Key Materials for Electronic Information and Communication Equipment

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OVERVIEW: Electronic information and communications are fundamental to the basic infrastructure of modern society. Today's advanced information society is built upon networked layers of transistors fabricated on silicon wafers and other semiconductor substrates. LSIs are fabricated by networking billions of transistors on a wafer, and CPU modules and other advanced capabilities are achieved by interconnecting LSIs to the outside devices. It is through this building-block approach that the PCs and other electronic products we use every day are constructed. In building up this network, advanced materials are critically involved in everything from the fabrication of LSIs to the implementation of optical communications. Anticipating these needs, Hitachi is striving to be a global leader in the research, development, and marketing of advanced highly functional materials products.

INTRODUCTION

IN recent years we have gained access to the wider world by connecting PCs to networks and thereby gaining access to the vast world of digital formatted data through communications over the Internet. Certainly this has improved the efficiency of business and industry, but just as importantly it has greatly enriched our personal lives by enabling us to pursue interests and cultivate new friendships and interpersonal relationships.

The emergence of this network of interconnected PCs is inextricably related to a wide range of advanced new highly functional materials. In many cases these materials are employed in processes and are consumed

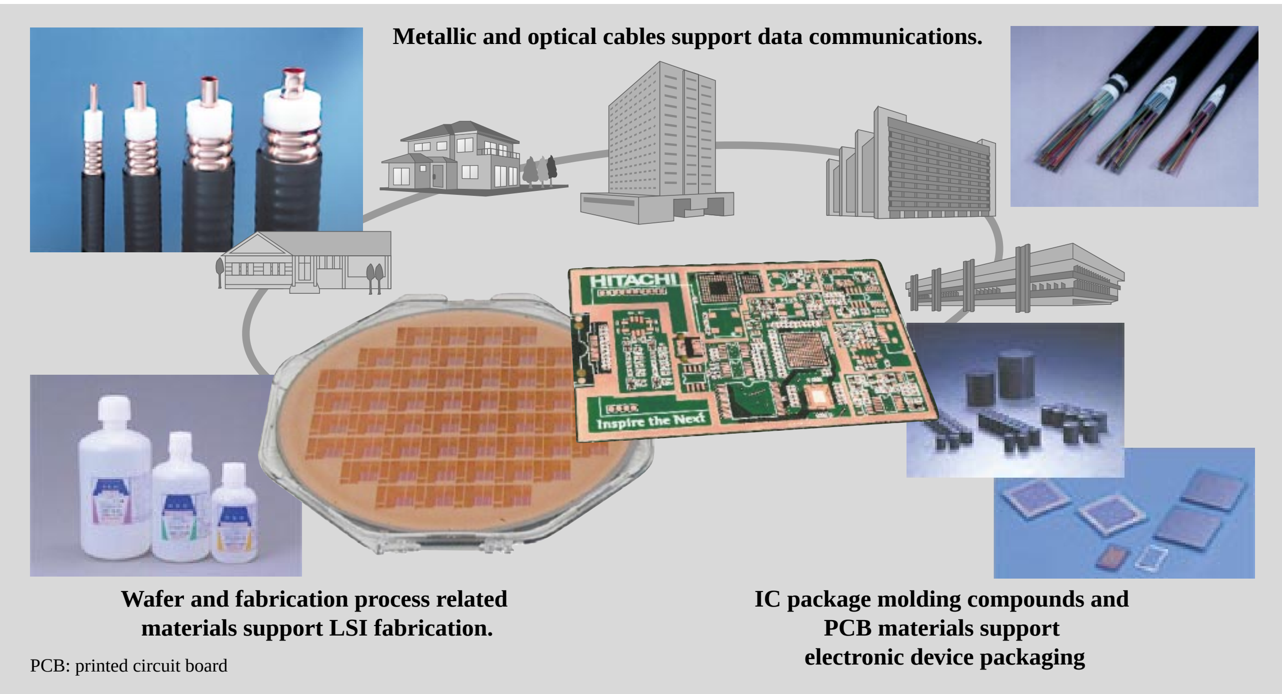

Fig. 1—Hitachi's Wide Ranging High-function Materials Initiatives Support LSI Fabrication, PCBs, and Optical Networks.
All the myriad IC devices, wiring boards, and communications networks supporting electronic information and communications of the advanced information age are made possible by advanced high-function materials.

in the manufacturing process. In other cases, advanced materials are used for interconnecting or transmission with a passive existence and they do not generate electricity or emit optical signals in and of themselves.

However, the importance of highly functional materials in sophisticated electronic devices or faster, greater capacity information and communications equipment cannot be overestimated. This paper will survey some of Hitachi's most recent development work on advanced highly functional materials (see Fig. 1).

MATERIALS FOR ELECTRONIC DEVICES

Wafer Process Related Materials

There are a diverse range of materials used in processes involved in fabricating integrated circuits on silicon wafers including CMP (chemical-mechanical polishing) slurry, low-dielectric (low-*k*) materials for interlayer dielectric films, and buffer coating materials. Fig. 2 shows a schematic cross-section of the IC (integrated circuit) chip illustrating the various wafer processing materials and where they are used in fabricating the device.

(1) CMP slurry

The various layers of IC chips must be planarized—that is, ground down until they are near perfectly flat—through a process called CMP, demanding a very high standard of both performance and productivity (see Fig. 2). The process uses an abrasive and corrosive chemical slurry, a material that has an enormously important influence on the performance of semiconductor devices. Table 1 shows the details for two slurries recently developed by Hitachi, one developed for specifically forming STI (shallow trench isolation) features, and the other tailored for shaping copper wiring. Both are excellent in terms of minimizing scratches and dishing (dish-shaped indentations), and both also work with low-pressure polishing, which is critically important when working with low-dielectric interlayer films.

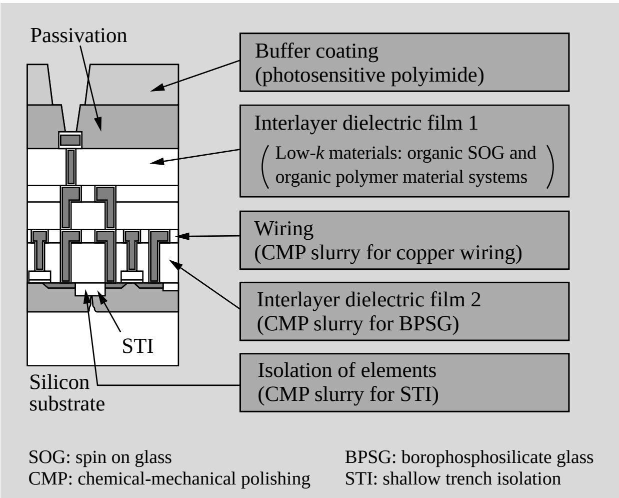

Fig. 2—Cross Section of IC Chip and Where Process Related Materials Are Used.
High-density multilayer copper wiring and low-k interlayer films are indispensable for 90-nm node chips and beyond. Layers must be planarized to nano-order degree of flatness by CMP (chemical-mechanical polishing).

TABLE 1 Characteristics of CMP Slurries
The optimum balance of chemical (C) and mechanical (M) action in combination with the right polishing speed produces excellent polishing (P) performance that minimizes scratches and dishing.

Item	Slurry for STI	Slurry for metal wiring	
Product	HS-8005	HS-C800	HS-T805
Polishing target	SiO_2	Cu (wire)	TaN (barrier)
Polishing speed	400 nm/min	600 nm/min	80 nm/min
Scratch performance	Good	Good	Good
Dishing (line and space: 100 µm)	10 nm	40 nm	20 nm

(2) Low-*k* materials

As VLSI (very-large-scale integrated circuit) technology evolves toward smaller features, the capacitance between wires increases and the signal transmission speed declines. The more this continues, the greater the importance of low-dielectric (i.e. low-*k*) materials that reduce capacitance as an insulating material between layers. Two notable products that Hitachi has marketed in this category are the Hitachi SOG (spin on glass)-R7 series ($k = 2.8$) that combines superior mechanical strength with excellent low-*k* performance and achieves excellent flatness in organic SOG systems, and the Hitachi SOG-255 series ($k = 2.3$), a porous low-*k* material targeting the 65 nm technology node.

(3) Buffer coating materials

Hitachi Chemical Co., Ltd. and US-based E. I. du Pont de Nemours & Company (DuPont) teamed to form the joint venture Hitachi Chemical DuPont MicroSystems L.L.C., which markets PIQ (polyimide isoindoro quinazorindione) and a number of other high-heat-resistant fine polyimides for VLSI (both photosensitive and non-photosensitive) that are used as passivation layer and buffer coating materials.

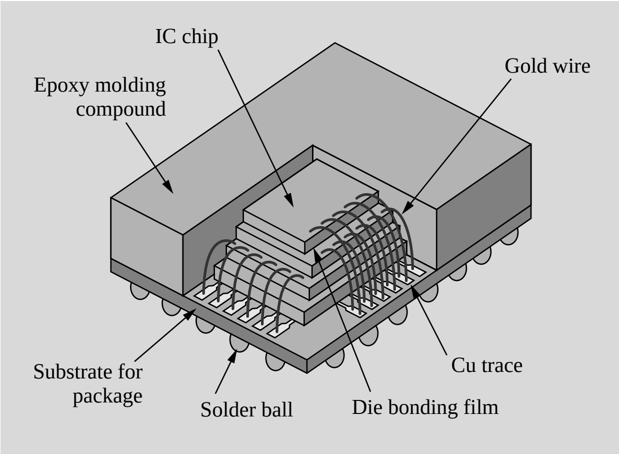

Fig. 3—Cut-away Structure of Stacked CSP (chip-size package) with Four Chips.
Die bonding film is used to bond chips to other chips or to the substrate.

Fabrication Process Related Materials

These are materials used in such wafer manufacturing processes as singulation of LSIs formed on silicon wafers, mounting ICs to lead frames and package substrates, and wire bonding and plastic molding processes, and a wide range of resin materials are employed. Here we will take a closer look at Hitachi's die bonding film and molding compound products.

(1) Die bonding film

Fig. 3 shows a cut-away schematic of a stacked CSP (chip-size package) that achieves high packing density by stacking multiple IC chips (dies). Die bonding film is used to bond chips to other chips or to the substrate, so it is essential that the adhesion surfaces are absolutely void-free and uniform in thickness. To implement a multifunctional product line, Hitachi developed the new FH Series film that integrates dicing tape used when sectioning individual chips with the die bonding film. This enables both tapes to be laminated to a wafer at the same time thus reducing the number of process steps, and permits easier handling of thinner wafers.

(2) Epoxy molding compounds

Finally the IC package is completed when the chip is sealed inside the package by an epoxy molding compound (see Fig. 3). The molding compound must of course provide good moldability and adhesion, but it must also exhibit low warpage and excellent reflow crack resistance. Hitachi's line up of environmentally-friendly molding compounds (that do not include halogen or antimony in the flame retardant) is a metal-compound flame retardant and a product without flame retardant (HF series). The company's liquid encapsulant C series can accommodate a wide range of packaging needs, and works very well as a coating or underfill material. As pin-counts multiple and pitch dimensions shrink, Hitachi is continuing its efforts to develop highly reliable underfill materials.

Printed Circuit Board Related Materials

IC packages are mounted onto PCBs (printed circuit boards). Basic materials for PCBs include high-Tg glass epoxy multilayer materials, low-dielectric copper-clad laminates for high-frequency communications, and materials with embedded capacitors that provide boards with condenser capabilities. Hitachi makes a variety of different environmentally-friendly multilayer products that are halogen-free and adapted for lead-free processes including MCL-E-679FG tailored for package substrates and MCL-BE-67 G (H) for motherboards. These products offer exceptionally additional value in terms of high heat resistance, low coefficient of thermal expansion, and stable dielectric properties in comparison with ordinary FR-4 materials. Clients have also expressed enormous support for Hitachi's Photec photosensitive film line of PCB process materials. In addition, Hitachi carries an extensive lineup of other state-of-the-art PCB products including FPC (flexible printed circuit) boards, high-layer PCBs, multi-wire boards, and a wide range of substrate products for IC packages.

MATERIALS FOR INFORMATION AND COMMUNICATION EQUIPMENT

Metallic Wire and Cable

There is unrelenting demand for smaller, lighter weight components and greater capacity, faster throughput semiconductor devices and information equipment, and corresponding demand for higher conductance thinner cabling and conductive materials.

It is also essential to endow conductive materials with sufficient bendability performance so that wires in equipment with movable parts do not break, and Hitachi is addressing this issue with a range of research initiatives. The company's work on metallic cable and conductive materials is primarily focused on conductor alloy technology, heat treatment technology, and wire drawing technology.

In the area of medical equipment, we are working to increase the fiber count and flexibility of cabling to improve the resolution of imaging systems such as ultrasound and endoscopic equipment, while thinning

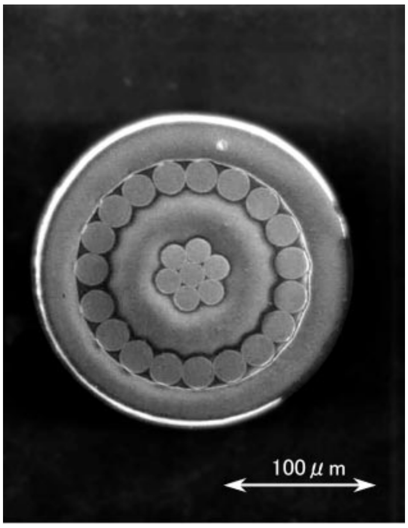

Fig. 4—Example of Ultra-thin Coaxial Cable.
This shows the center core consisting of twisted 16-μm diameter wires. With the addition of the conductor structure, a very thin cable with an outer diameter of 0.2 mm has been developed.

signal bearing lines to mitigate patient discomfort. Since cabling for these applications is bent and twisted over and over again in the course of its use, it is made of rugged material that is highly conductive yet provides excellent long-term bendable performance. Tailored specifically for such situations, Hitachi developed a high-performance copper alloy cable material that is extremely tough and effectively suppresses any significant reduction in conductivity. Compared to pure copper wire drawn under the same conditions, our new copper alloy exhibits far less loss of conductivity, better mechanical strength, and a 10-fold improvement in bending life. This material can also be drawn to a very thin diameter of 16 μm and used in all sorts of equipment with bendable parts including mobile and handheld devices, robots, and PCs (see Fig. 4).

FFC (flexible flat cable) used as a versatile wiring material in movable parts is made by laminating an array of parallel tin-plated conductor wires together with a strip of an adhesive insulator. This material is used extensively in printers, CD-ROMs (compact disc read-only memories), DVD-ROMs (digital versatile disc ROMs), and other consumer electronics products, as well as in tight, confined spaces such as in automobiles.

Optical Cable

Today optical cable and optical components are used extensively in long-haul terrestrial systems between cities, metro systems within cities, subscriber access systems, and residential wiring systems. Fig. 5 shows a schematic model of a high-speed large-capacity optical communications network. To accommodate relentlessly increasing demand for more

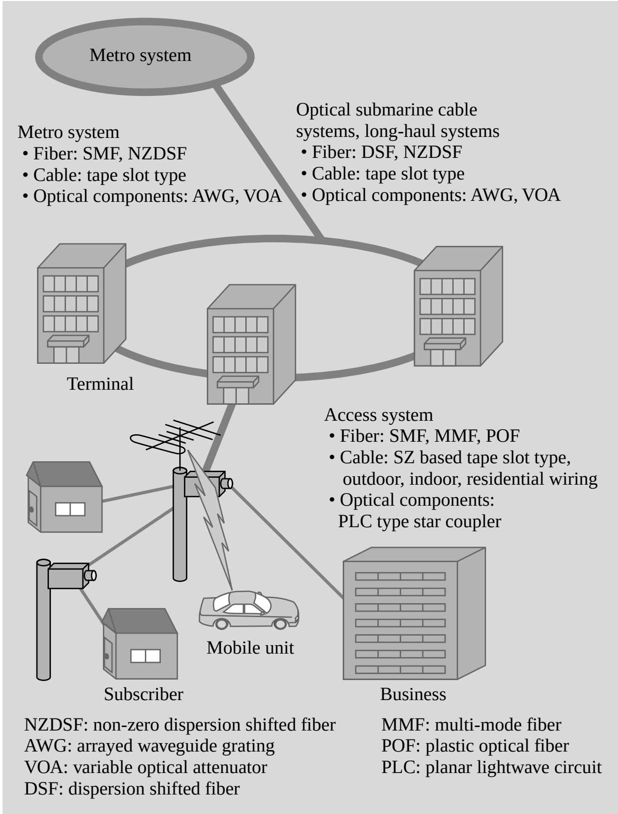

Fig. 5—Schematic Model of High-speed Large-capacity Optical Communications Network.
To accommodate higher throughputs and massive capacity, optical facilities are being deployed at all levels from long-haul trunk networks to local access systems. Appropriate optical cabling and optical components are used in each system level.

capacity, WDM (wavelength division multiplexing) systems with their ability to send multiple signals through a single fiber at different wavelengths are being deployed in optical submarine cable systems, long-haul trunk networks, and in city-wide metro systems. Considering the importance of fiber dispersion and nonlinear characteristics in these systems, a range of different types of optical fiber are produced—including SMF (single-mode fiber), DSF (dispersion-shifted fiber), and NZDSF (non-zero dispersion-shifted fiber)—as well as key optical components for splitting and combining optical signals and to provide an optical gain equalizing capability. In addition to Hitachi's expertise in manufacturing optical fiber, the company has also demonstrated its leadership in mass producing optical components for WDM systems including the development and manufacture of compact silica PLC (planar lightwave circuit) type AWG (arrayed waveguide grating) splitter-combiners, VOAs (variable optical attenuators), and other key components.

On the other hand, the ability to deploy low-cost system is the primary concern for access systems and some metro systems. Cost efficiencies are achieved by using CWDM (coarse WDM) technology with lower-cost light sources by setting a wide wavelength spacing between optical signals and deploying PON (passive optical network) technology permitting subscribers to share central office equipment. For this sector operating at the 1.38 µm spectral band, LWPF (low water peak fiber) with minimal hydroxyl group absorption loss is used in conjunction with PLC star couplers. Hitachi now has a system in place for developing and supplying all of these varieties of optical fiber and optical components.

Measuring only 125 µm in diameter, silica glass optical fiber is extremely thin and vulnerable to being damaged or cut. The fiber is thus covered with a protective cladding colored for identification purposes, so the fiber is protected from potential damage from outside forces. Hitachi has also developed a range of color codes and types of cabling tailored for different applications: for example, optical submarine cable that is highly resistant to water pressure and well protected against external damage, high-density cabling for long-haul and metro systems, and optical cables for access systems that facilitate easy branching of fibers at mid-span.

Hitachi has also developed a holey fiber in that, by surrounding the core through which the light travels with low refractive index holes, the light remains confined even if the fiber is bent at an extreme angle. Exploiting the optical characteristics of holey fiber that are not obtainable with conventional fiber, Hitachi is now manufacturing flexible optical fiber curl cord that has such low bending loss that it can be curled (see Fig. 6).

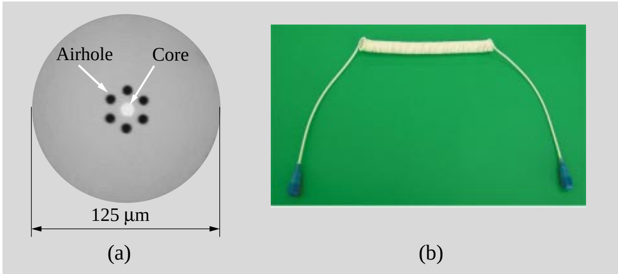

Fig. 6—Cross Section of Holey Fiber (a) and Optical Fiber Curl Cord (b).
Holey fiber has an array of airholes running down the length of the fiber near the silica glass core that greatly enhances the confinement characteristics of the fiber. The fiber can be used to implement optical fiber curl cord that has excellent confinement characteristics even if the cord is curled.

CONCLUSIONS

In this article we highlighted some of Hitachi's recent R&D (research and development) achievements in developing advanced highly functional materials that support electronic information and communications. Hitachi is striving to be one step ahead in anticipating society's needs, and is committed to researching, developing, and marketing advanced new materials that meet the needs of our customers and the needs of society at large.

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