A nonlinearity trend is not found in higher beam levels graphically, greater measuring ranges expected by increasing laser power. Utilizing beam interference, this method is directly affected by deflection and turbulence in mode caused by the photo attenuator with the result that ND filters with ranges of over 20 dB which were used for experiments resulted in extremely aggravated repeatability. As for a photo attenuator, a high precision one with a range of about 0.078 dB for 0-30 dB was obtained.

Conclusion

With regard to sensor technologies, a gas molecule sensor using a low-loss hollow fiber was initially planned. The project attached importance to the development of a hollow fiber as it is a core technology for that. As stated before, a principle, so far unavailable for optical fibers, was introduced into a hollow fiber--use of materials with a reflective index smaller than 1 (or such wavelength areas). As a result, in the infrared area, transmission efficiency of 2 dB/m was obtained, which is one digit inferior to the theoretical value and other types of infrared optical fibers (KRS-5, for example), leaving room for further improvement.

On the other hand, with a soft X-ray transmission optical fiber as well, transmission characteristic was one digit inferior to the expected value, but it was the first achievement in the world as an X-ray transmission fiber.

As sensor technologies using a hollow fiber, a gas sensor is considered significant. Since a great number of gas molecules individually show characteristic absorption spectrum in the infrared area (10 μm band), a microquantity of specific gas molecules can be detected by forcing gas into a long hollow fiber and by scanning it with a laser beam.

An X-ray fiber is not only effective as a sensor technology but expected to trigger social demand more than that. In medical use, for example, it is easy to imagine that it will be used with its transmitting distance within several meters and bending angle within 90 degrees. In this case, its utility value will be great, if its efficiency is 1 percent, as unnecessary irradiation into human bodies could be avoided or irradiation of X-rays for medical treatment could be made for affected parts from the shortest distance.

As for micropower measuring technologies, developments were made of two types of photo attenuation (power ratio) measuring methods utilizing characteristics of an acousto-optic modulator and of a precision photo attenuator. The development of the modulated power substitution method is historic in that unlike the substitution method conventionally used with microwaves, etc., linearity of modulation characteristic was utilized instead of that of wave detection characteristic. This method permitted a dynamic range of about 50 dB to be obtained, while the intermediate frequency substitution method utilizing optical interference provided that of 70 dB. The former features are less susceptible to the influence of optical plane of polarization, etc. As to the photo attenuator, a high-precision one with a range of 0.07 dB for 30 dB was obtained. Measurement of 10 μm can be made with an accuracy of about 1 percent at the present phase, so that this technology thus developed will provide the possibility of measuring 10 nW with an accuracy of several percent. Meanwhile, a laser beam transmission quantity measuring method using an acousto-optic modulator was also developed. These measuring methods and photo attenuators can be expected to find their applications in instrumentation in other photo sectors.

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LASER DEVELOPMENT, EVOLUTION OF APPLIED TECHNOLOGIES DESCRIBED

Tokyo OPTRONICS in Japanese Jan 87 pp 86-91

[Article by Takuzo Sato, head of the Laser Research Office, Electric Wave and Electronic Department, Electrotechnical laboratory]

[Excerpts] Technologies for Greater Output

Excimer Laser

The history of the excimer laser begins in 1970 when Basov and his colleagues of the Soviet Union succeeded in laser oscillation in the vacuum ultraviolet area by irradiating and exciting liquid xenon with electron beams (Table 1). The research was initially targeted at rare gas excimer or rare gas-oxygen excimer with low efficiency and capable of oscillating only by electron beams, but later was pushed forward to the development of a new short wavelength laser rather than a practical laser. The development of the rare gas halide excimer laser in 1975, however, has changed the world's understanding of the excimer laser.

Laser oscillation by the rare gas halide excimer by stimulating electron beams was confirmed in 1975, followed by successful laser oscillation by the discharge excitation method in the following year. With regard to the discharge excitation are gas halide excimer laser, progress has been made in the research of practical technologies for greater repeatability, greater power and longer life; lasers with repetition of 500 Hz and the average output of 100 W are marketed at present and thus have greatly contributed to the progress of basic research into the semiconductor process and medical sector as a short wavelength ultraviolet laser for the photochemical process. With the discharge excitation excimer laser, as stated so far, in addition to research and development (R&D) of greater repeatability, greater power and longer life, research is also underway into high efficiency, and long pulses of the laser, its applicability expected to be greater than ever.

On the other hand, with regard to the electron beam excitation method to excite directly a laser gas with electron beams, a KrF excimer laser with great volume (1 x 1 x 2 m^3) and great power (10.5 kJ, pulse width of 500 ns) has been developed in the United States for use in research into laser nuclear fusion. The discharge excitation method also has attained X-ray auxiliary ionization types, one with a caliber of 10 x 8 cm^2 and output of 44 J (85 ns), and the one with a caliber of 20 x 15 cm^2 and output of 66 J (180 ns).

Table 1. Developmental Chronology of Main Excimer Lasers

Excimer laser		Oscillation wave-length (nm)	Excitation method	Year of oscillation
Rare gas excimer	liq·Xe	176	e	1970
	Xe_2	172	e	1972
	Kr_2	146	e	1973
	Ar_2	126	e	1974
Rare gas-oxygen excimer	XeO	538, 546	e	1974
	KrO	558	e	1974
	ArO	558	e	1976
Mercury halide excimer	HgBr	502	e, d, l	1977
	HgCl	558	e, d	1977
	HgI	443	e, d	1978
Rare gas halide excimer	KrF	248	e	1975
			e.c.	
			d	1976
	XeCl	308	e	1975
			d	1977
			m	1981
	XeBr	282	e	1975
			d	1978
	XeF	351, 353	e	1975
			d	1976
			p	1979
	ArF	193	e, d	1976
	KrCl	222	e	1976
			d	1977
	ArCl	175	d	1977
	XeF (C A)	483	l, e, d	1979
	Xe_2Cl	518	e	1980
	Kr_2F	430	e	1980

e: Electron beam excitation
d: Discharge excitation
l: Photo excitation
m: Microwave excitation
p: Proton beam excitation
ec: Electron beam control:
A(*) mark is omitted as, for example, where excimer KrF*→KrF.

Free Electron laser

While efforts are being made to provide greater power of the excimer laser in the ultraviolet area, the research into great power by the free electron laser in the infrared area is drawing attention. The free electron laser, which makes use of braking radiation light produced when the transmit direction of a high-speed free electron (an electron free from atoms or molecules) is bent by a magnetic field, was proposed in 1971, and its laser oscillation first succeeded in 1977. Its developmental state is shown in Table 2 [omitted].

With regard to the Compton type free electron laser using high-energy small-current electron beam sources (linear accelerator, electron accumulation ring, van de Graff, etc.), research into laser oscillation from the visible to the near infrared areas is underway. In a study of the free electron laser using an electron accumulation ring, success has been achieved in its oscillation in the visible area (0.85 μm, 0.65 μm) (South Paris University).

A study is being made of the oscillation Raman-type free electron laser using low-energy great-current electron beam sources from the far infrared to the millimeter wave areas with a result that a laser providing a great average output of 6 kW in 9-35 μm wavelength bands has been developed.

Solid Laser

Success was achieved in laser oscillation in the first half of the 1960s by representative solid lasers such as the ruby laser (1960), Nd: glass laser (1961), semiconductor laser (1962), Nd: YAG laser (1964) and color center laser (1965). if we call this era the first solid laser boom, for example, the recent R&D of solid lasers which has been so active could be called a new solid laser boom, shown in the development of variable wavelength solid lasers represented by alexandrite, and by research into providing their great output, the development of a high-efficiency solid laser including Cr^{3+} added Nd^{3+}:GSGG, the development of a great-output solid laser, and the development of a high-efficiency semiconductor laser-excited total solid laser.

Table 3. Characteristics of Main Variable Wavelength Solid lasers

Laser crystal	Wave length (nm)	Action mode	Excitation illuminant	Output
Cr^{3+}: $BeAl_2O_4$ (Alexandrite)	701~826 701~826 726~802	Pulse CW CW	Flash lamp Mercury arc lamp Kr^+ laser	100W Average 50W 600mW
Cr^{3+}: $Be_3Al_2(SiO_3)_6$ (Emerald)	729~809	CW	Kr^+ laser	320mW
Cr^{3+}: $Gd_3Sc_2Ga_3O_{12}$ (GSGG)	742~842	CW	Ar^+, Kr^+ lasers	250mW
Cr^{3+}: $KZnF_3$	785~865	CW	Kr^+ laser	85mW
Cr^{3+}: $Gd_3Sc_2Al_3O_{12}$ (GSAG)	780 center	CW	Kr^+ laser	90mW
Cr^{3+}: $ZnWO_4$	980~1,050 1,030 center	Pulse CW	Rhodamine Kr^+ laser	
Ti^{3+}: Al_2O_3	660~986	CW	Ar^+ laser	

Table 3 shows a developmental stage of variable wavelength solid laser using vibronic transit. The Nd:YAG laser which has attained great output (average output of 640 W) is followed by a study pushed forward in pursuit of great output (average output of 105 W) by the alexandrite laser. Besides these solid lasers, results worth watching have been achieved in the studies of high output (CW output, 4 W; average output, 11 W) to be provided by the phased array semiconductor laser and the high-output color center laser (NaCl:OH, 1.41-1.81 μm; CW output, 1.25 W).

In the development of the glass laser with great output for use in laser nuclear fusion, outputs of 8 kJ (500-750 ps) and 18 kJ have been attained by the second higher harmonics and the third higher harmonics of the glass laser, respectively.

Infrared Gas Laser

As for CO_2 gas lasers with great output for use in laser beam machining, those with a continuous oscillation output of 20 kw have been developed in the cross-flow type and the axial-flow type.

In the study of the HF chemical laser, the output of 4.5 kJ (50 ns) has been obtained at high efficiency (electric efficiency, 226 percent; chemical efficiency, 18.5 percent).

Technologies of Shortening Wavelengths

In the vacuum ultraviolet (VUV) and the extreme ultraviolet (XUV) areas, studies are energetically under way to produce coherent light using nonlinear optical effects such as the production of higher harmonics and photomixing, and XUV and the soft X-ray lasers aimed at the X-ray laser (Figure 1).

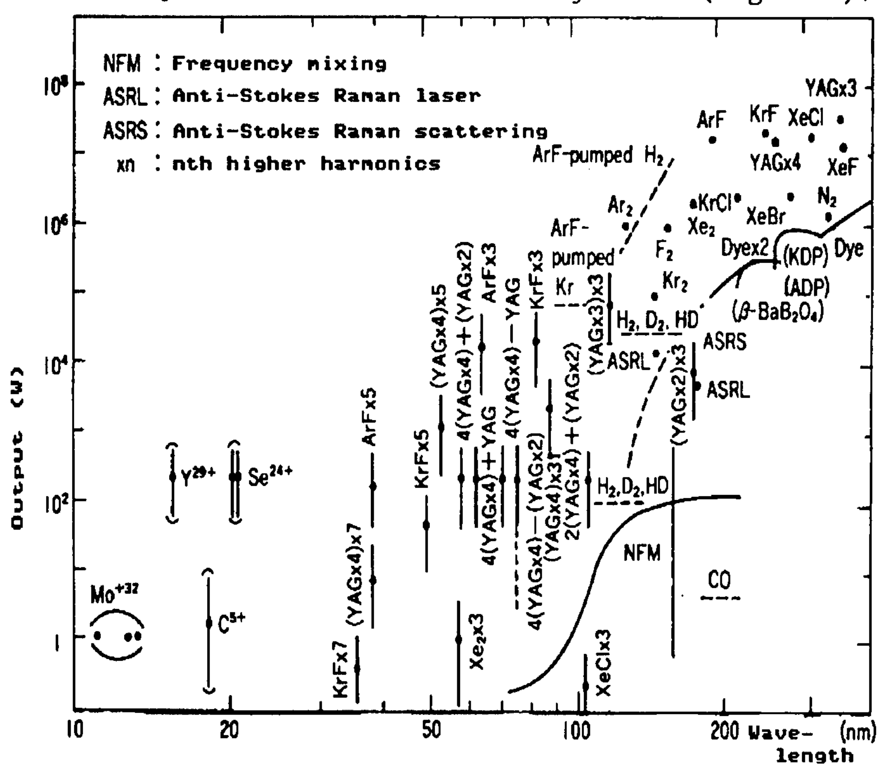

Figure 1. Main Lasers in UV-XUV Areas and State of Coherent Light Production by Wavelength Conversion

While in the XUV area (10-100 nm), coherent light has been produced only on a sporadic basis in terms of its wavelengths, but in the VUV area (100-200 nm), high output variable wavelength coherent light with the output of a kw level has been obtained in the area ranging from 110 to 190 nm by two photon resonance and four light wave mixing with metallic vapor such as Hg or Cd as a nonlinear medium.

The first laser oscillation in the XUV area was observed in Kr gas which has undergone excitation and ionization by four photon absorption of high-output ArF excimer laser beam (193 nm). This is an XUV laser involving transit of the Kr inner shell, with several oscillation lines observed at a wavelength of about 93 nm.

In addition, XUV stimulated emission at short wavelengths was observed in a laser producing plasma by glass lasers and CO_2 lasers with great power, thereby resulting in active discussions about the potential of the X-ray laser. In a laser producing plasma by the CO_2 laser, 18.2 nm stimulated emission light was observed in transit of C^{5+} ions while in a laser producing plasma by the second higher harmonics of the glass laser, stimulated emission light with wavelengths of 20.6 nm and 20.9 nm, 15.5 nm and 10.5 nm was observed in transit of Se^{24+}, Y^{29+} and Mo^{+32}, respectively. Based on these basic studies, the research into shortened wavelengths is expected to be pushed toward the X-ray laser in the future.

Technologies of Extremely Shortening Pulses

Since success in 1974 in producing extremely short pulses of below a picosecond by the passive mode synchronizing method with continuous oscillation dye lasers, followed in 1981 by producing ultrashort pulse of 90 fs by the colliding pulse mode synchronizing method (CPM), the research into femtosecond pulse laser technology has been made active (Figure 2).

In addition, the ultrashort pulse obtained by the PCM can be further shortened by the pulse compression system consisting of optical fibers and paired diffraction gratings. An ultrashort femtosecond pulse of 8 fs had been achieved by making an ultrashort pulse of 40 fs obtained from the CPM dye laser with its amplification system go through the pulse compression system.

Ultrashort pulses like this will provide an effective means for research into ultrahigh speed phenomena such as the relaxation process between solid excitation levels and the reaction process of biomolecules.

Developmental State of Commercial Lasers

As R&D improves technologies for greater output, shorter wavelengths and shorter pulses of lasers, the performance of market products using state-of-the-art technology has improved and new products have appeared in succession. Since it is impossible to describe the developmental trend of all of these commercial lasers, Table 4 shows only special items of major new lasers on the market.

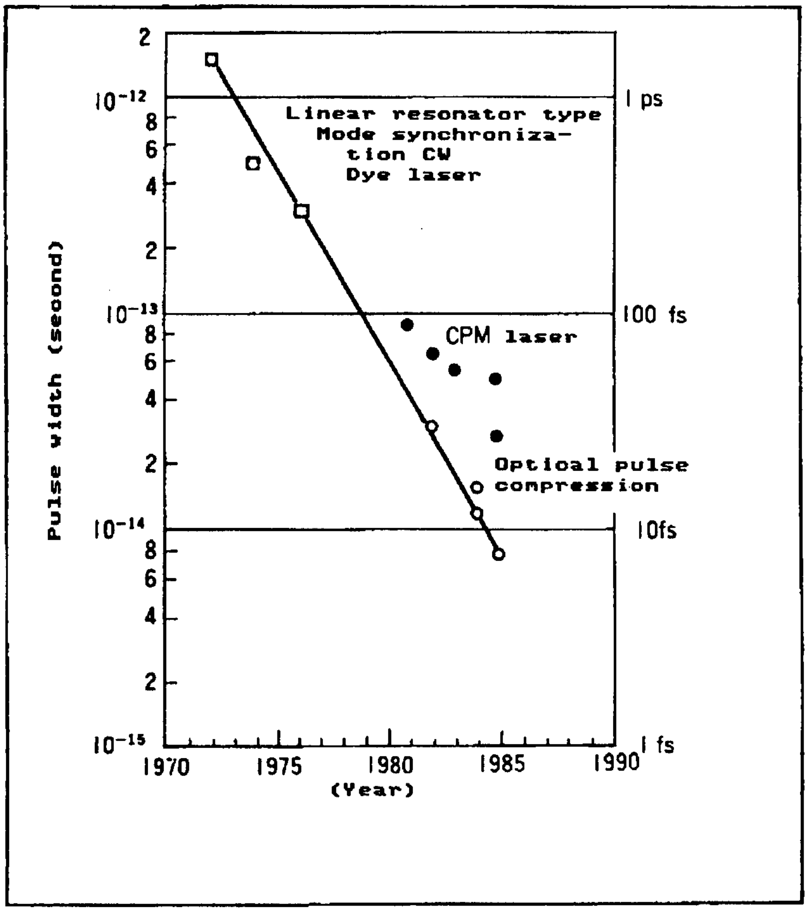

Figure 2. Trends of Ultrashort Pulse Production

Evolution of Laser Applied Technologies

The number of lasers sold in the noncommunist sphere in 1985 reportedly accounted for about 2.84 million semiconductor lasers, about 200,000 He-Ne lasers, about 11,300 ion lasers, about 4,800 solid lasers, about 2,900 CO_2 lasers, about 1,500 He-Cd lasers, about 780 dye lasers and about 360 excimer lasers. By value, they are as follows: the semiconductor laser, about $107 million; solid laser, about $106 million; CO_2 laser, about $101 million, ion laser, about $77 million; He-Ne laser, about $44 million; dye laser, about $25 million; excimer laser, about $17 million, and He-Cd laser, about $5 million (Figure 3).

The laser gross production 1985 (about $482 million) shows a 23 percent increase over the year ago level, and this stems from an increase in demand for semiconductor lasers in Japan. The production of semiconductor lasers in 1985 shows an increase of about 190 percent over the previous year, which is why 1985 is referred to as the year of the semiconductor laser. The production in 1985 of 789-nm semiconductor lasers for compact disks in particular increased to 2.7 million compared to 870,000 in 1984. The production for laser printers increased from 20,000 in 1984 to 200,000 in 1985, a further increase to 650,000 is estimated for 1986. Sixty percent of

Table 4. Developmental Stage of Commercial Lasers

Laser	Output mW (1981~1982)	Life h	Recent special items of commercial laser (1985-1986)
Semiconductor	1~15 (800nm ~1.5μm)	>10,000	· Shortening wavelengths: 750nm--Red · Providing higher output: Phase array type 200mW (CW, room temperature) Efficiency >25% Providing longer life: >50,000h (CW, 100mW)
He-Ne	0.5~20 (633nm)	~20,000	. Green He-Ne laser: 543.5 nm
Ar-ion	5~10 Air-cooling	~2,000	. Providing longer life: 10,000h
He-Cd	5~40 (442nm)	5,000	. Providing higher output: 15mW (325 nm) 100mW (442 nm)
Excimer	20W (200Hz)	10^6 shot	· Providing high repeatability great output: 100W (500Hz) · Providing longer life: 10^{-7} shot (XeCl, KrF)
Nd:YAG			. Providing greater output: 400W (average output) 200W/CW CW second higher harmonics (532nm, 2W) · Semiconductor laser excited: Nd:YAG laser 70mW (1.064 μm, CW) 10mW (532 nm, CW)
Variable wave-length solid laser	· Alexandrite (730~780nm)		· Cr: GSGG (745~835nm) Cr: $KZnF_3$ (780~850nm)
Dye	· Excimer laser excited dye laser		. Providing ultrashort pulses: 250 fs passive mode synchronization · CW infrared dye laser
CO_2			. Miniaturization: Mixing of lasers with robotics . Automation of control
Metallic vapor			. Gold vapor, copper vapor: Air cooling, 10W (628nm) (510,578nm)

the gross product of semiconductor lasers is related to optical communications while 20 percent concerns optical memories (audio disks, video disks, computer memories, etc.).

The gross product ($6.378 billion) of laser applied systems in 1985 shows a growth rate of 47 percent over the previous year. This stems from the growth of semiconductor laser applied systems (optical fiber communication systems, $1.5 billion; laser printer systems $1.8 billion; and audio disk systems $600 million) (Figure 4). [Figures as published]

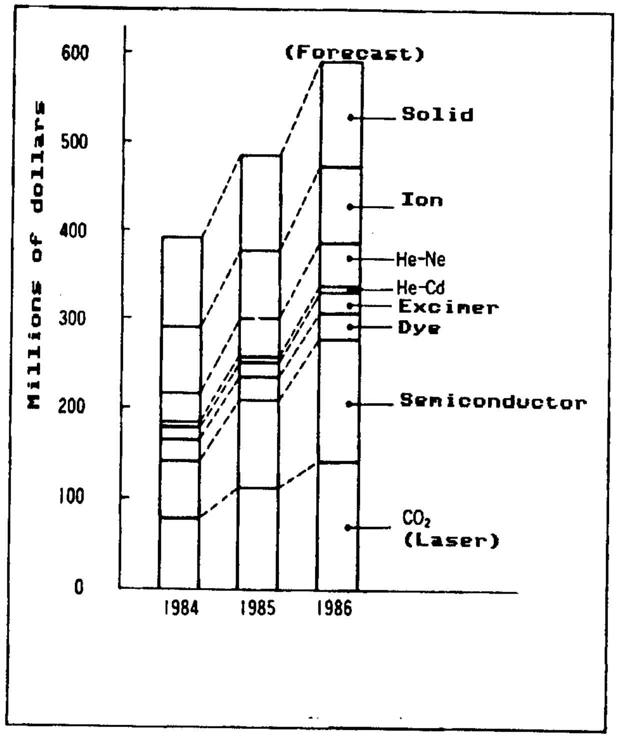

Figure 3. Production Scales of Various Lasers (in the noncommunist area)

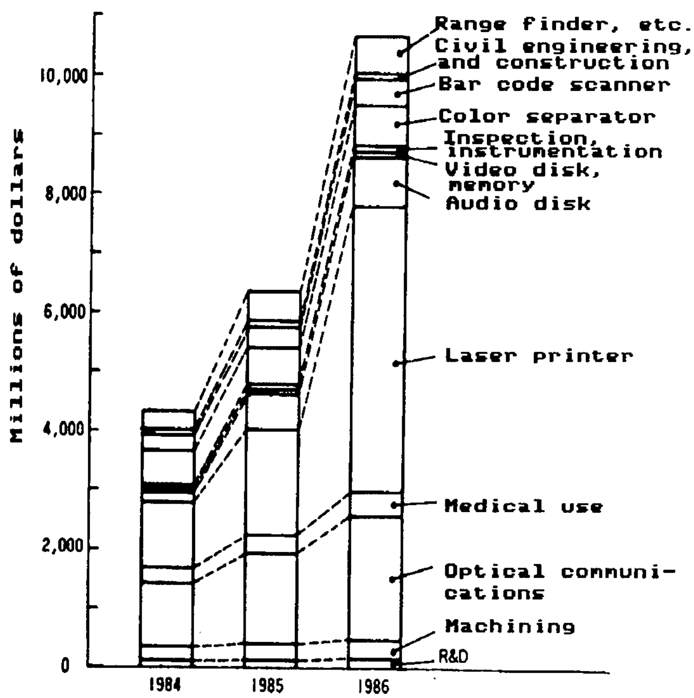

Figure 4. Production Scales of Laser Applied Systems (in the noncommunist area)

The CO_2 and the solid lasers, with a product equal to that of the semiconductor laser, are used mainly for laser machining and medical applications such as a laser surgical knife. The output of CO_2 lasers for laser machining and medical treatment accounted for 1,200 units (1985) and 1,100 units, respectively, while, by product value, 70 and 15 percent are for laser machining and medical treatment, respectively. Meanwhile, the output of solid lasers for laser machining and medical treatment accounted for 900 units and 650 units, respectively, while the product value for laser machining is a little below 14 percent and that for medical treatment is almost the same, a little below 15 percent. The Nd:YAG laser is, of course, the most important of solid lasers, about 50 percent of the value (output of 2,500 units) of the output of which is for military use such as a range finder.

Close to 40 percent of the ion laser output is used for medical treatment with about 15 percent for color separators. In the medical sector, it is in demand for treatment in ophthalmology and for diagnosis of cell separation, etc. The ion laser excited dye laser has been used for treatment because it permits free choice of wavelengths suitable for the absorption of ocular tissues. The dye laser is mainly used in basic research sectors, and good results have been achieved in studies of the production and instrumentation of femtosecond ultrashort pulses, cell separation and photochemical treatment of cancers.

While 40 percent of the He-Ne laser output is used for laser printers and 20 percent is for bar code scanners, the semiconductor laser has penetrated into this sector. Thirty-three percent of the He-Cd laser output is related to laser printers, but the demand has been moderate.

As for the excimer laser, 90 percent of its output is used for R&D as a laser providing high power in the short wavelength ultraviolet area. Good results have been achieved in the study of ultramicromachining such as laser CVD, laser etching and laser doping via the optical excitation process by the excimer laser plus the study of photochemical treatment of vital tissues. The demand for the micromachining device applying the excimer laser has increased since about 1984 and test manufacturing of medical treatment equipment began recently.

Conclusion

In this article, the development of lasers and the trend of applied technologies have been outlined. Progress in laser technologies has never stopped during the quarter of a century since its invention and we do not know where it will stop. New laser technologies have been developed in succession and they are in turn inducing new applied technologies. Demand for the room temperature CW oscillation semiconductor laser has, for example, expanded from optical fiber communications to the applied sector of welfare and industrial equipment including a laser printer, and, at the same time, it is expected that new applied sectors such as the development of the semiconductor laser excited solid laser, and its application to space airframe loaded laser applied systems and coherent communications. Also, future progress is to be noted and expected in new lasers and applied technologies such as new laser machining technology mixing laser technology with robotics, ultramicromachining technology and laser isotope separation using the excimer laser.

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STATUS, OUTLOOK OF OPTICAL TECHNOLOGY IN INFORMATION EQUIPMENT FIELD

Tokyo OPTRONICS in Japanese Mar 87 pp 65-73

[Excerpts] 1. "Optical Industry" Achieves More Than a 10-Fold Growth in 10 Years

The highly touted electronics industry, expected to be the trigger industry of the 1980s, suddenly lost steam in the latter half of the 1980s; in 1986 it stood at only 99.8 percent of the year before, suffering a minus growth for the first time in 11 years.

In this situation, only optoelectronics has been experiencing a boom in business.

Optoelectronics in the past was considered merely a part of electronics, but the founding of the Optoelectronic Industry and Technology Development Association (OITDA), which has been engaged in the gathering of data on its own and been making public since 1982 the results of the information thus collected, has elevated optoelectronics to the status of "optoelectronic industry. The optoelectronic industry has achieved a remarkable growth in the past 4 years, and as is shown in Table 1, it has now grown into a trillion yen industry.

The growth rate up till 1986 registered a high "year-ago" level, achieving a 167 percent gain over the preceding year in 1983, similarly a 138 percent gain in 1984, a 135 percent gain in 1985 and a 123 percent gain in 1986. Up until 1985, electronics as a whole had continued to enjoy two-digit growth over the previous year, attaining a 117 percent increase over the preceding year in 1983, a 129 percent increase in 1984 and a 110 percent increase in 1985; but in 1986 the industry suffered a negative growth of 0.2 percent compared to 1985. The setback naturally had a negative effect on the optoelectronic industry division, so a letdown in its 1986 growth rate in comparison with the figure for 1985 could hardly be avoided. Given the situation, the 123 percent growth rate can be called very strong.

The differences in the growth rate between the electronics industry and the optoelectronics industry are attributable to the following factor: while the former contains such merchandise as conventional color TVs, conventional audio equipment, VTRs and single work robots which are entering the maturity period in their life cycle, the latter is almost all made up of products which are at the beginning period growth period.

Table 1. Scale of Production of Optoelectronic Industry

(Unit: Y1 million)

Product names	FY 85 production records		Projected FY 86 production	
Optical parts				
Light-emitting elements		134,719		159,293
Semiconductor lasers	40,797		54,015	
Gaseous lasers	8,027		8,887	
Solid lasers	3,635		2,935	
Light-emitting diodes	82,198		93,386	
(for communications)	(5,075)		(16,034)	
(not for communications)	(77,123)		(77,352)	
Other lasers	62		70	
Light-receiving elements (such as discrete light-receiving elements)		23,946		29,325
Compound optical elements		32,463		39,186
Solar cells		10,565		12,002
Optical fibers (including cable)		54,059		67,228
Quartz fiber	51,771		64,665	
Non-quartz fibers (plastic, light guides, etc.)	2,288		2,563	
Other optical parts		46,371		62,449
Connectors/plugs	6,933		8,974	
Optical circuit parts/others	39,438		53,475	
Subtotal		302,123		369,483
Optical devices/equipment				
Optical transmission devices/equipment		28,234		36,456
Optical measuring instruments		20,717		26,753
Fiber-laying equipment		5,024		4,707
Optical fiber sensors		2,501		4,502
Laser-based sensors		6,894		8,864
Optical type disks		249,653		300,075
Digital audio disk service	198,252		236,861	
Video disk devices	45,783		50,279	
Additional storage disks (documents, data files)	5,130		12,030	
Recording media (for CD-ROM, additional recording)	488		905	
Optical input/output devices		75,943		102,440
Medical laser equipment		4,833		5,829
Laser machining equipment/others		52,878		53,570
Subtotal		446,677		543,196
Optics-applied systems				
Optical communications systems		92,662		119,662
Public communications systems	53,154		65,627	
Leased communications systems	39,508		54,035	
Others		6,434		7,226
Subtotal		99,096		126,888
Grand total		847,896		1,039,567

Prior to making public forecasts for the amounts of production of optoelectronics in 1986, OITDA came out with estimates on quantitative increases in the output of optoelectronics up to the year 1990, which are tabulated in Table 2. It shows how great an expectation people are placing on the optoelectronic industry. Putting aside the issue of farsightedness of the forecasts, the optoelectronic industry, which was in a scale of Y83 billion in 1980, will have grown at more than double the growth rate for the entire electronics industry.

Table 2. Current and Projected Future Demands for Optical Products

Optical Parts				
Optical products	Unit	1985	1990	Average annual growth rate (percent) 1985-1990
Semiconductor laser				
Long wavelength band (1.55-μm band)	piece	negl	1,000	·
Long wavelength band (1.30-μm band)	"	15,000	200,000	70
Short wavelength band(0.85-μm band)	"	15,000	108,000	48
Visible area (0.78-μm band)	"	3,500,000	34,000,000	58
Gaseous lasers	set			
He-Ne laser	"	150,000	180,000	4
Argon laser	"	2,600	6,000	18
Co_2 laser	"	700	2,500	29
Excimer laser	"	140	1,300	56
Solid lasers				
Ruby laser	set	15	15	0
Glass laser	"	30	30	0
YAG laser	"	900	3,500	31
Dye laser	"	100	640	45
Light-emitting diodes				
LED for discrete display	piece	1,600,000,000	5,000,000,000	26
LED for number/letter display	"	90,000,000	350,000,000	31
LED for communications (1.30-μm band)	"	10,000	730,000	136
LED for communications (0.85-μm band)	"	120,000	1,200,000	58
Optical fibers				
Quartz multimode Si fiber	km·core	6,700	30,000	35
Quartz multimode Ci fiber	"	35,000	800,000	87
Quartz single mode fiber	"	82,000	250,000	25
Multicomponent multimode Si fiber	"	4,000	13,000	27
Light-related parts				
Light branching/binding device	piece	3,500	58,000	75
Light wave branching/binding device	"	3,700	920,000	201
Light attenuator	"	16,000	225,000	70
Isolator	"	600	15,000	90
Optical switch	"	7,500	730,000	150
Optical connector	"	1,900,000	25,000,000	67

[continued]

There is, of course, no guarantee that the optoelectronic industry will keep on growing at that pace for the next five years, but it would not be too far-fetched if one thought the industry would achieve more than a 10-fold growth in the coming 10 years.

[Continuation of Table 2]

Optical Instruments/Equipment				
Optical products	Unit	1985	1990	Average annual growth rate (percent) 1985-1990
Optical transmission devices/equipment				
Digital optical transmission devices/equipment				
Simple type (links)	set	600,000	3,200,000	40
Ordinary optical transmission equipment	unit	3,500	110,000	99
Analog optical transmission devices/equipment				
Simple type	set	8,600	86,000	58
Ordinary optical transmission equip.		220	7,000	100
Optical modem	"	3,000	17,000	41
Spatial propagation equipment	"	430	63,000	171
Measuring devices for optical transmissions				
Standard power source	unit	1,800	7,400	33
Power meter	"	8,400	35,000	33
Measuring equipment of optical transmission features				
Baseband transmission characteristics measuring devices	unit	50	700	70
Wavelength dispersion measuring devices	"	negl	170	
Light loss measuring devices	"	500	2,000	34
Obstacle position detector (OTDR)		330	1,400	34
Wavelength meter		460	1,700	30
Optical sensors (sensors using lasers or fibers)				
Temperature sensor	unit	200	50,000	202
Others	"	760	9,700	66
Optical disk player				
Reproduction-only video disk	unit	200,000	1,000,000	38
Additional write-in optical disk	"	1,300	17,000	67
Rewritable optical disk	"	0	2,000	
Rewritable compact disk	"	900,000	8,000,000	55
Optical type printers				
Semiconductor laser printer	unit	20,000	640,000	100
Gaseous laser printer	"	1,800	4,700	21
LED printer	"	800	60,000	137
Liquid crystal printer	"	350	120,000	221
Laser scanner		5,500	22,500	33
Medical laser equipment	unit	280	710	20
Laser applied production equipment				
YAG laser	"	535	2,785	39
CO_2 gas laser	"	295	2,280	51

2. Three "Hardware Technologies" for Realizing an Information Society

The society is oriented toward an information society. In an information society, a service provision system must be in place, in which, by solving the contradictions between the time series and the amount of information existing in the conventional means of data transmission, user demands for various information can be met on a timely basis. The type of information service that will contribute greatly to an individual or a corporate decision-making but that is either unobtainable or too expensive to obtain with conventional means in terms of hardware or software can be obtained at a reasonable cost. The user would come to think it profitable to pay a price for the service provided, and an opportunity for starting a business would emerge.

For a service system as such to emerge, as things stand now, even the hardware technology, to say nothing of software technology, is scarcely satisfactory, and its development is awaited.

The necessary hardware technology can be summed up as follows: (1) technology for processing a large amount of data, (2) technology for stockpiling a large volume of data, and (3) technology for transmitting a large volume of data.

2.1 Massive data processing technology

Suppose you are a researcher and are looking for domestic and foreign literature on plant genetic engineering. With the conventional method, you would have to call on experts in the field or would have to browse through domestic or foreign academic journals. Even then, the available data may be limited. The time and labor needed for the checkup would be considerable. If, as is the case with the on-line database service, data could be checked in minutes or copies of it could be printed to within a few hours by merely typing necessary words into the keyboard following the guidebook, research efficiency would be greatly enhanced.

But if such a software service were available, an appropriate amount of hardware corresponding to the service requirements would have to be utilized. The first is that the data base center must be stockpiled with writing, with the papers indexed. On the part of the data base center, if the literature is to be speedily input, the conventional method of inputting in which an operator types words into the keyboard would require too many manhours. In other words, existing von Neumann computers are not provided with interface that can understand the natural language. Therefore, a machine with a large data processing capability is needed that will be able to scan the literature and turn the contents into electrical signals for storage. The non-von Neumann computer being developed by the Institute for New Generation Computer Technology (ICOT), the optical computer expected to be provided with the capability to recognize patterns easily, and AI (artificial intelligence) that will enable it to pick up appropriate answers from a large volume of data, for example, will fall into the category of such machines.

2.2 Massive Information Stocking Technology

Next comes a need for a storage device that can keep in stock economically a large volume of data. Conventionally, this role has been played by magnetic tape and magnetic disk. But, as the volume of data increased, if magnetic memories with a low surface recording density (storage capacity per unit area; the number of bits that can be stored in an area of 1 cm^2) were to be used, the storage system would have to be of an enormous scale, and this would also result in a slower retrieval time. Here arises the need for the development of large capacity filing systems like optical disk, optical magnetic disk and photochemical hole burning memory.

As a new audiovisual system that is expected to bring into reality the day of home theater, VD (video disk) is emerging rapidly. VD comes in optical and electrostatic types, and this is another area where optical technology is being made the most of. Differing from a CD that can record only voice, a VD can record a large volume of images. So, in it, recording is made not in digital signals but in frequency modulated analog signals, and a 0.63-micron HeNe gas laser is used for high-density recording.

If a laser diode with a wavelength on the order of 0.6 micron is developed, it will substitute for a HeNe laser, and this will open the way for a VD=CD compatible disk (temporary designation). In fact, Pioneer Electronic Corporation has already commercialized a such a device.

As the optical disk is called by another name of CD-ROM, it is not amenable to rewriting. So, the additional entry type of optical disk which has a margin of blank space is becoming the mainstay. But if optical disks are to substitute for magnetic disks completely, they will have to be amenable to rewriting.

Two systems are proposed for rewritable optical disk. One developed by ECD of the United States takes advantage of phase changes from crystalline to amorphous and vice versa in low tellurium oxide (TeO) and others, and efforts are being made to make commercial use of the introduced technology but no product has yet to be commercialized because of alterations in the recording with passage of time.

The other is the photoelectromagnetic disk developed by Kokusai Denshin Denwa Co (KDD) and Nihon Hoso Kyokai (NHK) that utilizes the magnetic Kerr effect in amorphous-Tb-Fe-Co alloys. Hitachi (12-inch diameter) and Sony (30-inch diameter) had developed prototypes as early as autumn 1985, and general-purpose 5.25-inch types are expected to be commercialized within one year. Since the photoelectromagnetic disk has a recording density as high as the optical disk and, moreover, since it has a rewrite capability as high as the magnetic disk, it has the potential to replace magnetic hard disks entirely. In connection with the disk, development of an LD with an overwrite capability, a capacity to simultaneously perform erasion and write functions, is being targeted.

The need for increased recording density is limitless. So, despite the technical barrier of how to set the access time, development of a short wavelength LD combined with SHG (second harmonic generation) is taking on the shape of a concrete theme. Studies are also being made for the introduction of the short wavelength and high energy excimer laser, wavelength variable lasers utilizing new solid lasers like alexandrite ($BeAl_2O_4$), and free electron lasers, and practical use of photochemical hole burning memories as the next-generation device is no longer a mere dream.

2.3 Massive Information Transmission Technology

Next, in the relationship between information provider and information user, a system will be needed that can transmit a large volume of information speedily in both directions. Existing data networks are satisfying the requirement to some extent, but under the existing telecommunications systems even the TV telephone is far from the stage of widespread use. In an information society the volume of information that includes not only numbers and letters but also graphics and images is greater by several orders of magnitude. Hence, there will arise a need for nationwide networks of optical fiber communications which are more suited for mass transmission of data than the telecommunications system, and such a need will also arise in the case of international transmissions. The wavelength multiplexed coherent optical communications and the transpacific submarine optical cable should comply with such needs.

Optoelectronic technology is expected to play a very great role in establishing the aforementioned three "hardware technologies."

3. Optoelectronic technology finds wide use in the data processing equipment field

3.1 Light-emitting diode (LED)

CRT and EL are widely employed in displays as light emitting elements, and the representative light-emitting element for optoelectronics is the compound semiconductor light-emitting diode, LED (Electro Emitting Diode).

LED is expanding its field of application as visible LED lamps, infrared LED lamps and LED numerical display elements.

Among the LEDs most widely used are the red color light gallium phosphide (GaP), gallium-arsenide-phosphide (GaAsP), and gallium-aluminum-arsenide (GaAlAs), and their peak wavelength is from 0.63 to 0.7 micron.

As for the luminance of LEDs being put to practical use, thanks to their double hetero layer, all have achieved a luminance ranging from 500 millicandelas to 1,000 millicandelas, and some are about to realize a luminance of several thousand millicandelas.

LED of blue color, the last of the three basic colors, is in the development stage. Matsushita Electronics Corp is developing a blue LED of a MIS (metal insulator semiconductor) structure that is formed by mounting gallium and nitrogen on a sapphire substrate. The three-member consortium of Kyoto University, Osaka University, and the Government Industrial Research Institute, Osaka, of the Agency of Industrial Science and Technology, along with Toshiba Corp, are separately engaged in the development of a blue LED of a MIS structure that is formed by fabricating the N layer of zinc sulfide (ZnS) crystal and an insulating layer by means of the MOCVD (metal oxide chemical vapor deposition) method and adding to the monolithic electrode metals. Furthermore, development of a blue LED based on silicon carbide (SiC) is underway. Compared with LEDs of other colors, blue LEDs have luminance levels that are smaller by two to three orders of magnitude, so the key is how to raise their luminance.

The current market for LEDs is only at the scale of Y93.4 billion, but the LED panel and optical communications light-emitting element markets should grow at an annual rate of 10 percent, pushing the total sales to a level of Y200 billion by 1990.

3.2 Laser diode (LD)

An LD is also a compound semiconductor light-emitting element in which light stimulated by an external energy and discharged is reflected in large part at the cleavage plane of a semiconductor single crystal to be returned to the active layer for a reexcitation, and the discharged light also repeats the same back and forth movement, gradually increasing its strength to a point where it wins over the propagation loss when the stimulated emission light is radiated to the outside.

Such light is called laser; it is a phased light with a fixed wavelength. Such a light-emitting element is called a laser diode (LD). The advantage of an LD lies in the fact that since it, although small in output power, utilizes its own cleavage plane, it does not need any reflecting mirrors, thus enabling it to be fabricated as an extremely small, compact device.

GaAs-$Al_xGa_{1-x}As$ semiconductor lasers which are representative LDs have wavelengths in the 0.78-0.85 micron range, and they are used as the laser source in fiber optic telecommunications or in DAD (digital audio disk).

Semiconductor Lasers for Optical Telecommunications

In optical communications, the key to repeaterless transmission is the light loss of optical fiber. Quartz fibers widely used at present have a feature that they show the minimum light loss at 1.55 microns in wavelength, so the loss will be great at 0.85 micron. So, development of semiconductor lasers in the 1.3 microns to 1.5 microns range is being undertaken.

The most promising materials for such lasers are a class of $In_xGa_{1-x}As_{1-y}P_y$ (indium-gallium-arsenide-phosphide) compounds, and they are of a structure in which InGaAsP-InP-InGaAsP is epitaxially grown on an InP substrate, and furthermore a buried-in type of products has been developed. The fiber optic trunk line running along the length of the Japanese archipelago is equipped with 1.3-micron LDs, a device that enables repeaterless transmission over a 30-kilometer span. Furthermore, a distribution feedback (DFG) type LD has been trial manufactured by using an $In_xGa_{1-x}As_{1-y}P_y$ compound and it has enabled 300-kilometer repeaterless transmission in an experiment, thus giving it a star role in the future long distance optical communications.

Ultralong distance transmissions beyond that are, however, beyond the limits of light loss of quartz optical fibers, so non-quartz optical fibers with a wavelength in the infrared region are needed. The National Research Institute for Metals, Science and Technology Agency, has experimentally developed a PbS/PbCdSSe double heterojunction laser for use as an LD in the 2-3 micron range.

Semiconductor Lasers for Optical Memories

For CDs (DADs), 0.78 micron-band LDs made from $Ga_xAl_{1-x}As$ compounds are mainly used. But for VD (videodisk) optical disks, a shorter wavelength is needed, and HeNe laser (0.63 micron) and Ar laser (0.5 micron) are employed.

But gas lasers have too many constraints in terms of both space and cost, so development of short wavelength LDs is awaited.

LDs in the 0.68 micron to 0.69 micron range have experimentally been manufactured using $Ga_xAl_{1-x}As$ compounds for $In_xGa_{1-x}As_yP_{1-x}$ compounds, but they have yet to be put to practical use. On the other hand, attempts have been made by Matsushita Electric Industrial Co and others to obtain 0.415 micron instead of the 0.83 micron from LD by taking advantage of the secondary harmonic generation (SHG) of nonlinear optical materials such as $LiNbO_3$ (lithium niobate).

Semiconductor Lasers for Laser Printers

Recently, in competition to conventional gas laser printers, commercialization of semiconductor laser printers has begun to catch on by taking advantage of their low cost and compact size, and $Ga_xAl_{1-x}As$ materials have come to be used as the laser oscillators.

Production of semiconductor lasers in 1986 was worth only about Y88.9 billion. However, with the addition of laser printers in addition to conventional optical fiber communications, DAD and optical disks in which they are being applied, production of semiconductor lasers should grow at an average annual rate of 30 percent, reaching the market level of about Y250 billion by the year 1990.

3.3 Light-receiving elements (photodiodes)

While a light-emitting element converts an electrical signal into an optical signal, a light-receiving element has the role of converting a received optical signal into an electrical signal. In optical communications, both devices are installed at both ends of transmission.

Different materials are used for light-receiving elements with different uses. Among the materials with a sensitivity to the 0.85-micron region of GaAs are Si (silicon), Ge (germanium) and GaAs-AlGaAs, but in practice, Si is widely used. The material suited for use for the 1-2 microns range of light such as that of InGaAsP is Ge, but the material has problems in the form of a large dark current (a current that flows without light radiation) in Ge-APD (Avalanche Photo Diode), slow response and large noise, so compounds of the II-V groups are beginning to draw attention. Included among them, for example, are $In_xGa_{1-x}As_{1-y}As_{1-x}P_y$, $In_{1-x}Ga/_xAs$. and $Ga_xAl_{1-y}Sb_y$.

Among application fields of light-receiving elements are solid imaging tubes for VTR cameras and visual sensors, in addition to optical communications.

The basic structure of photodiodes widely used in solid imaging tubes and visual sensors is the same as that of MOS for IC, and it consists of the three layers of Al metal electrode and SiO_2 and Si single crystals, further provided with the photodiode in the light-receiving region and CCD that stores and transfers electric charges. When a beam of light strikes the photodiode (reflected light), a charge is generated by the action of the photoelectric transfer effect in proportion to its strength. Up to this point, MOS IC and CCD are same in their mechanism, but the difference is that the latter stores and transfers charges.

The market for light-receiving elements at present is worth only about Y29.3 billion a year. This is because, as merchandise, optical fiber communications, visual robots, VTR cameras and magnetic disk cameras are still in their early stages of growth; but the demand may increase greatly as the markets for these products mature.

Growing at an average annual growth rate of 20 percent, the market should reach the level of Y60 billion by the year 1990.

The market for composite optical elements such as photocouplers and photointerlamps incorporating photodiodes is at a level of Y39 billion at present, but it should grow to the level of Y90 billion in keeping with the growth tempo of photodiodes.

3.4 Fiber optic communications

When the telephone is used as an example, the mechanism of optical fiber communications is explained as follows: first, voice is transformed into an electric current.

Next, the current is converted by a light-emitting device (LD) into laser. The laser light is transmitted via a quartz fiber to a light-receiving device (photodiode) at the receiving side where it is converted back into a current. The current is further converted into a voice to reach the human year.

Light-emitting device

Voice--current--laser--optical fiber--laser--current--voice

Light-receiving device

Quartz glass fiber of two-layered structure provided with a core of a high refractive index and a clad of a low refractive index is widely used for the optical fibers. With an external diameter of 125 microns, the single-mode fiber has an inside diameter of 10 microns and the multi-mode fiber has an inside diameter of 50 microns.

Besides the above, among optical fibers are included the multi-element glass fiber containing such elements as silicon dioxide, alumina and sodium oxide, and the methyl methacrylate plastic fiber.

Compared with quartz fibers, these fibers are low in cost, so they are appropriate for such short-haul applications as office automation, control cables in plants, or automobiles. Compared with quartz fibers, they, however, have a large light loss, so quartz fibers are still the mainstay.

NTT, the world leader in technology, completed in January 1985 a 3,400-km optical fiber trunk line system running along the length of the Japanese archipelago from Asahikawa to Kagoshima, and it has a transmission capacity of 400 Mbit/sec. The 1.3-micron LDs in the system are to be replaced by 1.55-micron DFB-LDs by 1988, and the capacity should be increased to 1.6 Gbit/sec. And it is almost certain that by the first half of the 1990s, the majority of the domestic trunk lines and links between stations will be connected by optical cables. By the year 2000, almost all domestic communications will have been switched over to fiber optic communications links.

The prerequisite for fiber optic communications networks to expand to the level of the subscriber loop is the practical use of such light-activated components as isolator-type optical amplifiers, optical switches comprising an optical switchboard, and optical IC (OEIC). Various ideas have been proposed by NTT and domestic makers, and these optical devices should reach the stage of practical application by the early 1990s.

The trends in the development of optical communications in the future will probably take the form of (1) increased transmission capacity and (2) increase in the transmission distance without amplification. As for item (1), Toshiba corp has already succeeded in a five wavelength multiplex transmission experiment using an optical wave dividing and combining device.

Furthermore, in place of the IM system using "1" and "0" the FSK and PSK systems called coherent optical communications are being developed.

Next, the key to the realization of transmission over ultralong distances of several hundred or several thousand kilometers without amplification is the development of non-quartz optical fibers in the infrared portion of the spectrum and work is underway for the development of ZrF_4, GeS and Tl (Br,I) fibers and these fibers should reach the levels of practical use by the latter half of the 1990s.

The market for optical fiber communications in 1986 was still small at about Y120 billion, but production of optical communications systems in 1995 should be at the level of Y1 trillion at the minimum. Of this, optical fibers and optical components are expected to account for Y600 billion. Of the Y10 trillion, public communications systems are expected to account for Y700 billion and the specialized user systems like LAN and OA Y300 billion. [Figures as published]

3.5 Storage devices

The debut of LP record albums 30 years ago had dispelled the conventional SP albums form the market in less than 10 years. A same phenomenon is about to take place. This time it owes to the debut of DAD (digital audio disk) that came to the market in the fall of 1982 and CD (compact disk).

A CD is one-third as large as a LP record but is crammed with five times as much sound. For the purpose, a CD has as many as 5 billion to 67 billion small bits of 1-micron size pitted on its surface. The small bits are equivalent to groove amplitudes of LP records. Consequently, CD can reproduce the original sound with high fidelity.

CD has not only brought about a revolution in the record album industry but is beginning to start a similar revolution in the field of data stock. The horizontal magnetic recording density of such peripheral storage devices as magnetic disks and magnetic tapes found in the computer room is from 300,000 to 400,000 bits per square centimeter (1 cm^2), but optical recording systems have more than 10 million bits for the same size. Consequently, the adoption of a recording system based on optical disks could do the job in a fraction of the space needed for the magnetic system.

This is the optical disk. Optical disks now on the market area of the same size as record albums with a diameter of 20 cm, but a single optical disk has a memory capacity of 1Gbite (G...1 billion, 1bite...8bit). [Figures in English as published]

The latent demand for CDs is said to reach 40 million units in Japan, with an additional demand of 300 million units coming from the United States and Europe. The market thus has potential to develop into a big market in the post-VTR age. The 1986 output of CD players was at the level of 7 million units, and the 1987 figure should surpass the 10 million mark. The 1986 production of optical-type VD players was 700,000 units. Consequently, the combined CD and VD market for 1990 is considered certain to reach the level of Y500 billion at the minimum.

Optical disks, on the other hand, have just taken off, so the market is only at the level of Y1.2 billion, but when rewritable type devices make their debut, they should garner to themselves an equivalent of a market share that otherwise would have gone to magnetic disks, reaching Y500 billion in 1995.

3.6 Optical input/output devices

Laser printers and laser photoengraving devices are the most important equipment of all optical input/output devices.

These devices, having a drum and a photosensitive material, work as follows:

A positive corona discharge in a darkroom gives the surface of the photosensitive material a static electricity charge, thus making the surface photosensitive. Next, the text to be copied is changed into an optical image of bright and dark spots. When the image is subjected to radiation for exposure, there follows a "generation and transportation" of an optical carrier in those parts of the photosensitive material exposed by light beams that passed through the bright spots, dissipating the surface electric charge in those parts. Conversely, the electric charge in the dark spots that have yet to be exposed remains there. When such a latent charge image is impregnated with a toner of a reversed polarity by means of electrostatic attracting force, it works like a printing font impregnated with ink. When a copying machine is pressed hard against it, an image as clear as a printed image can be produced. Once copying is completed, the toner and electric charge remaining on the photosensitive material's surface are removed, and the process is repeated again.

Laser printers are equipped with a laser oscillator for the exposure source, and they come in the two types of gas laser printer based on HeNe (helium neon) and semiconductor laser printer based on GaAsal, depending on the laser source. Since gas laser printers use short wavelengths, they feature large numbers of printing dots, thus assuring clear printed letters or graphics, but they are expensive because they use a gas laser. Thus, gas laser printers are for the high end of the market, while semiconductor laser printers are for the low end of the market.

Liquid crystal shutter printers, although they are not based on lasers, are beginning to show potential as a dark horse after semiconductor laser printers.

Impact printing systems are becoming the mainstay in the existing printer market worth about Y800 billion, and laser printers account for a mere 6.5 percent of the market, or Y50 billion.

But, helped by their high performance and with decreasing costs, laser printers should achieve more than 30 percent share of the market, with sales on the order of Y300 billion, by 1990.

3.7 Optical cards

In Japan, a group of 13 banks including The Sumitomo Bank, The Tokai Bank and the Kyowa Bank is conducting an experiment in a service using cards that incorporate both the cash card and credit card functions in Hikarigaoka area, Nerima-ku, Tokyo, as part of the NMS (New Media Service).

Furthermore, optical cards developed by (Drexler) Technologies of the U.S. and Dai Nippon Printing Co are emerging as the third ace.

These optical cards come in two types. The optical card developed by (Drexler) is based on a method in which, as with CD and optical disk, the recording surface of cards is pockmarked with pits (gelatin in the recording layer is dispersed with silver grains, and melting of the silver grains leads to the formation of the pits), while the one developed by Dai Nippon Printing is based on a plane block recording system.

In plane block recording, a data memory layer consisting of a non-silver salt pattern layer, three microns thick, and a reflective layer is sandwiched by a protective layer and a substrate material layer. When a laser beam is shined at it from directly above, instead of making pits the heat alters the composition of the organic resin in the memory layer and the metal salt precipitates at the time of electrolysis plating. The reflectance of light stays at only 5 percent at where the metal precipitated vs 80 percent at where no precipitation of metal took place, and the differences are read.

The card's memory layer consists of 812 (28 x 29) blocks, with each block capable of storing 4 bits (520 bytes) of memory, so the total memory capacity is 3376 Mbits (422 Kbytes). In other words, a single card can hold 160 pages of A-4 text. it can also be used in combination with magnetic stripes with ease. In the below are compared the three types of cards with respect to the storage capacity and the costs of unit storage capacity.

Card type	Memory capacity	Cost	Cost-memory capacity
Magnetic card	70-80 bytes	Y500	62.5 yen/byte
IC card	8000 bytes	Y5000	0.6 yen/byte
Optical card	422,000 bytes	Y300	0.0007 yen/byte

The optical card is advantageous in terms of memory capacity and memory capacity/cost, but it has a disadvantage in that it is lacking in a erase and rewrite capability.

The number of magnetic cards, including the 80 million cash cards, and credit cards and shopping cards, in circulation at present is considered to be about 200 million. And it is estimated another 40 million or so magnetic cards are printed annually, and this shows the extent of the potential market for optical cards.

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