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Future Outlooks for Technology Development in New Materials Bussiness

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Abstract:

Nippon Steel's New Materials Division is working together with Nippon Steel's Advanced Technology Research Laboratories and group companies to supply customers with "materials" that dynamically meet their needs on the basis of material technology Nippon Steel has developed through the manufacture of iron and steel. These materials are grouped into three areas: electronic and semiconductor materials, environmental and energy materials, and carbon fiber-based materials. The way technology development in the new material business should be carried out is discussed by taking as an example the semiconductor materials that form the core of the New Materials Division and have recorded remarkable growth in recent years.

1. Introduction

We may be safe to think that man's relations with materials trace back to the birth of mankind. Humans have successfully fabricated materials in various ways to enrich their lives. It is no exaggeration to say that this has been a driving force for creating cultures and flowering civilizations.

When we carefully look at the materials used by our ancestors, we notice that they took advantage of the resources found in nature. For example, the first material was earth, followed by wood, and eventually iron appeared. Recognition of familiar resources as materials was an idea comparable to "Columbus' egg". This achievement seems impossible until it is actually tried and easily accomplished. When our ancestors first took notice of the fabrication of tools from such materials, it should have had such an impact that their society was turned upside down. There certainly were no such persons who knew from the beginning that black powder in river sand would turn into iron when heated and melted, and that the iron could be hammered into hoes and plows.

We imagine that it took a considerable length of time to recognize familiar resources as useful materials after repetition of chances and accumulation of such experiences. It is thus unavoidable that the lifetime of materials, considering the process of their discovery and invention, should be extraordinarily long. Additionally speaking, what benefits materials bring to our lives is an important factor for materials to be perceived as such. For this reason, emphasis was placed on the fabrication of materials, and skill and technology have greatly advanced with the fabrication of materials into tools.

The progress of science and technology in recent years has shortened the time axis of this trend in no small way. For it has become possible to understand materials as substances and to control the properties of materials. Furthermore, science and technology have exponentially advanced. Now, materials can be controlled on the order of molecules and atoms, and the various prop-

*1 New Materials Division (presently Silicon Wafer Division)

erties of materials can be put to effective use. These are what are called new or advanced materials now.

The new material research committee established by the Basic Industries Bureau of the Ministry of International Trade and Industry of Japan defined the term "new materials" in 1988 as follows: "New materials" are based on metallic, inorganic and organic raw materials and their combinations, and are high-value added materials that provide new phenomenal properties and new social values by making the most of such advanced manufacturing, fabricating, and commercializing technology as microstructural control at atomic and molecular levels, improvement in purity, and combination with other materials.

New materials still take a long period of time before they change from raw materials to materials we can use. However this time has shortened to a considerable degree. Early in the 1980s, what is called the "new materials boom" occurred, and shape memory alloys and hydrogen storage alloys came into the spotlight. The phenomenon of low-temperature superconductivity was discovered in 1986, and cold nuclear fusion was announced in 1989. These events excited scientists and engineers the world over, prompting them to wonder if the future of mankind would undergo a big change. As noted previously, it takes a long time to develop technology to apply new materials until new materials are accepted by users as useful materials. Now that the "new materials" fever has subsided, the development of application technology for new materials and the research of new materials are being carried out.

Nippon Steel's new materials development has followed the same history. Nippon Steel has developed and proposed various materials on the basis of materials technologies, such as process and analytical technologies acquired through the production of iron and steel. From a business point of view, many of these materials have not yet be commercialized because customers are not ready for them. It is true for shape memory alloys, and also for hydrogen storage alloys. In retrospect the materials handled by the New Materials Division are "star" materials of the times and are not so-colled "new materials", but are the new materials group. They are value added conventional materials developed through Nippon Steel's material technology.

2. Material Groups in the New Materials Division of Nippon Steel

The material groups of Nippon Steel's New Materials Division cover the following three main areas (see **Fig. 1**):

(1)Electronic and semiconductor material area

(2)Environmental and energy material area

(3)Carbon fiber area

The first area accounts for the majority of the 1996 sales of the New Materials Division, and semiconductor materials occupy more than a half of the sales registered by the electronic and semi-

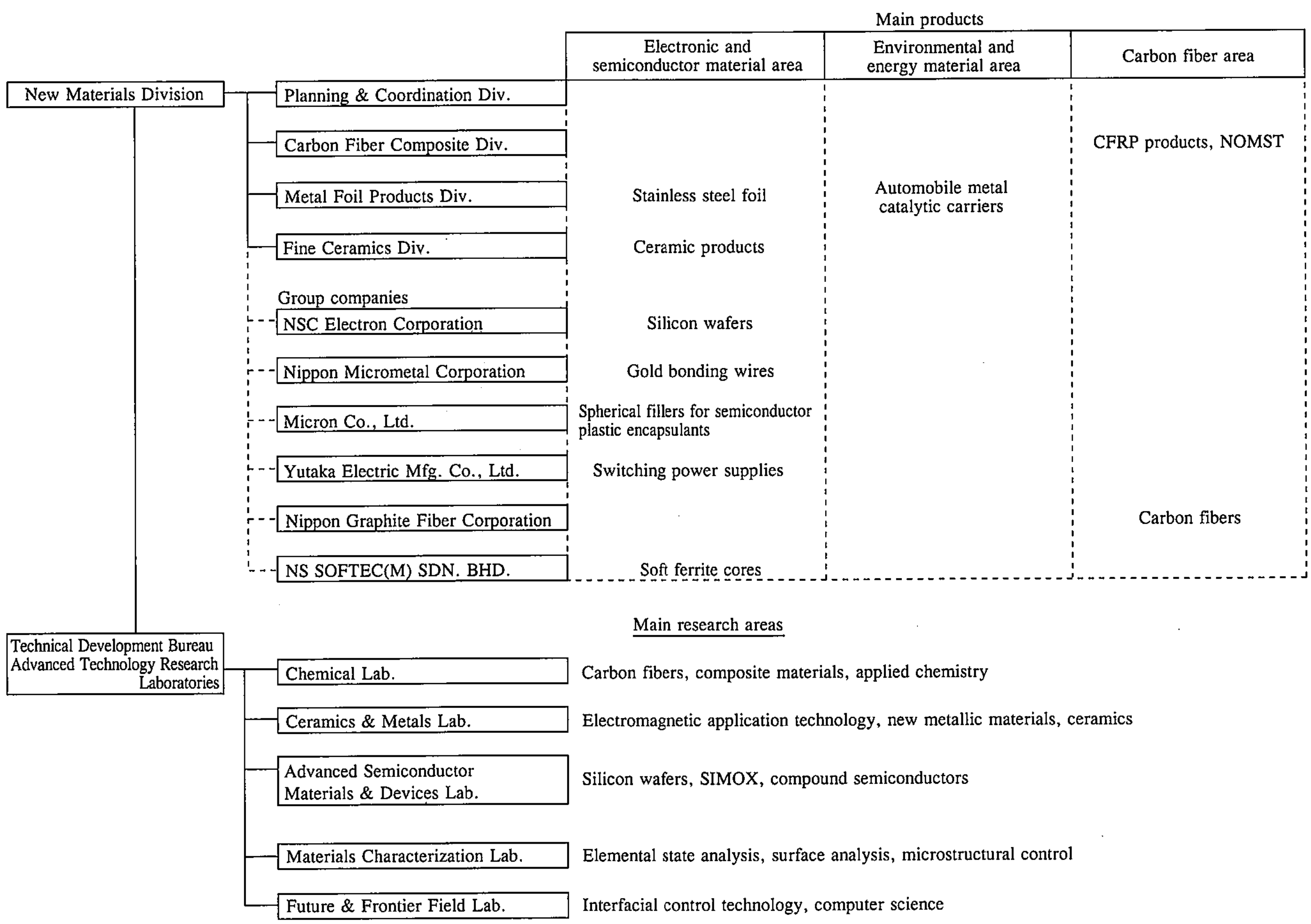


Fig. 1 Composition of New Materials Division

conductor material area. This area is projected to grow further by the end of this century. It is no exaggeration to say that Nippon Steel's new materials now depend on the progress of electronics. Future outlook is considered here by taking semiconductor materials as an example. Structural ceramics and stainless steel foil are included among electronic materials because of there mainly being used in semiconductor and liquid crystal display (LCD) fabrication equipment, and in hard disk drive units, respectively.

3. Future Technology Outlooks (Example of semiconductor material development)

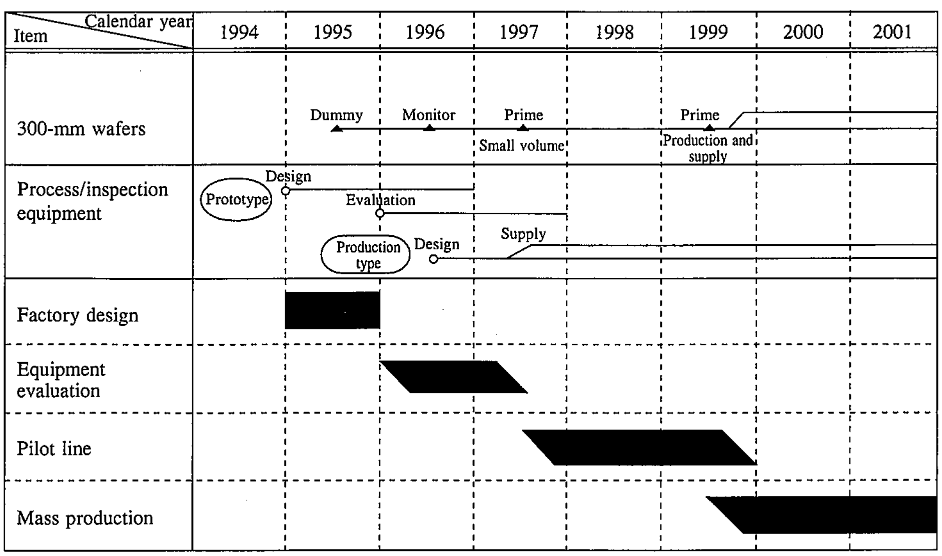
The semiconductor materials handled by Nippon Steel are basic materials and include silicon wafers, gold bonding wires, and spherical fillers for plastic encapsulants (see **Fig. 1**).

Silicon wafers are one of the most important semiconductor materials. No other material is more economical or has better semiconductor properties than silicon. As semiconductor process engineers often say, "silicon comes after silicon", silicon will not have its position as the predominant substrate material threatened by other materials for some time to come. The generation change of LSIs — especially DRAMs — makes increased demand for higher quality silicon wafers (see **Fig. 2**), however. Continued progress in technology is required in the production of silicon wafers. An example is in increasing the diameter of silicon wafers from 6 to 8 inches to the eventual 12 and 16 inches. Quality cannot be sacrificed. Increasing severity of quality calls for technical breakthroughs. Silicon wafer manufacturers are now eagerly engaged in the development of 12-inch silicon wafer fabrication processes to meet the change from 8-inch to 12-inch silicon wafers. By the year 2000, 12-inch silicon wafers will enter a mass-production phase (see **Fig. 3**).

To meet the improving performance of devices, Nippon Steel is developing SOI (silicon-on-insulator) wafers as SIMOX (separation by implantation of oxygen) wafers and engaged in the advanced level of technology development with the addition of its own process technology. Compound semiconductors and SiC single

	Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002-2005
Latest DRAM		4M				16M			64M				256M	1G
	Design rule (μm)	0.8			0.5				0.35			0.25		0.18
	Chip size (mm^2)	70			130				180			280		420
	Refresh time (ms)	32			64				128			256		512
	Voltage (V)	5.0			3.3				2.5			2.0		1.5
Enabling technology	Diameter of wafers used for latest devices	← 6 inches			8 inches								12 inches	
	Flatness (LTV) (μm)	0.8			0.5				0.30			0.20		0.10
	(site) (mm)	20×20			22×22				25×25			30×30		35×35
	Particles size (μm)	0.3			0.2				0.16			0.1		0.08
	metal contamination (Fe) (a/cm^2)	1 e11			1 e10				5 e9			1 e9		5 e8

Fig. 2 Increase in density of devices and wafer enabling technology



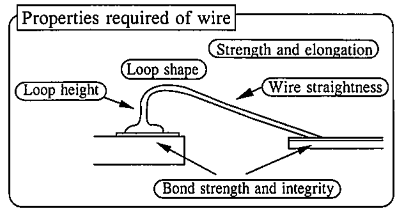
Source: EIAJ (1994)

Fig. 3 Road map for 300-mm (12-inch) wafers crystal research is being undertaken, among other things, in order to complete the materials grous for meeting a diversification of devices in the future.

Gold bonding wires and plastic encapsulation spherical fillers are categorized as basic semiconductor packaging materials. Packaging and mounting technologies rapidly change to meet higher speed, increasing pin count, and decreasing size and thickness of devices (see **Fig. 4**). Following this trend, gold bonding wires are acceleratedly enhanced in functionality (see **Fig. 5**). The choice of wires is being increased to meet a diversification of device packages. For example, fine-pitch, long-span wire to meet the increase in the I/O pin count and low-loop wire to meet the decrease in the thickness of packages. It is more difficult than generally thought to add different properties such as something smalls as 30μm gold wire. Nippon Steel has successfully achieved this feat by taking advantage of its crystal control technology. We are also attempting materials science approaches to the problems of device manufacturers. Focusing on the bond strength between aluminum pads and gold wires that has an important electric property, we have proposed gold bonding wires that feature improved bond strength and meet geometrical requirements.

The progress of the next-generation packages is also accelerated by the decreasing size and thickness of electric appliances. With the steep increase in the I/O pin count noted above, conventional technology is reaching its limit. To counter this situation, the BGA (ball grid array) is now commercially implemented as next-generation packaging technology. Not to be left behind, Nippon Steel is steadily carrying out technology development, such as ultrasmall metal balls for the BGA technology (see **Photo 1**). Furthermore, Nippon Steel has already completed technology for commercially producing these ultrasmall metal balls and mounting them. Nippon Steel is at the forefront of the BGA field. The BGA technology has a wide spectrum of applications, including not only the very high-pin count BGA as an extension of the conventional BGA, but also bare chip packaging like multichip modules (MCMs) and flip-chips. It is actively studied for applications in the semiconductor packaging field. These technologically advanced products have won the confidence of Nippon Steel customers.

As typified by these semiconductor materials, Nippon Steel puts its technology to good use in turning "substances" into "materials". This is the reason why Nippon Steel can successfully add values to its products. Nippon Steel's material technology is broadly based and applicable to a variety of industries. This is not as simple as applying one technology to a given application, but is



Wire development and products

Item	User's aim	Development point	Products
Loop height control	Loop height is correlated with recrystallization behavior of HAZ		
Lower loop (< 150μm)	Thin packages (TSOP and TQFP)	Rise in recrystallization temperature	L3 L4
Higher loop (200 to 250 μm)	High-speed bonding (prevention of wire sag)		K3 K5
Long-span wire	Multiple pins and fine pitch (Span: - 5.0 mm)	Improvement in Young's modulus → Reduction in wire sweep	T1 T2
Fine-pitch wire	Pitch: 60 μm Lower loop and longer span (> 6.0 mm)	Increase in strength and Young's modulus → bonding with small balls and prevention of wire deformation	T3 T4

Fig. 5 Improvement in functionality of bonding wire

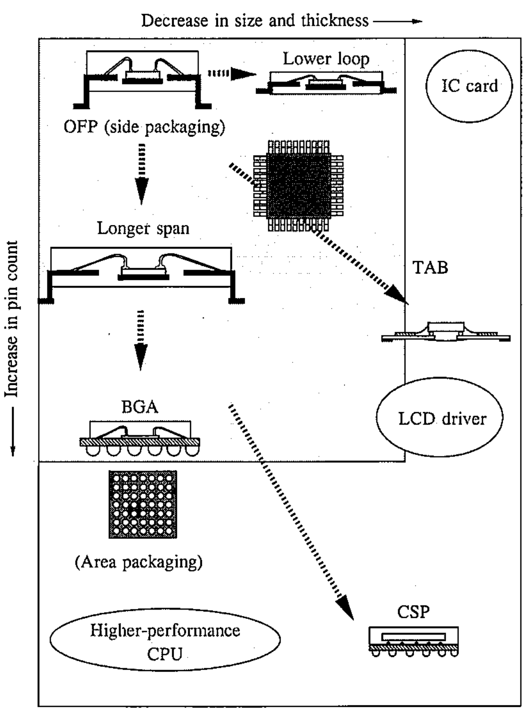


Fig. 4 Logic packaging technology trends

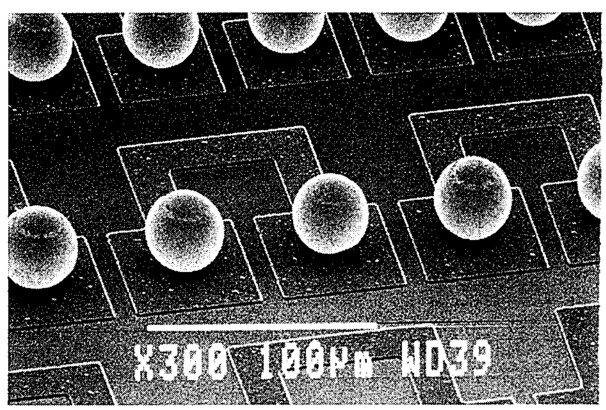


Photo 1 Ultrasmall metal balls

achievable only with the fusion of two or more brains by making the most of human and intelligent networks in and out of the company. We think that this is the true asset of Nippon Steel and is what our customers expect from us. This thinking also applies to Nippon Steel's other materials groups, such as very thin stainless steel foil and carbon fibers. We are continuing our development effort to make these materials into the stock to meet the requirements of our customers.

4. Conclusions

Nikkei Microdevices carried an interesting article in one of its recent issues. The article reports that Japanese LSI manufacturers introduced one new material in each DRAM generation (see **Fig. 6**). It also says that many LSI engineers ideally want to introduce as many new materials as possible at a time with the recognition that the benefits of microfabrication cannot be enjoyed without changing materials. Generally speaking, it takes about 10 years to put one new material to commercial use because several steps must be followed to verify its reliability. In reality, one new material is introduced in one DRAM generation. The article concludes that the process technology development for memory devices and logic devices will be carried out separately, and new materials will be introduced, creating room for the introduction of two or more new materials per generation.

The same thing may be said about the entire society as well as about the semiconductor industry. An increasing diversification of materials application technology is increasing the opportunities for new materials to appear on the markets. This is a chance for us. Since new materials take a long time to find acceptance in the society, we think it necessary to set our sight at fields other than electronics. Key words for future technology outlooks are light, environment, and energy in addition to electronics including semiconductors and communications. Following these trends, we are planning to become a materials manufacture to satisfy our customers with new "materials" having values added on the basis of our materials and material technologies.

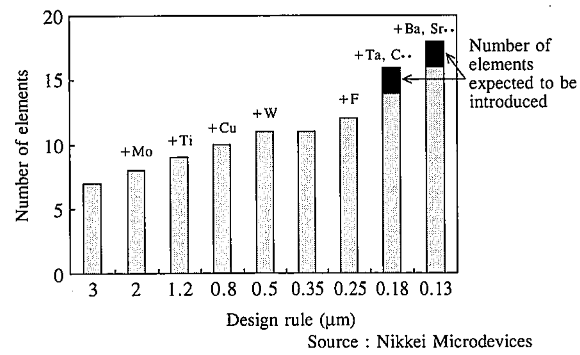


Fig. 6 Change in number of new materials introduced per DRAM generation