Original Paper

Glass science and glass industry in Japan

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In this paper, the history of the Japanese glass industry from the introduction of European glassware in the 16th century is presented first, and the current state of the glass industry, such as the change in number of workers and sales of glass products in recent years, is described next. Then, the research and development areas of industrial interest and the research topics in academic institutions are summarized.

Glasforschung und Glasindustrie in Japan

In der vorliegenden Arbeit wird zunächst die Geschichte der japanischen Glasindustrie seit der Einführung europäischer Gläser im 16. Jh. dargestellt und dann der derzeitige Stand beschrieben, wie er sich aus der Anzahl der Beschäftigten und den Verkaufszahlen von Glasprodukten in den letzten Jahren ablesen läßt. Schließlich werden die Forschungs- und Entwicklungsgebiete, die für die Industrie von Interesse sind, sowie die Forschungsschwerpunkte akademischer Institutionen genannt.

1. Historical view of the Japanese glass industry

Although a technique for making glass beads had been known in Japan as early as the 5th century and a number of glassware had been brought into Japan, glass had never played any significant role in the old cultural life in Japan. This is partly because glass had been regarded as a special material like precious stones and partly because lacquer and ceramic wares were far easier to be made and satisfied people's needs for daily use.

The history of modern glass in Japan was initiated by the introduction of European glassware to Japan in 1551 as gifts from Francisco Xavier to a Japanese feudal lord. From the 16th to the 17th century, Japanese culture saw a Golden Age, during which new tastes for modern things began to sprout just like the Renaissance in Europe and the incoming glassware gave a lasting impression on the minds of Japanese people. Domestically made glassware started to appear in the mid-17th century, and by the end of the 18th century glassware of various shapes was being made by blowing. More decorative glassware, such as cut glass or engraved glass, began to be produced at the beginning of the 19th century, and flourished as a unique technique of making "Satsuma Kiriko" cut glass. This technique of applying deep cuts in the thick red or blue colored glass-surface layer on a transparent glass body was not being practiced in Europe at that time.

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In the mid-19th century, the Meiji Restoration took place and the new Meiji government attempted to catch up with the western culture. The government placed a strong emphasis on developing the glass industry by setting up a state-owned glass plant and bringing in the modern blowing and pressing methods from abroad. Large-scale private glass-manufacturing plants for flat glass, bottles and laboratory ware were also established. However, these firms could not stay in the business too long and were eventually closed, because the production was too high compared with the demand. Only smaller ones remained. By the end of the 19th century, there were about 50 small glassmakers in the Tokyo or Kannto area and about 100 in the Osaka or Kansai area.

During the depression period of 1930 to 1931, many of these glassmakers suffered from financial difficulty and some of them gave up and merged with other firms. Those staying in business tried to make every effort to improve technical skill and increase efficiency, reducing the cost to a minimum. When the depression was over, Japanese glass products gained the reputation of the best in quality and the cheapest in price in the world. The drop of the exchange rate and the encouragement of export by the government helped to spread Japanese glass products in the world market and to expand their applications in Japan. For example, the production of flat glass in 1936 was 46.45 million m^2 ($\triangleq$ 500 million sq ft), which was the largest output in the world and about 20 % of the world production. So the glass industry was regarded as one of the most active and promising industries in Japan. In 1937, there were 5 companies producing

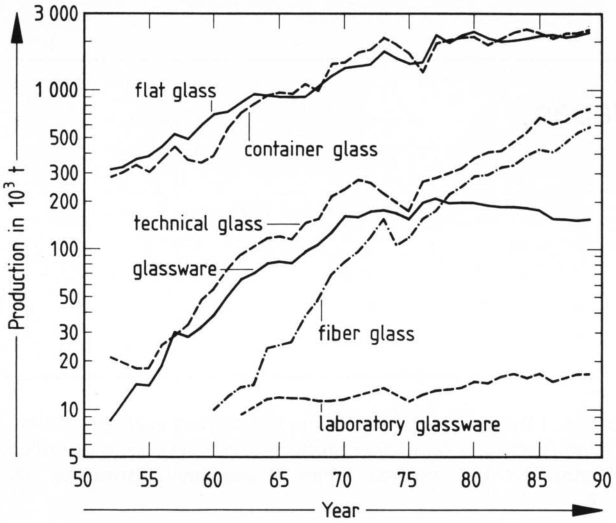


Figure 1. Yearly production of the Japanese glass industry.

Table 1. Major Japanese glass manufacturers

flat glass	fiber glass
Asahi Glass Co.	Asahi Fiber Glass Co.
Central Glass Co.	Fuji Fiber Glass Co.
Nippon Sheet Glass Co.	Nippon Glass Wool Co.
	Nippon Glass Fiber Co.
container glass	Nippon Electric Glass Co.
Daiichi Glass Co.	Nitto Boseki Co.
Hiroshima Glass Co.	
Ishizuka Glass Co.	glassware for daily use
Nihon Glass Co.	HOYA Corp.
Nihon Taisanbin Kogyo Co.	Ishizuka Glass Co.
Shin-Nihon Glass Co.	Sasaki Glass Co.
Toyo Glass Co.	Soga Glass Co.
Yamamura Glass Co.	Toyo Glass Co.
optical glass	electric and electronic glass
HOYA Corp.	
Minolta Camera Co.	Asahi Glass Co.
Nikon Corp.	Iwaki Glass Co.
Nippon Sheet Glass Co.	Nippon Electric Glass Co.
Ohara Corp.	Toshiba Glass Co.
Sumita Kougaku Glass Co.	

flat glass at 8 factories with 14 tank furnaces. With the outbreak of World War II the production dropped. When the war ended in 1945, the production index of glass products was 1/6 of that in 1940. In the following years, it started to recover, and in 1952 it returned back to the level of 1935.

In order to show the trend in glass production from 1950 to 1990, the products were divided into 6 categories as given in figure 1. With the rapid economic growth and the adoption of a modernized and westernized life style in the 1960's, the productions in all categories increased enormously. Although the oil crisis made a dip in each curve, it did not change the overall trend. During the 1980's the increase in production of flat glass, container glass

Table 2. Number of workers in the Japanese glass industry

year	flat glass	fiber glass	other	total
1980	9 083	5 698	24 842	39 623
1981	8 769	5 604	23 223	37 596
1982	8 771	5 572	22 286	36 629
1983	8 319	5 589	22 104	36 012
1984	8 327	5 686	21 799	35 812
1985	8 629	5 480	22 077	36 186
1986	8 268	5 274	21 338	34 880
1987	8 345	5 072	21 364	34 781
1988	8 162	5 094	20 512	33 768
1989	8 701	5 118	20 118	33 937

Table 3. Sales of glass products in billion Yen

year	flat glass	fiber glass	other	total
1980	395	114	400	909
1981	407	117	411	935
1982	418	131	415	964
1983	445	138	458	1 041
1984	460	157	585	1 202
1985	497	164	597	1 258
1986	509	151	548	1 208
1987	533	159	560	1 252
1988	586	183	596	1 365
1989	635	199	605	1 439

and laboratory glassware slowed down, and the production of glassware for daily use decreased a little. However, for technical glass and fiber glass the expansive trend of the 1960's and 70's continued in the 80's. The electric and electronic applications of glass were the driving forces for this expansion.

2. Current state of the Japanese glass industry

2.1. Employment and sales from 1980 to 1989

There is a large number of glass manufacturers in Japan. The major manufacturers are listed in table 1 according to the division into 6 categories of glass products as shown in figure 1. The change in the number of workers in the glass industry from 1980 to 1989 is shown in table 2; the figures refer to the production branches of flat glass (category 1), fiber glass (category 2) and other glasses (categories 3 to 6) as well as to the glass industry as a whole. Flat glass is produced in large-sized companies where the number of workers remained about the same. Glass products of categories 3 to 6 are produced in medium- to small-sized companies. The number of workers in these companies decreased by 15 % in the years between 1980 and 1989. According to the sales figures given in table 3, the sale of glass products of categories 3 to 6 was not much different from that of flat glass. This indicates that the necessity of reducing the number of workers and increasing the productivity was much more severe in the small- and medium-sized industries.

2.2. Production and sales 1990

Each year, the Ceramic Society of Japan publishes the Annual Report of the Japanese Ceramic Industry in its bulletin "Ceramics Japan". In the following a brief summary of the annual report 1990 in respect of the glass industry sections is given [1]. The report for 1991 will appear in the September issue of 1992.

2.2.1. Flat glass

About 60 % of flat glass produced was used for buildings, 30 % for automobiles and 10 % for other applications. Increase was observed in the production of safety glass for buildings among other things, reaching now about 15 % of the total production. The production of the double-layer glass was still only about 0.6 % of the total amount, but it has increased at the rate of about 10 % during the past 10 years.

Due to the recession in the industry, particularly in the automobile industry, and an increase in production in developing countries, little increase in flat glass production is expected in the near future. Therefore, constant efforts are being made to improve the quality of glass and to popularize new high-quality types of flat glass, such as laminated safety glass, decorative glass, energy-saving double-layer or IR-reflecting glass, display glass for electronic equipments, and so on.

2.2.2. Container glass

About 50 % of the container glass produced was used for beverage bottles, 25 % for pharmaceutical containers, 20 % for food and seasoning containers, and 5 % for cosmetic containers. The productions of the first two items increased by about 10 % in the last two years, but those of the last two items decreased. The total number of bottles increased more than the total tonnage. It were 10.9 billion bottles in 1990, which is 1.69 times more than that of 1980 in comparison with 1.32 times more in tonnage than 1980. The trend in the production of beverage bottles is towards small and light ones. The mean weight of current soft-drink bottles is 228 against 432 g in 1980.

As for the production facilities, the emphasis is being placed on the introduction of fast manufacturing machines, new efficient inspection and packing lines and computer-controlled systems. The energy consumption was reduced by about 20 % from 1978 to 1983, but since then it stayed about the same level due to the diversity of products and a small-lot production of each product.

The recycling effort of glass bottles is making a progress. The cullet from used bottles amounts to about 30 % of the raw materials. In order to survive in the packaging industry, the container glass industry aims at solving such difficult problems as developing superlight-weight glass containers, designing more stylish forms, establishing more effective and value-adding total package lines, and advancing recycling of bottles.

2.2.3. Fiber glass

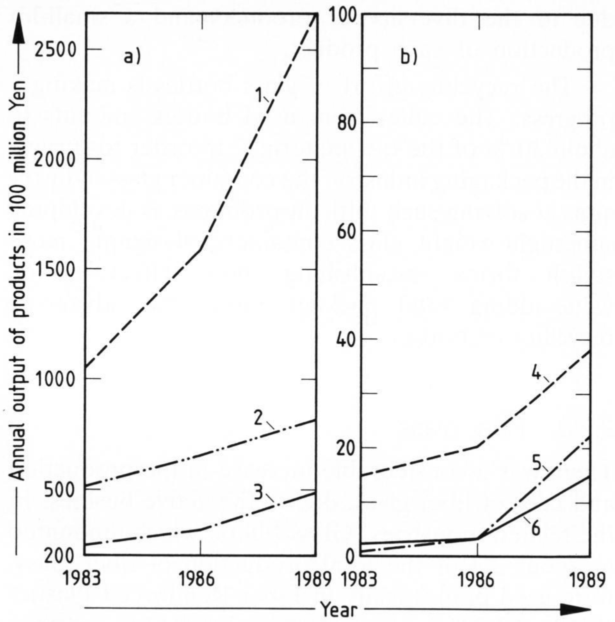
There was a considerable increase in the production and sales of fiber glass, due to the active business in the related industries. Glass fibers, which amounted to about 2/3 of the total production of fiber glass, were used domestically in Fiber-Reinforced Plastics (FRP: 63.3 %), for electric insulation purpose (11.7 %), general industrial use (7.0 %) and other applications (4.5 %). The rest (13.5 %) was for export. 93.1 % of glass wool were used as building materials, mostly for the thermal insulation of houses.

2.2.4. Technical and other glasses

Among the various items in this category, the production and sales of illumination and signal light fixtures and electric glass bulbs increased, but those of TV and other electronic glass bulbs, which amounted to about 80 % of the total production in this category, decreased considerably because of severe competition abroad with those from NIES.

A steady increase was observed in optical glass. Although the weight of lenses per each video camera decreased considerably, a large increase in its number of sales contributed to an increase in optical glass, along with good sales of various types of conventional cameras. In future, the overseas processing of secondary products of optical glass may become necessary to cope with the globalization of buyers. Moreover, the industry is facing a lack of labor force.

Optical fiber is one of the items for which more than 20 % increase in production has been observed in recent years. The production of single-mode silica fibers doubled between 1988 and 1990 while that of multimode-graded-index silica fibers decreased by 1/2, due to the introduction of large-capacity, long-range optical communication systems. The production and sales of bundle fibers, particularly multicomponent image fibers, were good due to a large demand for them as the light guide for semiconductor production and industrial ultraviolet light. The production of optical fiber cables in 1990 was 1.4 million km or 92 billion Yen, and that of



Figures 2a and b. Annual output of new glass products for different application fields, a) 1: optical, 2: thermal, 3: electric and electronic; b) 4: chemical and biological, 5: magnetic, 6: mechanical.

other optical fiber products was 4.7 million km or 30 billion Yen.

3. Japanese associations in the glass field

Although there are a number of industrial and commercial associations dealing with specialized glass products in Japan, there is no independent society devoted to glass science and technology. Glass is regarded as a part of ceramics in Japan, and so the Glass Division of the Ceramic Society of Japan not only serves as the central body to promote glass science and technology but also represents Japan at the International Commission on Glass. Most of the glass researchers in universities, governmental institutions and industrial laboratories are personal members and major Japanese glass companies are corporate members of this Society.

As described in section 2., the expansive trend in many Japanese glass products levelled off recently, and the challenge by NIES is getting severe more and more. Since glass has excellent properties, particularly optical and electronic ones suitable for high-tech material of future industries, it is considered that the Japanese glass industry can keep its strength if all industries interested in new kinds of glass get together, find a way to cope with the current problems by exchanging information about new glass among researchers and engineers in academic and industrial fields, looking for the possibility of new kinds of glass suitable for new technologies, and proposing nation-wide plans for technical and industrial advancement of new glass. These aims were the background for setting up the Association of New Glass Industries or "New Glass Forum" in Japan in 1986 under the guidance of the Ministry of International Trade and Industry (MITI). The Association has now 177 corporate members whose main business fields are glass (about 25 %), chemicals (about 22 %), ceramics and metal (about 18 %), electrical and electronics (about 15 %), automobile and machinery (about 10 %) and others including trading and banking.

4. Research and development fields of industrial interest

Since its establishment, the New Glass Forum has made the following five survey reports: 1. Potential topics of R & D in new glasses; 2. Industrial trend in new glasses; 3. Trend in the technology of new glasses; 4. New glasses for automobiles and 5. New glasses for functional application in building. In this section a summary of surveys 1. and 3. is given.

In figure 2 the annual outputs of new glass products are given for the years 1983 to 1989 according to their various applications. The largest increase can be observed in the output of glasses for optical purposes because a considerable effort has been made to advance optical communication and so its components have been much in demand. In order to describe the current R & D level of new glasses, 24 specific types of new glass were selected based on required properties and they were evaluated. The results are as follows:

Optical fibers:

The application of optical fibers is expanding. Current silica fibers have attained a loss of 0.154 dB/km, close to the theoretical value. Thus, the Japanese R & D has reached the technological top level. Future important R & D tasks are:

a) search for a highly efficient fabrication process to lower the cost from current 10 Yen/m,

b) development of better coupling and dividing ways in fiber optics, and

c) development of improved properties, such as

- lower loss of 0.001 dB/km by use of fluoride glasses,
- better performance in the Gbit/s range,
- very high strength to allow microbending of fibers,
- radiation and high-power resistance.

Plastic fibers could become a competitive material because of their price, but the field of applications is different due to their high loss (29 dB/km).

Photomask glass:

Glass for photomasks is being applied increasingly in photolithography for semiconductor production, because of its monochromic light transparency. In order to satisfy the increasing demand for low thermal expansivity, the glass composition has been changed from soda–lime over aluminosilicate to silica. The tasks for R & D are the achievement of

– flatness of less than 1 μm on a large-sized plate,

– avoidance of coloration and defects larger than 0.3 μm for a plate to be used for 64 M disks in 1995, and

– reduction of cost to less than a half of the current price. No competitive material exists at present.

Graded-refractive-index glass:

The trend in optical equipments is away from a multiple lens system to a single one, for which graded-refractive-index (GRIN) glass is suitable. This type of glass is now used in optical communication systems as connectors, pick-up lenses, etc., or lens arrays for photocopiers. The ion-exchange process is mainly applied to make glass with a refractive index of 1.53 to 1.61 with a difference between the center and surface of 0.004 to 0.07, but the CVD process is also used. The Japanese technology level is matured in respect of silica rods and considered highest now. R & D is aimed at:

– development of a new production system so as to fabricate various types of GRIN glass with a small quantity at 1/5 of the current cost,

– improvement of precision machining and surface modification process for optoelectronic applications. Because of its optical transparency, heat resistance and reliability glass has an advantage over other materials, but low-cost transparent high polymers may become competitive.

Nonlinear optical glass:

Nonlinear optical glass is now one of the most actively investigated glasses, because of its potential application for photoamplifiers as well as for switching elements in a future photonic computer. Searching for semiconductive dopants to obtain a large nonlinear index and faster response continues. Basic research is directed toward clarification of quantum effects at interfaces. Ceramics, metal semiconductors and high polymers can be used, but competition is not likely to appear within the next 10 years.

Photochromic glass:

Photochromic glass has been used for eye glasses due to its durability, and now finds application as a hologram or optical memory device because of its 10-nm resolution and stability for memory of 1 Gbit/cm^2. Its technology level is well-matured, but it needs a breakthrough to achieve higher sensitivity from the present extremely low level of 0.0001 ASA compared with a common photographic film of 100 ASA, as well as faster response time of less than 0.2 s. For optical memory devices polymers are a competitive material, but there is none for eye glasses.

Photosensitive glass:

Photosensitive glass has not found wide application since its first appearance 35 years ago. The chemically machinable one is being applied to make wire guides, printer heads or printed circuit substrates due to its advantage of precise and fine machinability. One drawback is that it makes only two-dimensional patterns. It is technically well developed, but a low-cost manufacturing process is needed to expand its application. Photosensitive high polymer is the main material in this field.

Laser glass:

Fluorophosphate glass with rare earth elements is now being developed and used in nuclear fusion, welding or boring because of its capability of producing high-energy and high-power pulses of 1000 J and 1 trillion W. In addition to the laser itself, glass is used for the optical parts of the laser system. The R & D level is still regarded to be at the developing stage, better thermal conductivity, preferably twice the current value, and matching of refractive index and temperature coefficient are aimed to achieve. It is still considered that a new glass composition may be possible. Ceramics, such as YAG or ruby, and semiconductors are competitive materials.

Glass for optical disks:

Glass for optical disks is being used in CD, VD or CD-ROM, and it is now at a mass-production stage. R & D for better surface precision and narrow track pitch is being done. Improvement of reliability by making high-strength glasses and a new production system for lowering the current cost to 1/5 are being sought. High polymer may become competitive because of its low cost.

Glass with conductive film:

The application of glass with conductive film is expanding as LCD, ECD or EL panels, as well as substrate for amorphous solar cells. Antielectrostatic panels changed their composition from soda–lime, over aluminoborosilicate to silica glass. The R & D level is at an advanced stage with such research subjects as a suitable non-alkali glass composition, high mechanical strength with better transparency, lower resistivity from the current 100 Ω to 10 Ω and a large-size production system with low cost. Currently, no competitive material exists, but a high polymer film may appear in future.

Superion-conductive glass:

This type of glass could be used for humidity or pH sensors and thin-film batteries, but it is still on the research level and has not yet been applied. At present silver-containing glass having a conductivity of 0.01 to 0.001 S/cm is used in the research work, but the one with higher conductivity of 0.1 to 0.01 S/cm is sought. Three conductive mechanisms have been proposed, but no definite conclusion has been reached. A way to make thin films is needed. Ceramics may be a competitive material but up to now glass excels this material in conductivity.

Chalcogenide glass:

The potential application field for chalcogenide glass has shifted from the electronic to the optical field. Its fiber will probably be applied as IR-transparent material. As–S glass has a loss of 35 dB/km and can transmit the power of 16 kW/cm^2. Its reversible phase transformation is used for thin film memory devices, and its photoconductivity for photocopiers. The R & D level is regarded to be at the development stage; the tasks are a) impurity elimination to achieve better transparency, b) improvement of heat resistance up to 500 °C, and c) high contrast and fast erasing speed for memory application. Glass is in a good competitive position among various other materials.

Glass for low-temperature sintering composites:

IC used for high-capacity, high-speed and high-frequency purposes requires a substrate with lower dielectric constants than alumina, and a composite of 50 % borosilicate glass and 50 % ceramic fillers satisfies such a requirement. R & D is almost completed and the glass is now in the initial stage of actual application. Glass with a lower dielectric constant is preferred. Since the application field is different from alumina, this material will be applied in the future.

Dielectric glass:

Dielectric glass is needed for the insulating layer of electric circuits or passivation of semiconductors, as well as for hybrid IC. The main requirements are: air tightness, low dielectric constant, fineness of glass powder and easiness of paste making. Silica-glass fibers made by the sol-gel process are being used for printed-circuit board, because of their low dielectric constant. R & D aims at better properties such as low dielectric constants, low firing temperature, low resistivity and a higher refractive index (more than 2.5). Other requirements are transparency for electromagnetic waves and a way to make ultra-thin films.

Amorphous ferrite:

Amorphous ferrite is considered to be applied for optoelectronic devices, such as isolators or modulators. However, it is still on the fundamental research level, and not only the theoretical explanation for the phenomena is being worked out, but also the experimental studies on compositions and properties are being carried out. The glass making process is another problem. The competition against ceramic soft ferrite and amorphous metals will be hard.

Sealing glass:

Low-melting point glass is required for electronic parts. Low radioactivity in glass is required for IC packages, and fluidity below the Curie temperature of ferrite is required for magnetic-head applications. Suitable basic glass compositions have been studied and adjustments are being made to meet the requirement of each application with respect to thermal expansion coefficients, film thickness, sealing temperature and so on. Although low-melting metals and epoxy resins may be used for sealing, they have different application fields.

Low-thermal expansion glass:

This type of glass is being used for high intensity lamps because of its transparency and for telescope bases because of its stability. Material development is completed, and mass production is being attempted to expand its applications to home wares. Ceramic materials may be competitive, but the transparency of glass is a great advantage, therefore, only little competition is expected.

Heat-resisting glass:

Laboratory and home wares are the main applications, but it could also be used for precision-machine parts. Silica glass is well developed, but a reduction of cost is needed for expanding its use. Aluminosilicate glass ceramics have been developed, but higher strength is still desirable. In order to compete with ceramics, better heat resistance is needed.

Fiber-reinforced glass-ceramics:

This material could be used for heat engines as a substitute for heat-resisting super alloys. Higher fracture toughness and bending strength of 800 MPa at 1000 °C are required. So, the material is still at the fundamental research stage to improve high-temperature mechanical properties. New methods of making composites with carbon or SiC are needed with emphasis on the fiber-matrix adhesion state.

High-toughness glass-ceramics:

This material is in great demand for applications as building materials, cooking wares and machine parts. Fundamental studies are being carried out. Zirconia-dispersed glass-ceramics as well as ceramic-fiber-reinforced glass-ceramics are being studied to obtain higher fracture toughness, but they are still far away from actual applications. Ceramics such as partially stabilized zirconia and super alloys are competitive materials.

Oxynitride glass:

Because of its good mechanical properties such as high transformation temperature, Young's modulus, hardness and chemical durability, oxynitride glass may be used for FRP or FRM, but there are no real applications yet. It is still at the research stage, and a way to increase the nitrogen content above the current highest amount of 16 % is investigated.

Because of its transparency, this material may find a special application.

Porous glass:

This is one of the very useful materials with various applications, not only as the precursor or matrix of other stuffing to make graded-index glass, high-level radioactive-waste glass and carbon resistor, but also as a separator or filter for gas or liquid and a carrier for bioreactors or catalysts by utilizing its sharp pore-size distribution and large pore-surface area. Although it is at the application-development stage, studies of pore control and surface-modification ways as well as chemical durability are in progress. Ceramics and polymer films are competitive materials, but the glass will find its own application fields.

Bioglass:

Artificial tooth roots, bones and filler are made from bioactive glass, apatite–wollastonite glass-ceramics, and calcium–phosphate glass-ceramics. Material development is well-advanced and testing in situ conditions is being carried out. Tooth filler and apatite–wollastonite bone have proved in human medicine. High stability and reliability and better biocompatibility are still sought.

Glass for artificial tooth crowns:

Because of its good compatibility and color, glass is also suitable for casting tooth crowns. This kind of glass is at the material testing stage, safety and properties close to natural teeth must be achieved. Ceramics and metals are competitive materials, but ceramics are difficult to shape.

Superconductive glass:

After the ceramic high-temperature superconductors were discovered, various attempts have been made to fabricate similar glass-ceramics by a melting-recrystallization process or the sol-gel process. However, this material is still far away from an actual application.

5. Research at academic institutions

From the financial view point, research and development in Japan are supported mostly by private companies. Only 20 % of the total R & D expenditure are covered by governmental spending, which is about 0.5 % of the Japanese gross national product. Furthermore, 2/3 of the governmental funding goes to industry, mostly through MITI and partly through the Science and Technology Agency. Consequently, the governmental support for fundamental research in pure and applied science is not high. Because of such a funding situation, only a part of the results of R & D being currently performed in Japan is made public, except those of universities and public institutions. This is also the case for R & D of glass. It can be seen in the few number of papers presented at the annual meeting in the Glass Division of the Ceramic Society of Japan or other occasions. On the other hand, the research activities in the academic field are made public through contributions to conferences and publications. Below the current major research topics being carried out at universities and governmental research institutions are listed, as stated in the recent Bulletin of the Ceramic Society of Japan. The research positions are abbreviated as follows: (P) = Professor, (AP) = Associate Professor, (L) = Lecturer, (RA) = Research Associate.

Aichi Institute of Technology:

M. Nogami (AP). Preparation and properties of glasses doped with semiconducting microcrystals; Preparation of organic-inorganic composites by the sol-gel method.

Chiba Institute of Technology:

N. Shimizu (P). Spinning technology of glass fiber; Glass lining process.

Hokkaido University:

T. Yokogawa (P), Y. Kawamura (RA). Thermodynamic equilibrium of silicate melts; Molecular dynamic calculation of silicate melts.

Keio University:

S. Hirashima (P). Preparation and properties of transition metal oxide films by the sol-gel method; Electroconducting oxide glass; Reaction between metal and silica glass.

Kobe University:

Y. Kawamoto (P), R. Kanno (AP). Optical properties of rare earth-doped fluoride glass; Preparation, properties and characterization of highly ion-conducting fluoride glass.

Kyoto Institute of Technology:

R. Ota (P), J. Fukunaga (L). Viscosity and glass-forming tendency of nonalkali multicomponent glasses; Gel formation and glass formation of various borate systems; Crystallization and structural analysis of borate glass.

Kyoto University (Fac. of Engineering):

N. Soga (P), K. Hirao (AP), K. Nakanishi (RA), K. Tanaka (RA). Preparation and characterization of glasses with opto- and magnetic functions; Computer simulation of glass structure and properties; Fracture and stress corrosion of glass and glassceramics; Porous glass by phase-separation process of the sol-gel method.

Kyoto University (Fac. of Engineering):

T. Kokubo (P), N. Miyata (L), T. Yao (RA). Preparation of bioactive glassceramics; Synthesis of glass for bioactive cement and apatite coating; Mechanical properties of glass composites.

Kyoto University (Inst. of Chem. Res.):
S. Sakka (P), T. Yoko (AP), H. Kozuka (RA), S. Miyaji (RA). Synthesis, structure and properties of functional oxide glasses without silicate; Preparation and evaluation of nonlinear optical materials and functional films by the sol-gel method; Transport characteristics in fluoride glass.

Kyoto University (School of General Studies):
T. Hanada (AP), S. Tanabe (RA). Preparation and properties of various amorphous oxide films by the sputtering method; Optical properties of rare earth containing amorphous material.

Kyushu University:
K. Morinaga (P), Y. Masuda (RA). Basicity and optical characteristics of oxide glasses; Reaction between ceramics and molten glass.

Kyushu Industrial University:
T. Yanagase (P). Technology of utilizing slugs; Redox reactions in molten glass.

Mie University:
K. Kamiya (P), H. Nasu (AP), J. Matsuoka (RA). Synthesis and characterization of functional glass and ceramic fibers by the sol-gel method; Structural analysis of gel, glass and ceramics by X-ray and EXAFS; Preparation of high-temperature superconducting glass-ceramics and nonlinear optical glasses.

Nagaoka Institute of Technology:
K. Matsushita (P), T. Komatsu (AP), T. Sato (RA). Preparation of high-temperature superconducting glassceramics; Precipitation of semiconducting microcrystallites in glass; Reaction between glass and magnetic materials; Viscosity and crystallization of fluoride and oxyfluoride glasses.

Nagoya Institute of Technology:
Y. Abe (P), H. Hosono (AP). Development of porous calcium–phosphate crystallized glass; Ion implantation into glass; New photosensitive amorphous materials.

Okayama University:
Y. Miura (P), A. Osaka (AP). Development of IR-transmitting amorphous solid; Structure and properties of mixed anion glass; Preparation of functional films by the sputtering method.

Ristumeikan University:
K. Kojima (L). Spectroscopy of glass under low temperature and high pressure; X-ray irradiation effect and electron conduction of glass.

Shinshu University:
N. Tagusagawa (P), K. Kitajima (AP), S. Taruta (RA). Preparation and application of porous glass and low-temperature melting nonalkali glass; Synthesis of mica-type glassceramics.

Shokugyo Kunren Daigakko:
K. Yamamoto (AP). Electric properties of oxide glass.

Tohoku University:
K. Suzuki (P), T. Kamiyama (RA), K. Shibata (RA). Small-angle refraction analysis of silica- and titania-sol films; Structure of magnetic oxide glass.

Tokyo Institute of Technology (Fac. of Engineering):
M. Yamane (P). Graded-index glass by the sol-gel method; Spectroscopic study of glass structure.

Tokyo Institute of Technology (Inst. of Engineering Materials):
H. Kawazoe (P). Structure and defects of silica glass; Search for inorganic nonlinear optical materials; Valency control of amorphous chalcogenide semiconductor.

Tokyo Institute of Technology (Inst. of Industrial Materials):
H. Koinuma (P), M. Yoshimoto (L). Synthesis and characterization of amorphous superlattice; Optical properties of amorphous semiconducting films.

Tokyo Metropolitan University:
J. Yamashita (L). Preparation of Nasicon glass-ceramics and phosphate films.

Tokyo Science University:
T. Tsuchiya (P), T. Sei (RA). Preparation and electric properties of halide-containing superion-conductive glasses.

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Yokohama National University:
T. Mochida (RA). Properties and structure of telluride glass; Raman spectra of oxide glass.

Governmental Industrial Research Institute, Osaka:

Section leaders: H. Hayakawa, H. Tanaka, H. Wakabayashi, H. Yamashita; Chief scientists: K. Kawakita, T. Kitaoka, T. Kokura, M. Makihara, H. Nakamichi, M. Suzuki, H. Tanigawa, N. Uetsuki, H. Yamanaka, T. Yazawa; Research scientists: K. Fukumi, H. Kadono, K. Kinugawa, N. Kitamura, I. Matsubara, M. Yamashita. Optical properties of halide glass; Forming and shaping of glass; Opto-functional glass; Ion-conductive glass films; Glass for encapsulating wastes; Composite glass membrane; Nonlinear optical materials.

6. Abbreviations

ASA	american standard association
CD	compact disk
CD-ROM	compact disk – read only memory
CVD	chemical vapor deposition
ECD	electrochromic display
EL	electroluminescence
FRP	fiber-reinforced plastic
FRM	fiber-reinforced metal
GRIN	graded index
IC	integrated circuit
LCD	liquid crystal display
MITI	ministry of international trade and industry
Nasicon	$Na_3Zr_2Si_2PO_{12}$
NIES	newly industrializing economics
R & D	research and development
VD	video disk
YAG	yttrium–aluminium–garnet

7. Reference

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