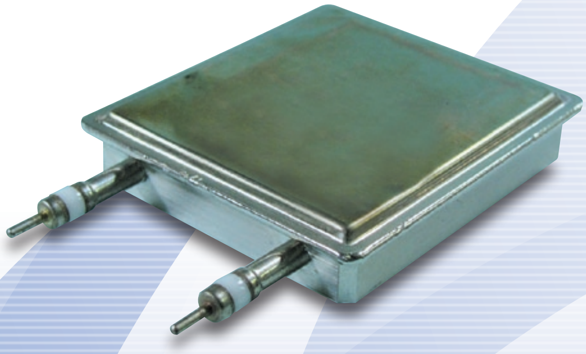
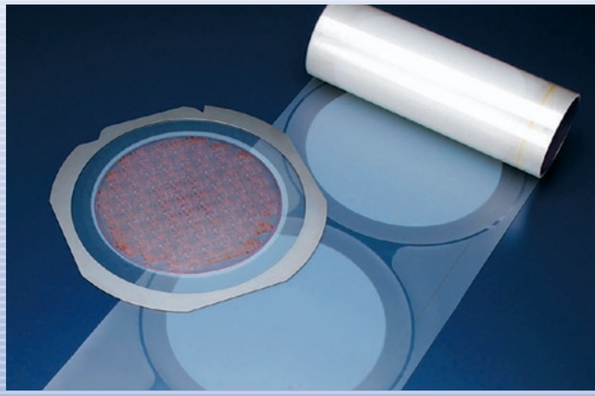
Hitachi Chemical

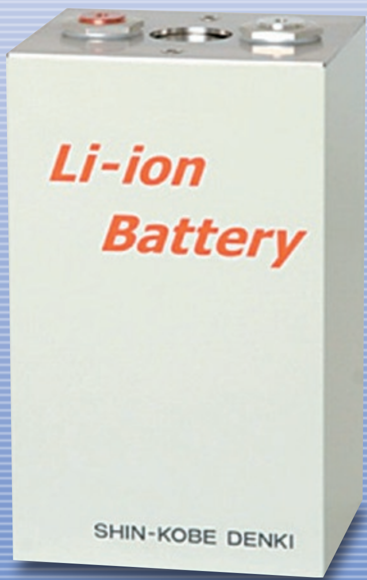
Technical Report

No.55 ⁄ May 2013

Hitachi Chemical
Working On Wonders







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No.55／May 2013

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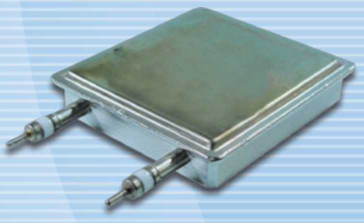

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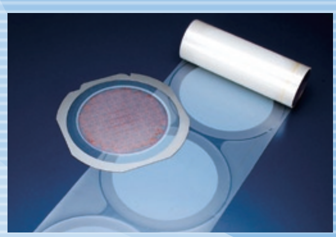

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President and Chief Executive Officer

Kazuyuki Tanaka

Challenge to Create New Value Based on Uninterrupted Research and Development

We, Hitachi Chemical, celebrated our 50th anniversary last year since our spin-off from Hitachi Ltd. in 1962. We succeeded business of four original products (electrical insulating varnishes, carbon brushes, industrial laminates and porcelain insulators); since then we have improved materials, processes (synthesis, fabrication), and evaluation technologies and produced many groups of products. We prioritized four business areas, namely "Telecommunication and Display", "Automobile and Transportation", "Environment and Energy" and "Life Science" as our key business areas. Today, we are a group of companies supplying a wide variety of materials and components. To date, we have engaged in not only supplying materials and components but also contributing to our customers by proposing new value through MSS (Material System Solution).

In 2013, we, Hitachi Chemical Group, on the occasion of our 51st anniversary, advance toward the next half century and beyond. In an increasingly uncertain business climate, we wish to be a growing enterprise group by challenging new field in R&D. We believe this is the way of realizing our corporate philosophy, "Contribution to Society through New Products and Technical Advancements to Open-Up the Era of the Next Generation".

This issue of Hitachi Chemical Technical Report introduces our new challenges in each business sector. In this, our milestone year, we want to clarify the directions of R&D activities promoted by Hitachi Chemical Group with insight and foresight. We believe our stakeholders will understand our future status by this clarification.

The wide-ranging product lineup arranged by Hitachi Chemical Group and classified as functional material stands out. In particular, in Telecommunication and Display field, we are the only supplier with full lineup of materials, from pre- to post-process of semiconductor as well as packaging materials. We will continue proposing novel materials which lead the development in this field to our customers. To enhance performance and provide new functions, it is crucial for us to extend our R&D to the molecular level. The outcome of our efforts and a vision of our future from inorganic to organic materials in each product are introduced here.

Automobile and Transportation field is a business sector encompassing our unique product groups based on competitive material technology. Currently, we are actively introducing these items to the global market, and under keywords of "Environment", "Safety" and "Comfort", we continue striving in R&D of future automobile parts. Please see

the progress of our technology which utilizes material characteristics.

Environment and Energy field is positioned as a third business sector next to those of functional material and automobile parts, the growth of which will be fully backed by Hitachi Chemical Group. To efficiently utilize various energies, e. g. renewable energy, an energy storage device is essential. Our business plan involves developing Li-ion batteries for various energy storage devices and systems for industrial use. We introduce our approach to hone the advantage of Hitachi Chemical Group by pursuing high reliability and extended service life based on competitive material technology.

Life Science field covers a broad range of businesses. Hitachi Chemical Group, however, has specialized in diagnostic reagents and diagnostic systems and continues R&D activity in this area. We continue proposing new systems realized through our high technical background.

Henceforth, the market may continue changing dynamically at unprecedented speed and expanding globally. Amid this changing market environment, Hitachi Chemical will continue growing through new challenges. We want to evolve ourselves continually and keep us at the position of leading ever-changing market. We will respond to customers' needs by our deep knowledge of material technology, search future products which will be globally sought, and become a group of companies offering value exceeding customers' expectations.

The catalyst to make this happen comes in the form of the three genes inherited within Hitachi Chemical Group. "Spirits of Trail Blazer" to challenge new things unhesitatingly, "Flexibility" to respond to the changing era and market, and "Strong Orientation on Customers". With this competitive edge, we continue R&D activity constantly and realize our corporate philosophy, "Contribution to Society through New Products and Technical Advancements to Open Up the Era of the Next Generation". Please anticipate and count on the great success of Hitachi Chemical Group in future.

Lithium Ion Battery

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The market of lithium ion battery (LIB) is growing year by year in small electronic equipment, cars and industrial applications, and the further expansion in future is expected. We have developed and commercialized the LIB related materials such as high-performance carbon cathode based on the technologies of various organic and inorganic materials. In October 2012, the development group of our Tsukuba Research Laboratory and the LIB equipment development group of Shin-Kobe Electric Machinery Co., Ltd. were consolidated for the fusion of technologies of material and device. In this paper, our LIB and LIB material technology for industrial use is outlined.

1 Trend of the Lithium Ion Battery Market

The LIB market got underway with applications to consumer products represented by cellular phones and personal computers (PC), followed by cars and then industrial use. Currently however, LIB used in consumer electronics products must offer even higher energy density due to the emergence of new devices such as smartphones and tablet computers. In response, silicon anode active material looks set to replace carbon anode active material for LIB. Moreover, technology[1)] to apply ceramic coating to the surface of a separator or electrode is being practically applied to further enhance safety.

In the LIB field for car applications, car-grade battery cells tailored for individual vehicles such as HEV and EV has been developed, the full-scale practical application of which is already underway. In response to the high LIB power output requirement for HEV, battery cells with power density of 4500 W/kg have been developed. Various innovations are being attempted to reduce the internal resistance of a battery. Since LIB for EV requires a high-energy output to extend driving distance, a battery cell with power density of around 130 Wh/kg has been put into practical use. Technologies to control the battery cell condition and cell temperature are also important because LIBs for car applications are used in battery modules comprising many cells.

In contrast, LIB for industrial use has now reached the stage of performing wide-range verification tests for output variation control for photovoltaic power generation system and wind power generators, back-up power supply while striving to reduce power consumption during peak demand at factories, buildings, etc., back-up power supply during power outages and partly employed for practical use. Performance requirements for LIB for industrial use vary significantly depending on the intended applications but the extended service life, high-level safety and reliability are common baseline performances, which development activity is thus continuing to achieve.

As case examples of LIB for industrial use, we introduce products and technologies developed/manufactured by our group company, Shin-Kobe Electric Machinery Co., Ltd., in the following:

2 LIB for Industrial Use

2.1 Large-Capacity, High Output Power and Long Service Life: CH75

This battery cell comprises a 75 Ah large-capacity cell that can be built into a large-scale electric energy storage system using relatively few cells with reliable performance and low operating cost. Even though CH75 is a large-capacity cell, it can maintain continuous discharge at 3 CA (225 A) and meet the required discharge current of a battery for 30 minutes or less while reducing power consumption during peak demand at factories, etc. Also CH75 can expect a service life to endure up to 4,000 repeated charge-discharge cycles (25 ℃, at a 75% depth of discharge). To achieve such high output power and extended service life, we employed a newly Mn-rich cathode active material, reduced the electrode and electrolyte resistance and stabilized the SEI layer formed on the anode surface.

Notwithstanding its high-energy storage capacity, CH75 maintains a high level of safety and satisfies JIS (Japanese Industrial Standards) C8715-2, etc. Photos showing the external appearance of a cell and a module comprising 6 cells are shown in **Figure 1**.

2.2 Large-Capacity, Long Service Life, Float Charging: KL200F

KL200FL is a type of 210 Ah large-capacity float charging cell co-developed by Shin-Kobe Electric Machinery Co., Ltd. and NTT FACILITIES, INC. KL200F is used in a battery system to supply back-up power in emergencies for communication equipment and data centers. The distinctive feature of the cell is a type using non-flammable electrolyte by replacing flammable organic electrolytes to achieve high-level safety as we anticipate numerous cells will be installed in data centers and other facilities

Figure 1 CH75 Cell and Module

Figure 2 KL200FL Cell and 48 V Battery System

inside urban buildings. To make electrolyte non-flammable, phosphazene flame retardant is used in combination with a new electrolyte composition[3]. Also, an expected service life of a decade or more has been achieved by improving the Mn cathode active material and employing the aforementioned new electrolyte composition[4]. Photos showing the external appearances of a battery cell and a 48 V Battery System for Back-up Power Supply using this cell are shown in **Figure 2**.

Our technologies developed for LIB for industrial use are introduced as mentioned above; as for LIB service life for use in large-scale electric energy storage systems, a lifetime of 10 to 20 years, almost equivalent to installed facilities, is desired. Hence, we are engaged in developing technologies to secure intrinsic safety and extended battery life by using non-flammable electrolyte or non-combustible ionic solution.

3 Toward the Expanded Application of LIB in Future

The market size of LIB for consumer products, cars and industrial use is expected to continue growing in future. The LIB market for cars in particular has been soaring in recent years, while the market size for industrial use is also expected to reach around 4.5 billion yen annually. To maintain the expansion of the LIB market for cars, a huge breakthrough in terms of improving electric energy density and cost reduction is required. NEDO announced electric energy density of 250 Wh/kg and product cost of about 20 yen/kg as its development targets for 2020 or so. Furthermore, NEDO set an energy density of 500 Wh/kg and a product cost of about 10 yen/kg as targets for around 2030 in anticipation of the post-LIB age.

Since the expansion of the LIB market for industrial use in our business domain is expected to trail the market growth of LIB for cars, we foresee that proven LIB technologies backed by experience in consumer products and car markets can be provided for industrial applications at lower cost. Accordingly, we must be engaged in developing new LIB technologies for industrial use while constantly monitoring leading technologies. We must also validate various large-scale electric energy storage systems considered promising in a future energy plan, at an early stage and accumulate such technologies as required for practical use.

Conversely, LIB usage varies significantly depending on the intended use, such as the output variation control for photovoltaic power generation systems, back-up power supply during reduced power consumption at factories during times of peak demand. Therefore we need buildings and proposals for optimum electric energy storage systems from a cost perspective and with long-term reliability in mind by adopting a performance-sharing approach supported by an LIB/lead-acid battery hybrid energy storage system where LIB provides a quick charge/discharge rate and a lead-acid battery one that is slow. In addition to LIB improvements for industrial use, the development of technology offering optimum solutions established by combining our lead-acid battery, lithium ion capacitor and condenser is expected and will become increasingly important in future.

4 Overview of LIB Materials

LIB was first commercialized in 1991 and its market size is expected to reach 1 trillion yen in 2020 thanks to soaring demand for compact mobile equipment such as mobile phones and PCs, the market for environmentally friendly HEVs and EVs and that for industrial applications prompted by the introduction of a renewable energy policy after the Great East Japan Earthquake. Conversely, given the need for a breakthrough in battery performance including even higher energy density, extended service life, enhanced safety or further product cost reduction, the development of new technologies, including new battery materials, is considered crucial. The major common challenges for us to develop main LIB materials are indicated in the following:

- Cathode material: Higher capacity, Improved electronic conductivity, Accommodation of a swift charge/discharge rate, and others
- Anode material: Higher capacity, Improved cycle life performance characteristics, and others
- Separator: Safety improvement (balancing heat resistance and shutdown mechanism), and others
- Electrolyte: Non-flammable, Non-combustible, Lithium ion conductivity, Permeability, and others
- Binder resin: Electrolyte resistance, High adhesion, and others

Many materials are under development to meet wide-ranging performance requirements with potential LIB applications and usages. To date, we have been involved in R&D and production of mainly high-performance carbon anode LIB materials utilizing our material-related proprietary technologies, including various synthetic technologies involving organic/inorganic materials and process technology. Here, we introduce LIB material and other material technologies which we have developed in-house as case examples.

5 Our Proprietary LIB Materials and Material Technologies

5.1 Anode Material

Since LIB was commercialized in 1991, there has been sustained demand for high-energy density and improvement of the high current property required in the high-performance environment. While carbon material remains the mainstream material, metal anode materials such as silicon (Si) and tin (Sn), which can stoichiometrically allow higher battery capacity, and hybrid materials, have already been practically applied on a partial scale. However, some pending technical issues remain to be solved, including (charge/discharge) cycling characteristics, hence continued effort to boost the conventional performance of carbon anode materials[7] is required. Currently we are continuing efforts to develop and commercially produce graphite anode materials selected within our carbon anode material group, and supply them to our clients thanks to the advantageous feature of graphite anode material, where graphite anode material shows a rated capacity close to the theoretical capacity of graphite (372 Ah/Kg), a slight decrease in discharge capacity under high current discharge conditions, superior fast charge/discharge performance, a slight decrease in discharge capacity at high electrode density and the ability to materialize a higher-capacity battery. In addition, in response to the needs for a next-generation material which can offer battery capacity exceeding the theoretical value of carbon, we are in the process of validating the commercialization of next-generation metal anode material with more than twice the capacity of carbon and superior fast charge/discharge performance. We will continue this R&D activity toward commercialization of products to achieve even higher performance targets.

5.2 Binder Resin

In the resin binder field, a critical building block to construct electrodes, we newly developed solvent-based acrylic binder resins with superior anti-swelling property, thanks to electrolytes and good adhesion[9]. Since this solvent-based acrylic binder resin shows high adhesion, with even small amounts of resin sufficient to fully activate the active material with a high specific surface area, and a slight decrease in discharge capacity at higher electrode density, it is effective to construct a high-capacity battery. In recent years, we have seen increasing demand for water-dispersible binders (hereinafter referred to as “waterborne”), which gives advantages from the point of adverse impact to environment and availability of resources, as a binder resin used for constructing anode material. Also, dimensional change (expansion and contraction) of next-generation metal anode material such as Si during charge-discharge cycles is relatively significant compared to carbon anode material, meaning additional performance improvements in binders will be required to retain the electrode structure. Accordingly we have been engaged in developing waterborne acrylic binder resins capable of meeting these performance requirements and have established the following elemental technologies:

(a) Improve the modulus of elasticity at elevated temperatures by controlling the cross-linked structure and improving battery cycle life performance.
(b) Achieve the target of high adhesive strength by screening monomers.
(c) Realize high adhesion strength between layers of active material and current collector and balance with low (contact) resistance during the construction of electrodes by controlling optimum dispersibility and the degree of binder coverage.

We will continue our efforts to enhance performance by incorporating waterborne acrylic binder resin developed based on these elemental technologies toward next-generation LIBs.

5.3 LIB Safety-Enhancing Additive/Metal Impurity Trapping Material: Imogolite

Amid a continuing trend for upscale higher-capacity LIB, demand is also soaring for environmentally friendly cars and expanding industrial applications. In response to the increased significance of safety improvement, the progress of our approaches to enhance material safety, such as the development of flame retardant and the implementation of a short-circuit protection mechanism alongside system-related measures such as an excessive charge/discharge protection circuit and protection element is remarkable[6]. We are in the process of developing and commercializing imogolite, a material to trap metal impurities that is effective in preventing LIB short circuits. Photos showing its external appearance are shown in **Figure 3**. Imogolite is an aluminum silicate of a monolayer nanotube with a high specific surface area and featuring many hydroxyl groups bound to inner/outer peripheral surfaces. Moreover, its superior capability to absorb Mn, Fe, Co, Ni and Cu to other adsorption materials such as zeolite and activated carbon has also been confirmed. To validate the principle of enhanced LIB safety based on such findings,

electrolyte added with minimal short-circuit suppression effect using Cu (foreign object) was assessed. Consequently, the degree of reduction in the open-circuit voltage of the cell using cathode material with an imogolite layer was improved. It was also confirmed that said short-circuit suppression effect achieved via an imogolite layer was better than with a ceramic or chelating agent/ceramic layer. Henceforth, we anticipate enhanced safety for next-generation large size/high-capacity LIBs by matching imogolite with LIB component materials (cathode/anode materials, separator and electrolyte).

Figure 3 Appearance of Imogolite

6 Organizational Integration of LIB Next-Generation Material Development Group and Device Development Group of the Hitachi Chemical Group Companies

In future, we expect performance and other requirements against LIB component materials (cathode/anode materials, separator, electrolyte), including aforementioned materials, with high-level safety and reliability, advantages in terms of environmental compatibility and resource availability, a flexible manufacturing process, high performance and economically superior as well as excellent electrochemical performance will be further intensified. To date, we have been engaged in the business of high-performance carbon anode material. Henceforth, we intend to fully exploit our proprietary organic/inorganic material technology, promote new materials following current technical trends and wish to contribute to the development of next-generation high-performance LIBs.

The LIB Device Group, Shin-Kobe Electric Machinery Co., Ltd. and our LIB Material Development Group merged and formed an organization to promote battery technology in an integrated manner as of October 1, 2012. Henceforth, we will accelerate competitive product development activities by integrating material technology and LIB device technology and wish to make continuing contributions to energy industry.

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Hitachi Chemical
Working On Wonders

Energy Storage Devices and Systems

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Shin-Kobe Electric Machinery Co., Ltd. has been promoting the development of energy storage devices such as lead-acid batteries, lithium ion batteries for industrial use, and lithium ion capacitors. In this paper, we outline the key features of these storage devices for application in both a renewable energy generation scheme and a micro-hybrid automobile system. In a MWh-scale power generation system that collects energy from both wind and large-solar units, hybrid-energy storage devices are required to enhance operating rate and efficiency. In micro-hybrid automobiles that make use of an idling stop system (ISS), enhanced lead-acid batteries are key energy storage devices, and are required to have high dynamic charge acceptance to recuperate braking energy and high cycle durability under stop-start cycle conditions.

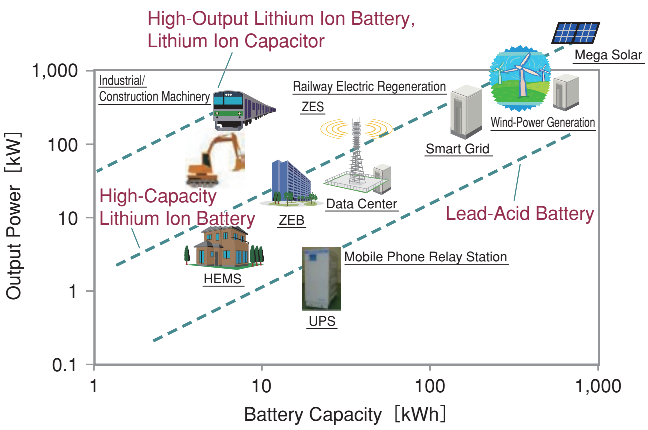
1 Introduction

An energy storage device is an apparatus used for storing electric energy when needed and releasing it when required. As a measure to counter global warming, the role of energy storage device technology in fields such as renewable energy generation and hybrid automobile systems will become increasingly important. Case examples of the role of energy storage and its relationship with infrastructure systems in our society in future promoted by the newly established Energy Storage Device Division of Shin-Kobe Electric Machinery Co., Ltd., are introduced in this report.

The lead-acid battery has a history of 150 years or more[1] and provides superior output performance over a wide temperature range, from extremely low temperature zones to high-temperature environments, e.g. engine rooms, while ensuring high reliability. Recycling technologies of materials of used lead acid batteries have already been established, and the lead-acid battery and its market have been still progressing technically and expanding, respectively[2]. Following the increasingly widespread use of new energy storage devices as represented by the lithium ion secondary battery (LIB), a lithium ion capacitor (LIC) was newly developed as a next-generation energy storage device[3]. The basic LIC construction comprises an active carbon cathode as a material used for an electric double-layer capacitor, and an LIB anode. Despite low energy storage capacity, it features superior power output/input performance especially within a short time window and durability. Shin-Kobe Electric Machinery Co., Ltd. is promoting the energy storage device business to cover lead-acid batteries, large LIBs for industrial use and LICs.

Figure 1 shows the relationship between output power and battery capacity, and characteristic outlines of the above three different energy storage devices are indicated. As shown in **Figure 1**, energy storage devices must meet wide-ranging device system needs, ranging from domestic applications to very-large capacity (MWh) used for wind power generators, etc.

Hereinafter we introduce the role and performance required for renewable energy generation systems and hybrid automobile



ZEB：Zero Energy Building, ZES：Zero Emission Station, HEMS：Home Energy Management System,
UPS：Uninterruptible Power Supply

Figure 1 Large Energy Storage Systems and Energy Storage Devices

micro-systems, which are new and differ from existing units.

2 Renewable Energy Generation System

Lead-acid batteries and LIBs, as indicated in **Figure 1**, are suitable for large capacity storage devices. LICs and LIBs, which are designed with high power output specifications, show superior performance in high output applications. There is even a good example of our lead-acid battery product group where the battery capacity with a minimum voltage level (2 volts) exceeds 1000 Ah. Renewable energy, e.g. solar and wind power, largely depends on natural conditions and is unstable since the former fluctuate. To reduce fluctuations in the power supply and convert such systems to more stable and efficient power supply systems, it is crucial to combine different types of energy storage devices.

Figure 2 shows a large-capacity hybrid energy storage system used for renewable power generation which features a lead-acid battery, LIB and LIC connected in parallel.

To build a system capable of supplying stable power highly efficiently, these energy storage devices must not only store generated electric power but also level the fluctuation of output power.

Waveforms of electricity generated by windmill or mega solar systems change in response to weather conditions such as wind, day or night and sunny or rainy, as seen in (a) schematic diagrams of the waveforms of generated power. To supply stable electric power as seen in **Figure 2** (b) after converting from such unstable generated power, large-capacity hybrid energy storage systems are equipped with power-conditioning systems (PCS). This system undertakes an important role to deliver stable electric power (b) by outputting electric power with a charge/discharge pattern of (c) and superimposing it on waveform (a) to obtain a smooth leveled waveform (c).

The lead-acid battery, among the three energy storage devices seen in **Figure 2**, has sufficient energy storage capacity to handle generated power within a certain range and with waveforms involving long cycle fluctuations. The LIB also has a large energy storage capacity and can handle generated power with a waveform of long cycle fluctuations stabilized by lead-acid batteries as well as short-term fluctuations. Conversely, although the LIC has a small energy storage capacity, it can handle short-term fluctuations or pulse waveforms of generated power which lead-acid batteries or LIBs cannot handle. Therefore by hybridizing these three energy storage devices, not only can generated power be stored efficiently by wind power or mega solar batteries, stable power can also be delivered with waveform (b) obtained after superimposing pattern (c).

The lead-acid battery can have the advantage of a greater storage capacity at lower cost compared to LIB. Conversely, the LIB is superior in terms of its ability to form a large energy storage capacity system in a confined space due to the LIB's higher energy density and output power density.

In response to the trend for scaled-up electric power generators, multi-serial and multi-parallel control systems for energy storage devices will be needed. Currently a standalone lead-acid energy storage battery supplies a total of 10 MWh or more power at the Shiura windmill electric power station in Aomori-Prefecture[4]. Shin-Kobe Electric Machinery Co., Ltd. can now offer not only standalone operation of energy storage devices but also a new hybrid energy storage system combined with high space utilization, improved capacity utilization and high reliability, based on the aforementioned energy storage devices.

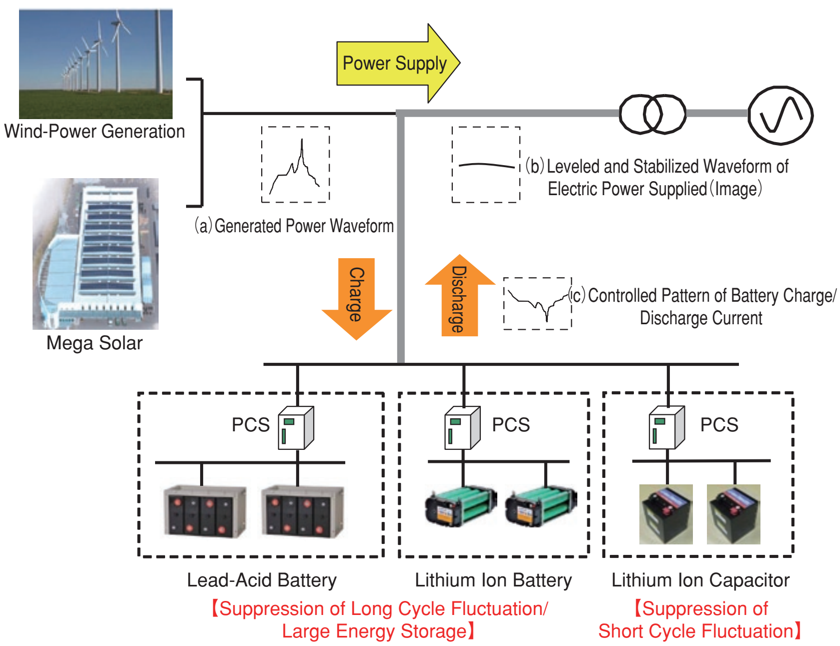


Figure 2 Scheme for Renewable Energy Generation Systems with Hybridized Large Energy Storage Devices

3 Micro-hybrid Automotive Systems

Hybrid cars are largely grouped into full, medium and micro-hybrid cars based on the function and voltage of the hybrid system. In the full hybrid zone, the system voltage of which is around 300 volts, the primarily power source is usually nickel metal hydride or lithium-ion batteries, with the lead-acid battery as an auxiliary power source. Micro-hybrid systems, so-called idling stop systems (ISS) with 14 volts, tend to use lead-acid batteries. An ISS-equipped car has a function to stop an idling engine while stopping at traffic lights, curb exhaust gas emissions and improve the gas mileage.

Figure 3 shows a correlation between the global total of cars manufactured and ISS cars[5]. As is self-explanatory from the diagram, half or more of manufactured passenger cars are predicted to be equipped with the ISS function, meaning the future market for lead-acid batteries mounted on such ISS cars will be huge.

The way in which lead-acid batteries are used for ISS cars differs significantly from the traditional approach. Traditionally, a large current was only required when the engine was started, whereupon a generator mounted on the car would continually charge the current to a battery. In the case of an ISS car, however, the lead-acid battery not only discharges a current of a few hundred amperes when restarting the engine but also repeats relentless operations such as supplying power to run audio equipment, fans, etc. during idling-off time when stopping at traffic lights. Accordingly, the magnitude of discharge current and frequency of charge/discharge cycles should increase significantly. If discharged electric power loss is recharged only when the engine is running, this further increases the level of exhaust gas from cars and impairs fuel efficiency. Accordingly, many ISS cars now mount a kind of system to recuperate braking energy by a motor generator in order to allow efficient recharging and retain fuel efficiency. A mounted lead-acid battery should be rechargeable to a sufficient extent to allow regenerative braking. However, as the traditional lead-acid battery has an intrinsically high resistance to the flow of charge current, the battery charge will soon be depleted if it is mounted on ISS cars. Therefore, to ensure ISS for cars remains sufficiently functional, the first step is to considerably boost the dynamic charge acceptance of a lead-acid battery, and subsequently secure sufficient durability of the battery to endure repeated charge/discharge cycles between idling stops and engine starts.

To meet such technical challenges, battery manufacturers are striving hard for a breakthrough in lead-acid battery technology. On-board lead-acid batteries for ISS cars have been considered different products from conventional automotive batteries because of their very different performance criteria, meaning very few battery manufacturers may be responsive to market needs from markets requiring a technical breakthrough[6]. Shin-Kobe Electric Machinery Co., Ltd. has actively been engaged in developing new lead-acid batteries for ISS cars and has a proven track record for applications in this market.

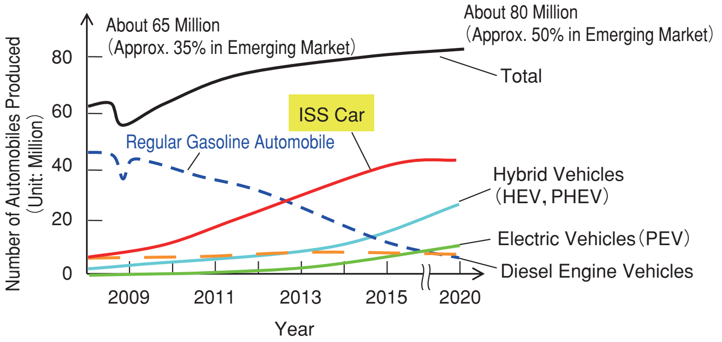


Figure 3 Global Production Prospect, Including ISS Cars and Others

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Functional Materials for the Smart Community

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Establishing a smart community containing renewable energy requires many technologies, e.g. power transmission network and power electronics technologies, as well as renewable energy. Hitachi Chemical has developed many kinds of functional material, including silicon carbide single crystal, thermally conductive materials and solar cell related materials towards the realization of a smart community. In this paper, their features and applications are described.

1 Introduction

What is a suitable source of electric power? How can we cope with the global warming issue? Finding an answer may take quite some time. Accordingly and given current circumstances, we must determine the most appropriate answer for the utilization of available energy. One of the answers will be the realization of a smart community. In other words, it involves building an efficient, safe and reliable electric power system by optimally utilizing the capability of power grid control technologies, including power transmission line network control systems, information and communication technology, power electronics technology, electric energy storage technology and renewable energy technology. Here, we propose a broad range of functional materials to help realize a smart community. In this paper, our approaches to and the future image of power electronics materials and materials related to renewable energy are described.

2 Power Electronics Materials

High-power semiconductors are critical components; used to increase the efficiency of power transmission network line operation, electric cars and home appliances such as air-conditioners. Since SiC has band gap energy 3 times greater, breakdown voltage 10 times greater and thermal conductivity 3 times greater than Si respectively, scope to downsize the inverter and significantly boost efficiency is anticipated, by optimally exploiting the superior insulation property and heat dissipation ability of SiC. SiC, as shown in **Figure 1**, forms a slightly ionic crosslink structure due to the formation of Si- and C-sp3 hybridized orbitals. The multiplicity of multilayer Si and C structures results in 170 or more crystalline structures (Polytypes). The key to obtaining an SiC single crystal wafer is dependent on the successful control of polytypes.

We have developed and commercialized many SiC polycrystalline products and are promoting development work into SiC single crystal wafers using a solution growth technique which is suitable for ideal crystal growth near the thermal equilibrium state by utilizing ultra-high temperature (1500 °C or more) process technology that was developed and proved in the production of SiC polycrystalline products. To fully exploit the potential capability of SiC, a precision control, to obtain a hexagonal polytype with high carrier (electron) mobility and control technology to prevent imperfections or defects in crystals such as micropipe defects, which may adversely affect device performance, are required.

We participated in an R&D Partnership with Future Power Electronics Technology (FUPET) in 2009 and are involved in the joint development of high quality SiC with The National Institute of Advanced Industrial Science and Technology (AIST), Tokyo Institute of Technology and Nagoya University. Following completion of the confirmation of theory, we started the preparation of a large-diameter SiC wafer[1].

A simpler cooling system for SiC wafers is advantageous, because SiC can operate at higher temperatures than Si. To enjoy said benefit, we need a material for mounting, which is workable at high temperatures. We developed heat-resistant bonding materials such as heat-resistant and highly thermally conductive silver sintering paste (**Figure 2**), but not necessarily organic materials, as well as ultra-high temperature-resistant encapsulation resins developed based on our proven thermosetting resin technology.

Power semiconductors generate significant heat when controlling high-current loads and the ability to dissipate this generated heat is crucial. We have already developed

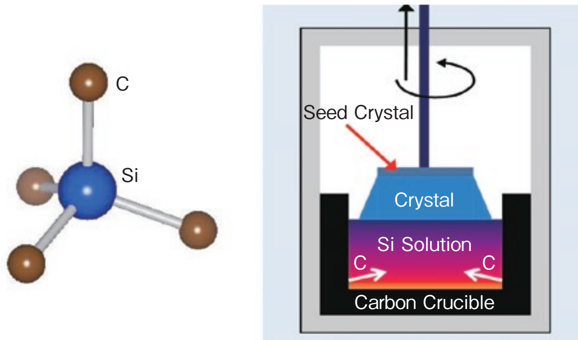


Figure1 SiC Structural Unit and the Method of Growing Single Crystal SiC from Solution

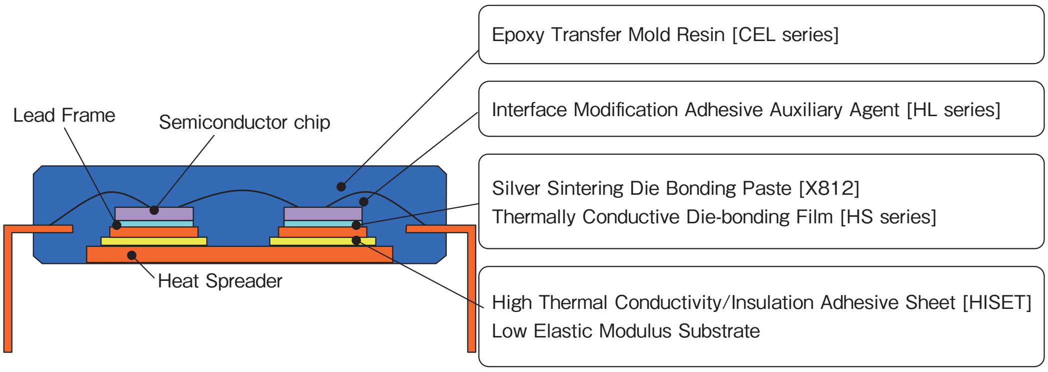


Figure 2 Hitachi Chemical's Technology for Power Module Package

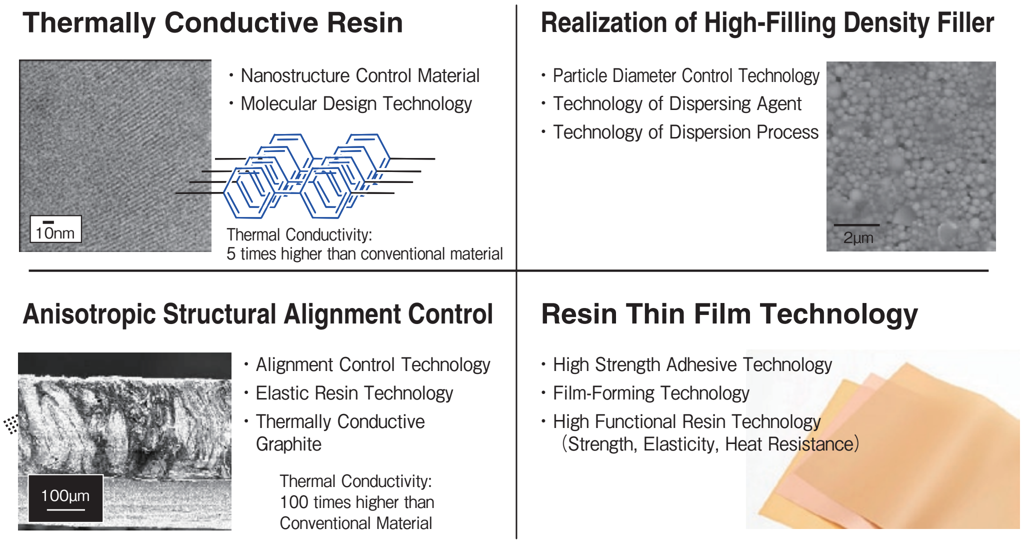
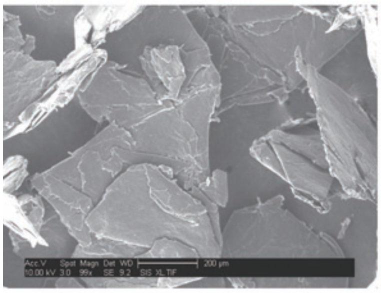


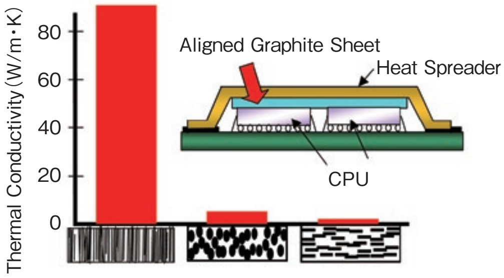
Figure 3 The Key Technologies of Hitachi Chemical

and marketed many applicable heat dissipation materials for power semiconductors and own various proprietary fundamental technologies (**Figure 3**). Among these technologies, an insulation adhesive sheet[3-5] with thermal conductivity of 5-15 W/m.K, which was prepared by combining a mesogenic epoxy resin jointly developed with Hitachi Ltd., our own thermoset resin technology and our own high-filling type ceramic filler packaging technology, is being used for applications such as power modules, Because this adhesive sheet is used as an insulation material to connect substrates and semiconductor chips, strong adhesion is required at the interface. Conversely, an insulator placed between the semiconductor device and heat sink should have some flexibility to follow up the thermal deformation. Accordingly, the thermally conductive sheet (TC series) was developed using thin-film-like graphite particles with high thermal conductivity and flexible resin. The crystal plane of the graphite shows a few thousand W/m · K of theoretical thermal conductivity. In this TC series, many crystal plane of graphite particles are aligned vertically using our proprietary crystal alignment process. Consequently, the TC series now shows thermal conductivity several tenfold higher than that of spherical graphite particles or horizontally-aligned graphite particles[4]. Additionally, since said particles we originally developed are soft and easily deformed, the sheet is flexible; easy to form to the desired shape and tending to adhere to the substrate. Consequently, it effectively reduces stress as well as effectively conducting heat across the interface. A conventional paste-like connecting material (grease) soon start emerging as the heat generation temperature increases, which creates problems in terms of declining connection reliability. The TC series, however, does not pump out because it is sheet and can hold its original shape for an extended period. Currently, although the TC series are used for dissipating heat from CPUs in high-performance servers, their applications include dissipating heat from power modules at the assessment stage.

Also, we are developing and marketing various heat-related products by combining our original material technologies[8]. For example, in response to energy-saving requests these days, and the accelerating shift to LED lighting, we market a thin flexible heat dissipation board (HT-5000ITM), with superior heat dissipation and workability and applicable to LED lighting as a heat-dissipation component material. Also, a flexible heat dissipation board (HT-9000ITM), which is pre-laminated with a heat-resistant adhesive layer, can eliminate one step in the process of attaching a scale-like surface of the substrate with an adhesive layer as before, thus simplifying the board manufacturing process. We also propose various materials including heat dissipation coatings



a) Shape of Graphite Particles



b) Shape, Alignment and Thermal Conductivity of Graphite Particle and Location for Application

Figure 4 Picture of Graphite Particles, Thermal Conductivity of Sheets and Example Applications

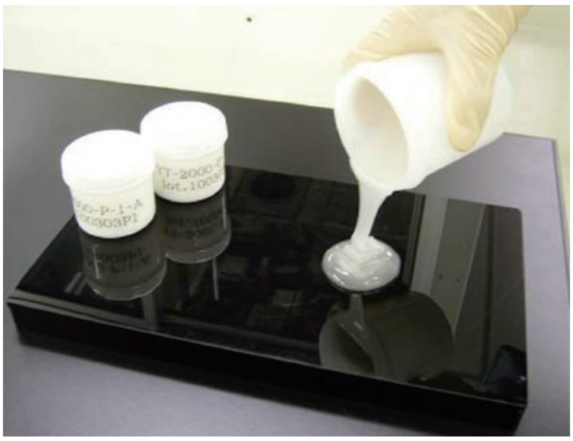
and insulation materials, etc., which are helpful in controlling heat.

These days, we have to propose optimum combinations of these materials. To do so, insulating reliability, durability, technology to evaluate thermal property and simulation technology are all essential. By applying our Material System Solution (MSS) technology for the material to be mounted to the thermal management material, which is our original technology nurtured over many years, we have started proposing an optimum combination of materials.

3 Renewable Energy Related Material

Currently, there is a need to strive to improve the economics of renewable energy by boosting efficiency. Solar batteries, among other forms of renewable energy, may be a promising source of distributed energy because of their lack of mechanical parts and ease of maintenance. We marketed the CF series, which is a solder-replacement, electro conductive film, capable of connecting the current collection tab and the solar battery electrode at low temperatures, and conductive paste, CP-300, which can reduce the usage of silver paste for bus bar electrodes; these products help simplify the manufacturing process and suppress warping and cracking.

Moreover, we also developed and marketed the YT-2100-N doping paste, which was developed utilizing know-how acquired through experience of printable functional material technology and could further boost efficiency. This paste, seen in **Figure 5**, is highly viscous, contains complex chemical compounds containing phosphorous, and is suitable for screen printing. After coating this paste and applying heat treatment at around 900 °C, the required amount of phosphorus can be doped to the site where required, thanks to which conversion efficiency can be improved and the overall process considerably simplified compared to the etching process using $POCl_3$ gas and resist.



Item	Unit	Property
Viscosity (25 ℃)	Pa・s	10-100
Thixo index	—	1.6
Printed line width (150 μm wide, masked)	μm	220
Ash (after heating at 400 ℃)	%	10
Resistance Value (after sintering at 900 ℃, 10 min)	Ω/cm^2	45 or less

Figure 5 General Properties of the YT-2100-N Doping Paste

4 Future Image of the Material Related to Smart Community Scheme to Secure Stable Supply

One of the risks exposed during the Tohoku Earthquake was that of material supply stoppages. Highly efficient and centralized semiconductor and automotive industries will be in serious trouble if the supply of a single material or part stops. However, since the aforementioned group of materials is at constant risk of raw material supply shortages, an appropriate formulation design, including robustness against such risk, is required. Even if the supply of multiple raw materials was disrupted due to disaster on a major scale, we would still have to continue a highly-stable supply operation utilizing alternative materials; hence our involvement in synthesizing and seeking alternative materials on a daily basis.

In addition to such efforts, we are investigating a more quantitative assessment system of supply stability jointly with Prof. Matsuo of The Advanced Institute of Industrial Technology (AIIT). To date, we have developed searching method for new formulation (weak conditioned combinatorial linear programming) to accomplish the target values[10-12] and software. Consequently, the assessment of suitable materials for reaching the target value and that of design flexibility was enabled, whereupon the final product supply risk after adding the supply risk of raw materials could be calculated[13, 14]. We will attempt to apply this formulation searching method to the product development process once the method has been converted to a software program to facilitate handling. We wish to further improve the final product supply stability utilizing technical expertise accumulated through ceaseless efforts and improve our supply stability to support infrastructures in our society.

5 Summary

Currently, many challenges remain before us, including problems of global warming, explosions of atomic power stations triggered by giant earthquakes and subsequent electric power shortages. Under such circumstance, we must build a smart community, including the utilization of natural energy e.g. in the form of solar batteries. We continue to steadily accumulate technologies covering thermal dynamics, analytical chemistry, material science and computer science and intend to propose as many new materials related to power electronics and renewable energy as possible to help solve problems of global warming and the environment.

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Hitachi Chemical
Working On Wonders

Semiconductor Wafer Process Materials

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The shrinking design rules, increased number of layers, and application of new materials are the aspects characterizing progress in semiconductor devices, in accordance with the downsizing and multi-functionalization of electronic devices such as smartphones, tablet computers, notebook PCs, and so on. The required properties for semiconductor wafer process materials have been increased and diversified under these circumstances.

Hitachi Chemical has been developing and commercializing various kinds of CMP (Chemical Mechanical Polishing) slurries, "HS-series", wafer coating materials such as siloxane-based spin-on film, "HSG", and low temperature curable organic type photo-definable dielectrics, "AH-series" suitable for stress buffers and the redistribution of bumps. Technical trends, features of our products and future works for CMP slurries and wafer coating materials are described in this report.

1 Introduction

Recently, efforts to downsize and functionally expand electronic devices, typically cell phones and personal digital assistants, have been rapidly promoted. Semiconductor LSIs are getting denser under these circumstances, therefore shrinkage of its design rule and multilayer metallization (Logic ICs currently have ten or more layers, for example) are the key technologies. Planarization of each layer is essential to achieve multi-layer wiring, and application of CMP for global planarization (complete planarization) from local planarization using SOG (Spin-on Glass, Hitachi Chemical product name "HSG-R7") allows a significant reduction in step height in wiring layers. Currently, CMP is applied to a wide range of semiconductor production processes[1], including formation of shallow trench isolation (STI), p-Si plugs, tungsten plugs, Cu wiring and planarization of interlayer dielectrics between wiring layers, and so on. At the same time, wafer-level packaging has also been accelerated in semiconductor packages to facilitate downsizing and density growth[2]. This has expanded the applicable range of wafer coating materials such as protection films for solder bumps, and redistribution insulation layers if the redistribution of bumps is required, in addition to the conventional application of interlayer dielectrics between wiring layers and stress buffers for semiconductor packages. The trends in CMP slurry, and wafer coating material technology, the present state of development and future deployment are presented in this report.

2 CMP Slurries

2.1 STI Slurries

STI process is polishing the area in contact with transistors is most sensitive to defects among CMP processes. Therefore, preventing polishing scratches is particularly important as shown in **Figure 1**. **Figure 2** suggests that as the wiring of semiconductor devices shrinks, even the small scratches would seriously impair the operation of devices. High planarity performance in the STI process is essential since STI is the bottom layer of the device as well as reducing scratches.

Slurries using silica (silicon oxide) abrasive have been widely used in the STI CMP process, but silica slurries also have issues such as scratches, insufficient planarity and low removal rate. Focusing on cerium oxide ("ceria") particles, which have advantages such as less scratches and high removal rate, Hitachi Chemical developed submicron ceria slurries in the HS-8005 series, featuring less scratches and high removal rate of SiO_2 film, which was marketed in 1999. We also developed the HS-8102GP additive, primarily composed of organic polymers for ceria particles, and marketed at the same time. This additive is absorbed in SiO_2 film to facilitate the polishing of uneven surfaces, and stops polishing when the SiN film, which is the polishing stop film in the STI process, is exposed.

Table 1 shows the HS-8005 series lineup. To reduce scratches, Hitachi Chemical has developed various products with optimized particle sizes and distributions. With the HS-8005-X3, polishing scratches can be reduced to 1/10 or less of the HS-8005. We established production technology for fine control of particle size and distribution of ceria particles to supply stable quality products, with top global shares of the ceria slurry market. To meet the requirements for further scratch reduction, Hitachi Chemical developed ultra-fine particles in the form of the NC series, for next-generation slurry. While conventional ceria particles are crushed for microparticulation, the size of NC series particles is mud by crystalline growth method, minimizing scratches due to large size particles. **Figure 3** shows the appearance of the HS-NC and HS-8005. HS-NC is an ultra-fine, transparent, nano-level particle.

The functions of additives include to control the removal rate of the polishing stop film (SiN, pSi) and planarity of the SiO_2 film. To improve these functions, we designed new organic polymers to develop new additives (HS-7000 series) to control and optimize the planarity performance of additives to the film to be polished (SiO_2, SiN, pSi). The 7000GP series provides higher adsorption by specially controlling the adsorption to the SiO_2 film. Polishing scratches caused by the aggregation of particles were also reduced by controlling the adsorption to ceria particles. Hitachi Chemical has offered various combinations of ceria slurries and additives to meet the various needs of customers.

Recently, ceria slurries have been increasingly used in the ILD (Interlayer Dielectric) and PMD (Pre Metal Dielectric) CMP process in place of silica slurries. We have also striven to develop ceria slurries with much higher removal rate of SiO_2 as required in these CMP Processes.

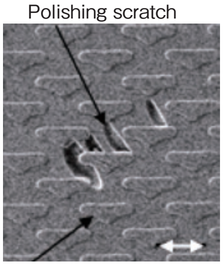

Figure 1 SEM Image of Scratch on STI Test Pattern Wafer

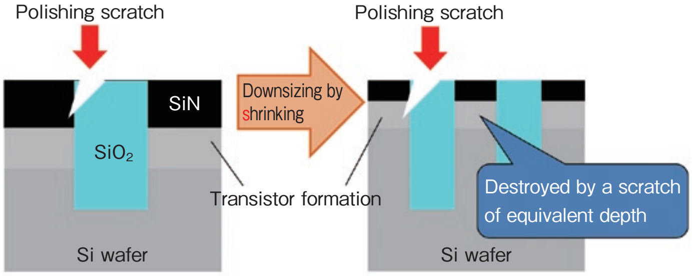

Figure 2 Influence of Scratch to the fine Design-rule Device

Table 1 Polishing Performance of Ceria slurries with Additive

Slurry	HS-8005	HS-8005-X	HS-8005-X2	HS-8005-X3	HS-NC
Removal rate [nm/min]					
SiO_2 film	350	330	300	250	250
SiN film	8	8	8	8	4
pSi film	1	1	1	1	<1
Planarity* [nm]	<10	<10	<10	<10	<10
Scratch [relative value]	100	40	20	<10	<1

*Dishing of Active/Trench=100/100 µm
Polisher : Rotary type
Polishing pad : Polyurethane hard pad

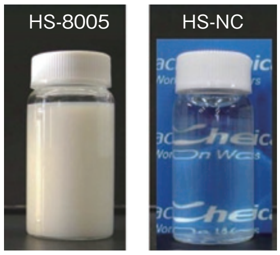

Figure 3 Appearance of HS-8005 and HS-NC

2.2 Metal Slurries

Low-resistance Cu wiring has recently been replacing Al wiring to improve the operating speed of semiconductor devices, and Cu-CMP is essential for the Cu wiring manufacturing process. In Cu-CMP, two types of slurries are used for two-step polishing processes, the process of removing Cu and the process of removing the underlying barrier metal (Ta, TaN). High removal rate, high planarity and high Cu:Ta selectivity are required for Cu-CMP, while a low defectivity and high planarity (controllable selectivity of Cu: Ta: SiO_2) are required for barrier metal CMP.

Table 2 shows the CMP performance of the HS-H700 for Cu and the HS-T915 for barrier metal developed by Hitachi Chemical. When polishing Cu using the HS-H700, a complex layer is formed on the Cu surface due to the chemical reaction of the complexing agent included in the slurry, and the complex layer is removed by the friction between the polishing pad and wafer surface at a removal rate of more than 500 nm/min. The mechanism achieving planarity of less than 50 nm (dishing) is selective polishing of the complex layer only on the protruding portions, and the polishing pad does not remove the concave portions to protect the surface. Since there is a trade-off between removal rate and planarity, the choice of chemical composition and an abrasive coating for polishing are key techniques for optimizing both variables. The wiring yield for advanced devices of 1X -2X nm generations is affected by several nanometers of Cu corrosion (voids) or defects slurries providing high-process stability in mass production processes are also required.

Barrier metal CMP removes three materials, Cu, Ta and SiO_2, simultaneously. Since a mechanical action is more effective for removing Ta and SiO_2 compared with Cu, the choice of abrasive is important. Excessive mechanical strength causes scratches and even fine scratches may result in wiring open and short failure. We have succeeded in minimizing defects by adding a small quantity of soft colloidal silica for the abrasives. As residual insoluble Cu complex on the polished surface has recently become an issue, Hitachi Chemical has developed slurries that hardly produce any residue or are easily removed in the post-CMP cleaning process. **Figure 4** shows the result of defect evaluation on the wafer after CMP with HS-T915. Compared with conventional

Hitachi Chemical slurries, a significant reduction in defects is obvious in newly developed slurries.

Figure 5 shows a cross-sectional TEM photo of a patterned wafer polished with Cu slurry HS-H700 and barrier metal slurry HS-T915. The two-step polishing process, using two different slurries, achieves highly flat Cu wiring with fewer defects. Because the ultimate goals for the dishing amount of a 100 μm wide wiring pattern is less than 10 nm and for the erosion amount in dense narrow wiring under several nanometers (**Table 2**), steps produced in Cu-CMP is recovered by controlling the polishing selectivity in barrier metal CMP. The finishing would be optimally planarized when the selectivity of Cu:Ta:SiO_2 is in the order of 1:3:3 under optimized polishing conditions and oxidizer concentration. Although there are various patterns in devices, such as logic, memory and image sensor, adjustments are required according to customers' needs.

Table 2 CMP Performance of Metal Slurry

Metal slurry			HS-H700 series	HS-T915 series
Application			Cu slurry	Barrier slurry
Polishing condition (Pressure : kPa)			14.0	10.5
Removal rate (nm/min)		Cu	850	27
		TaN	<1	95
		SiO_2	—	90
		SiOC	—	31
Planarity (nm)	100/100 μm	Dishing	<50	<10*
	9/1 μm	Erosion	<10	<5*
Defect and corrosion			Good	Good
Cu residual			None	None

*HS-H700 series slurries were used for Cu-CMP
Polisher : rotary type
Polishing pad : polyurethane hard pad

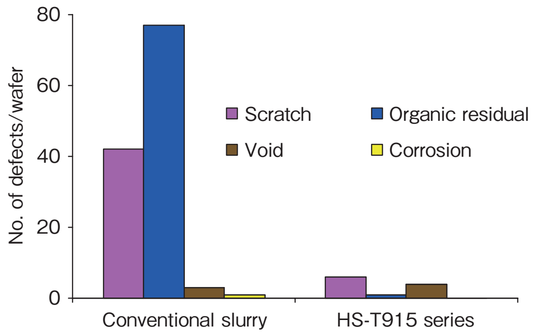

Figure 4 Defect Classification and Counts after Barrier CMP

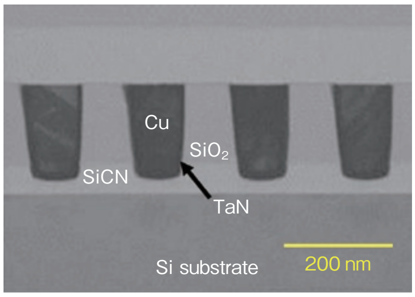

Figure 5 Cross Section of Patterned Wafer after CMP

3 Wafer Coating Materials

Hitachi Chemical and group companies have marketed coating type insulation materials such as polyimide and siloxane resins as interlayer dielectrics and wafer coating materials for semiconductors. These materials have been used in semiconductor devices. To meet the requirements of recent semiconductor packages for downsizing, high speed and high capacity and density, area-array type packagings such as BGA (Ball Grid Allay) and CSP (Chip Size/Scale Packaging) and 2.5- or 3-dimensional packagings, such as TSV (Through Silicon Via) have become increasingly prominent[2]. In these packagings, redistribution on the chip is required to adjust the design of chips and those of substrates (module boards). **Figure 6** shows a schematic illustration of an example. Hitachi Chemical promoted R&D on coating materials for photo-definable dielectrics as semiconductor insulation materials for redistribution insulation layers, etc. and marketed the AH series.

The insulation layer requires various properties, including photosensitivity to simplify engineering processes, heat resistance, mechanical and electric properties, chemical resistance and compatibility with redistribution. In addition, lower curing temperature will be required to prevent device degradation due to high-temperature processing, or when materials with low heat resistance may be used in the preceding processes[3]. The AH series will meet various needs as described before utilizing Hitachi Chemical's proprietary photosensitive materials, heat-resistant materials, resin synthesis and resin modification technologies.

Table 3 shows the general properties of an AH series material, which is made of positive photosensitive resin that can be developed with alkali solution (2.38% TMAH), and offers practical photosensitivity. Curing temperatures of 180 to 200 °C, which are lower than those for existing polyimide resins, could be achieved by optimizing chemical species and taking into account the temperatures causing a cross-linking reaction of the base resin with a cross-linker. The mechanical properties, which are by no means inferior to those for polyimide resin, could be implemented by additives which are compatible with the base resin. The low curing temperature and elastic modulus result in low residual stress, which

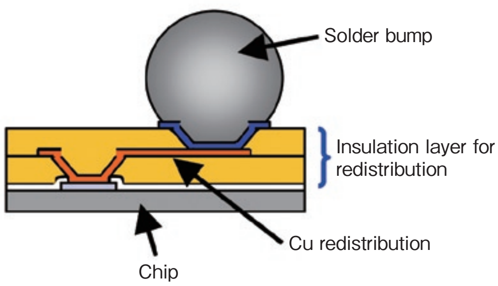

Figure 6 A Semiconductor Packaging Bearing a Redistribution Layer

Table 3 General Properties of an AH-Series

Item	Unit	AH series
Thickness	μm	2～20
Optimum exposure*	mJ/cm^2	400
Curing temperature	℃	180～200
Glass transition temperature	℃	>200
Elastic modulus	GPa	2.0
Elongation	%	50
Coefficient of thermal expansion	10^{-6}/K	58
Residual stress	MPa	20

＊Film thickness after curing 10 μm

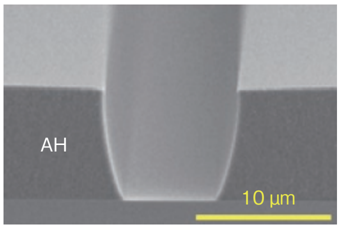

Figure 7 A Cross Section of a Cured AH Pattern

allows the material to be used as insulation layers for the chip stack packages, on which the warpage of the silicon substrate is an issue. **Figure 7** shows the cross-section of a cured AH pattern. Although this figure shows a rectangular pattern, one with smoother profile is feasible by optimizing the cure conditions. This makes it possible for the AH series to be applied to various packages, possessing through via, and bump connection. A wafer-level CSP was prepared using the AH series to investigate its reliability. The result showed that moisture/reflow resistance and thermal cycle resistance are both very good[4].

As explained above, the AH series have good photolithographic performance and their physical properties and reliability remain good even after cure at relatively low temperatures such as 200 °C. For this reason, the AH series are applicable to novel semiconductor packages which have recently come to the fore.

4 Conclusion

This report described the technical trend and status of development in CMP slurries for STI, Cu wiring and wafer coating materials as those used in semiconductor wafer processes.

Electronics will evolve into ubiquitous and cloud entities in future, which requires finer, more sophisticated and power-efficient semiconductor devices and smaller, faster and denser semiconductor packages. Under these circumstances, applications of new materials for next-generation semiconductor devices have been well discussed. For example, the use of insulating oxide layers with good filling performance for the STI process in place of TEOS and HDP-SiO_2, and the application of interlayer dielectrics with lower dielectric constant for the ILD process have been promoted. Changing barrier metal from Ta to Ru and Co has been accelerated in metal processes due to the advantage of the latter for filling performance of Cu into micro trenches. CNT (carbon nanotube) has been studied for wiring instead of conventional Cu. The application of three-dimensionalizing techniques such as TSV (Through Silicon Via) and PoP (Package on Package) is also subject to considerable discussion[2]. Moreover, semiconductor packages will become increasingly diversified, and MEMS[5] and flexible devices[6] may grow as well.

Based on the above technical trends, the application of the CMP process has also increased, and in addition to the properties required for CMP slurries such as a low defectivity rate and high planarity, the development of new slurries to suit changes in target materials to be polished is also important. As for wafer coating materials, improvement of properties for not only insulation, resolution, and residual stress, but also reliability are important.

Semiconductor electronics will evolve continually. We will go on proposing new wafer process materials by accurately predicting future technical trend of cutting-edge devices.

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Film Technologies for Semiconductor & Electronic Components

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Advanced Integrated Materials Business Sector
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Hitachi Chemical's film materials are widely used for small & thin electronic equipment, primary examples of which are anisotropic conductive film (ACF), used to connect displays from the late 1980's and die attach film (DAF) used for memory packages from the late 1990's. These materials using Hitachi Chemical's film technologies have become established global standards and have contributed to a dramatic increase in flat panel display and various other electronic equipment for over 20 years. We will establish low-temperature fine-pitch connection technologies and high heat-radiation, film thickness control technologies to apply to various displays and package structures, on a continuous basis. Furthermore, these materials are also expected to spread to new fields such as three-dimensional packages.

1 Technical Trends and Future Development of Anisotropic Conductive Film

1.1 Introduction

Anisotropic conductive film (ACF) is a film adhesive with uniformly dispersed conductive particles several micrometers in diameter in thermosetting resin. Metal-plated plastic particles, or nickel and other metal particles are used for conductive particles[1]. ACF is capable of interconnecting micro electrodes electrically and mechanically within 10 seconds by simultaneously heating and pressurizing[2]. As shown in **Figure 1**, it is used for connecting electrodes of the COF (Chip On Film) package containing a driver IC with the display panel, COF with PWB (Printed Wiring Board) in the assembly of the FPD (Flat Panel Display) such as LCD (Liquid Crystal Display) or OLED (Organic Light-emitting Diodes), and connecting the bare chip of the driver IC on the display panel during the COG (Chip On Glass) process.

LCDs are used for cell phones, laptop PCs, monitors and television, and have recently attracted increasing attention for their contribution to rapid improvements in the performance and production of mobile information terminals, such as smart phones and tablet PCs, featuring excellent operability with high-resolution and high quality displays, slim lightweight bodies and touch control systems. At the same time, ACF has been improved to meet changing needs.

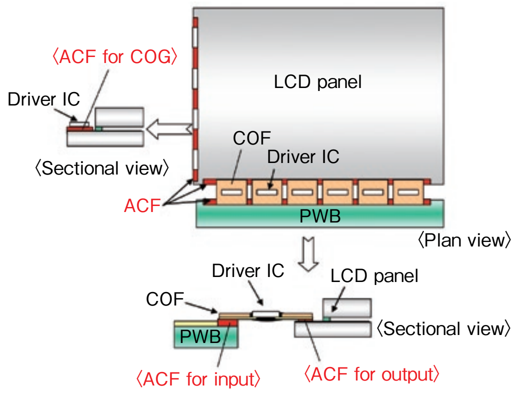

Figure 1 Illustration of Mounting Technology using ACF

1.2 ACF Products

ACF is a 10–50 μm thick, 1–3 wide and 50–300 m long tape product with conductive particles dispersed on a support film (e.g. PET). As the frames of smart phones and tablet PCs are getting thinner to enlarge the display area, an ACF of 0.8 mm or less in width is discussed.

As shown in **Figure 2**, the ACF is placed on the electrodes, and the upper and lower electrodes are aligned with the ACF inserted in-between, and simultaneously heated to between 150 and 180 °C and pressurized at 2 to 3 MPa. For narrow ACF, its adhesion to the support film must be sufficient to facilitate the separation of ACF from the reel. Excessive adhesion, however, may cause ACF to be drawn by the support film, resulting in failure to attach to the electrodes. Careful adjustment is required to ensure suitable adhesion.

The need for fine pitch interconnection may be met using an anisotropic conductive adhesive (ACA), a printable connecting material that can be easily attached to a micro region using a general-purpose dispenser, but the liquid form of uncured area and unsuitability for fine pitch interconnection restrict its application[3].

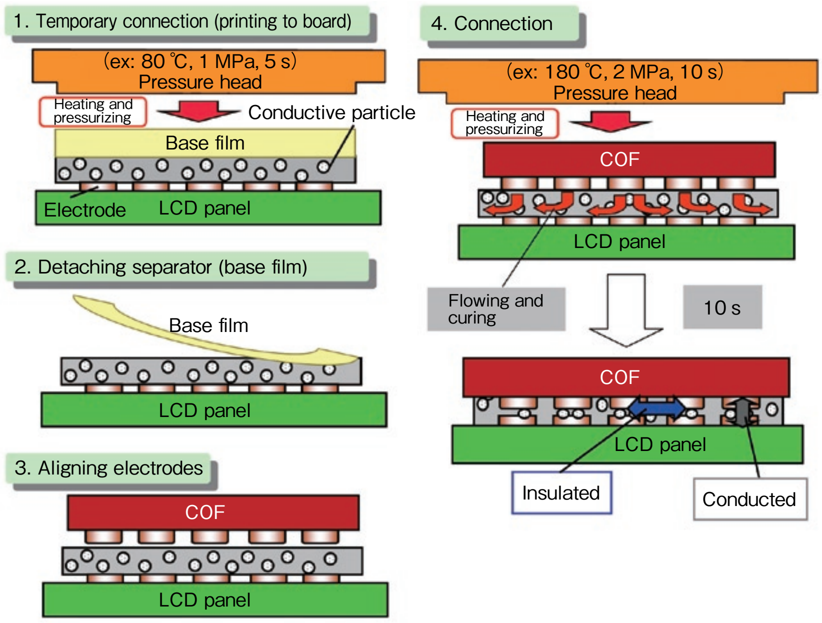

Figure 2 ACF Bonding Process

1.3 Low-temperature Interconnection with ACF

The interconnection using ACF, as shown in **Figure 2**, starts by attaching ACF to the electrodes, whereupon the upper and lower electrodes are aligned with ACF inserted in-between, and heated and pressurized simultaneously to between 150 and 180 ˚C and 2 to 3 MPa respectively.

The COG packaging is used for mounting devices on small- and medium-sized display panels for smart phones, tablet PCs and other mobile information terminals. COG interconnects the IC chip and glass substrate, both of which are highly elastic, with the ACF, potentially resulting in deformation of the connection area due to the heat-induced stress. Consequently, the brightness of LCD areas near the connection may become uneven, which is known as “uneven display.”

The stress on the connection area is caused by the difference in thermal expansion between the IC chip and glass substrate, due to a temperature gradient arising when the ACF is heated from the IC chip side which the pressure head touches, and the IC chip becomes hotter than the glass substrate. The thermal contraction of the IC chip exceeds that of the glass substrate when they cool to room temperature after being interconnected, causing the glass substrate[3] to warp. **Figure 3** shows the relationship between the warpage and the thickness of the IC chip and glass substrate. The IC chip and glass substrate for smart phones and tablet PCs become increasingly thinner, and the thin glass substrate increases the warp. It has been suggested that a low-temperature connection may be effective in preventing the warp.

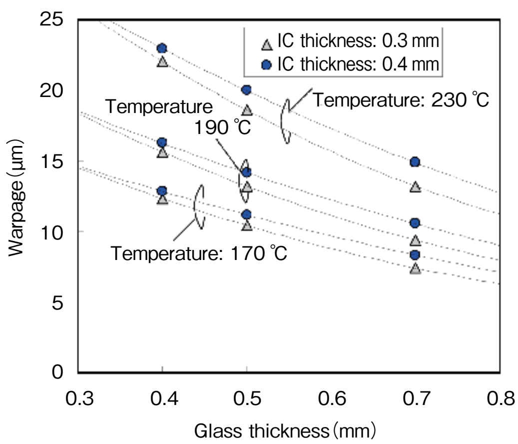

Figure 3 Relationship between Warpage and Thickness of IC (glass)

We have developed and are currently commercializing a product usable for connection at low temperatures, namely 150 ˚C and 5 s, which is 30 ˚C lower than the conventional bonding temperature. This product, which has successfully reduced the warp by about 50%, can also effectively reduce any unevenness of LCD displays, hence its widespread use in tablets and thin laptop PCs at present. There is, however, an urgent need to lower the connection temperature more drastically to meet the demand for thinner LCDs, and our new product development is focused on achieving connections at 100 ˚C and 5 s using a curing method other than hot curing.

1.4 Double-layer ACF

In COG interconnection, bare chips are mounted on a glass substrate by connecting the bump on the bare chip with the glass substrate, meaning an electrode area of about 2,000 μm^2 or less, smaller than the COF connection area, is typical in the COG process. The recent demand for higher resolution panels and shrinking chips requires a bump pitch of less than 15 μm, and a connection area including an allowance for displacement of less than 1,000 μm^2.

To meet this demand, we have developed and commercialized double-layer ACF that separates functions for bonding and

insulation and conduction respectively, to effectively capture more conductive particles on the electrode[4]. The double-layer ACF consists of an adhesive layer containing dispersed conductive particles (conductive particle layer) and a layer containing only adhesive (adhesive layer). The adhesive layer contains inter-circuit bonding and an insulating function, while the conductive particle layer contains a conduction function. Its application for narrow pitch connections is enabled with more connecting particles captured on the electrode than single-layer film by arranging a layer of thin conductive particles of 10 μm or less on the side of the glass substrate, meaning good performance of the tape, despite the number of particles remaining unchanged.

Uneven distribution of conductive particles on a particular layer, which allows finer pitch connection, is a feature of ACF and paves the way for a new function to control fluidity and adhesion on individual layers. As shown in **Figure 4**, flow reductions on the conductive particle layer exceed the adhesive layer flow during the connection of adhesive, enabling the connecting particle capture rate on the electrode to improve[5]. We are focusing on interconnecting smaller areas, such as 500 μm^2, by developing these technologies in future.

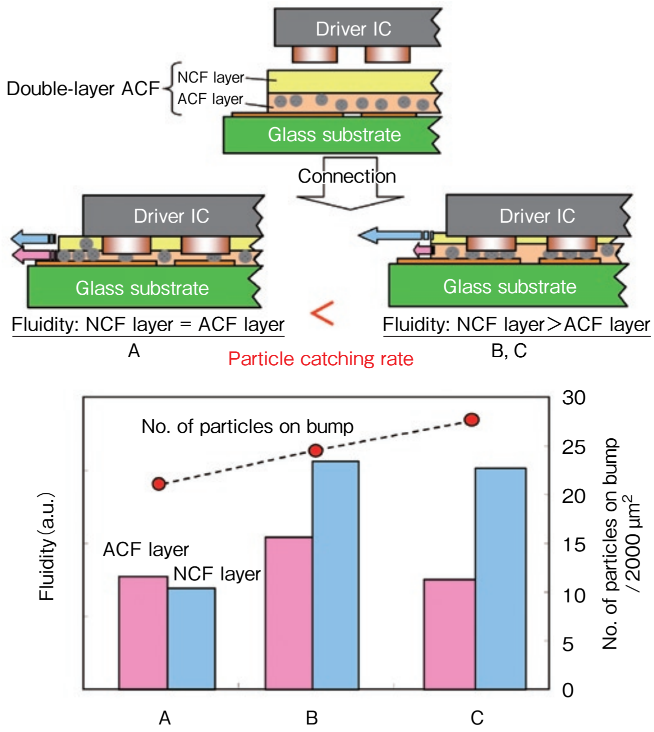

Figure 4 Relationship between Particle Catching Rate and Fluidity

1.5 Conclusion

As mentioned above, ACF for interconnecting FPD devices, typically LCD modules, has evolved based on the advantages of a film adhesive. To meet the needs for thinner substrates in recent mobile information terminals, we are currently developing materials specifically made for low-temperature, finer pitch connections, while considering the importance of developing general-purpose products for more wide-ranging applications in future.

2 Technical Trends and Future Development of Die Attach Film (DAF)

2.1 Technical Trends

As electronic equipment, typically cell phones, becomes faster, more sophisticated and more compact, organic substrate-based area array type packages BGA (Ball Grid Array) and MCP (Multi Chip Packages) are increasingly used as smaller and thinner semiconductor packages enabling high-density mounting[6]. Die bonding films are crucial for these semiconductor packages, which must meet various functions.

Compared with packages using a lead frame, the wire bonding terminal of BGA and MCP packages is significantly closer to the chip, hence the problem of the wire bonding terminal being prone to contamination due to extrusions and bleeds of the conventional die bonding paste. Another problem arising in the latest MCP, which tends to have thinner chips due to the limitation of the package thickness, is the fact that the extra paste may emerge on the surface of the chip. Film-type materials have a definite advantage in this case, and are also advantageous in terms of insulation reliability, void freeness and uniform thickness to prevent chip inclination. To solve the aforementioned problems, we developed the world's first die attach film (DAF) in 1995[7, 8].

Figure 5 shows the structure of typical BGA and MCP packages connected with wire bonding. The wire bonding approach is beneficial for reducing costs because its connection method is the same as packages using a lead frame, and conventional equipment can be used. Almost all semiconductor assembling manufacturers introduced this system.

Today, DAFs with various characteristics are demanded according to the types of semiconductor packages shown in **Figure 6**. For example:

1) Chip-substrate bonding film (step filling type)
2) Chip-chip bonding film (uniform film thickness, thinner film)
3) Film allowing wire bonding of complicated layered structures
   (Spacer film: thicker film, gold bonding wire supply film: fluidity)
4) Small chip film (high elasticity)

Hitachi Chemical has met these requirements through our studies on

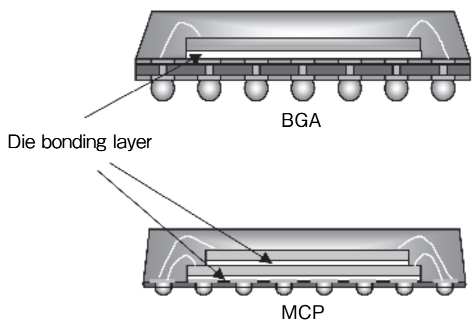

Figure 5 Structures of BGA/CSP and MCP

various base polymers[9], research into thermosetting materials, and the use of reaction-induced phase separation structures and other technologies[10, 11], as well as various products.

As the number of layers in the chip increases, the need to solve new issues, such as ensuring wafer conveyance, has arisen. In the process of selecting a chip with DAF and die bonding it to the substrate or lower stage chip, two laminating processes for DAF and dicing tape are ineffective in that the number of processes is increased and potential damage (cracks, omission) to the wafers is possible during the conveyance of wafers between processes.

To solve these problems, an integrated tape combining dicing and die bonding ("DC-DB") becomes a critical factor. With this tape, two processes for attaching DAF and dicing tape to wafers are integrated into a single process, simplifying the work. Once laminated, the wafer and tape are fixed to the wafer ring to facilitate the wafer conveyance. This also reduces potential damage to wafers in the laminating process.

Hitachi Chemical developed Dicing/Die-bonding (DC-DB) Double Functioning Tapes, "High Attach FH/HR Series" and "DC-DB Integrated High Attach DF Series" (**Figure 7**). These films boost the adhesion of the dicing tape and DAF, and prevent chips from scattering during dicing. They are also designed for picking up chips with DAF. DC-DB double functioning tapes suitable for process compatibility and reliability have been widely used[12].

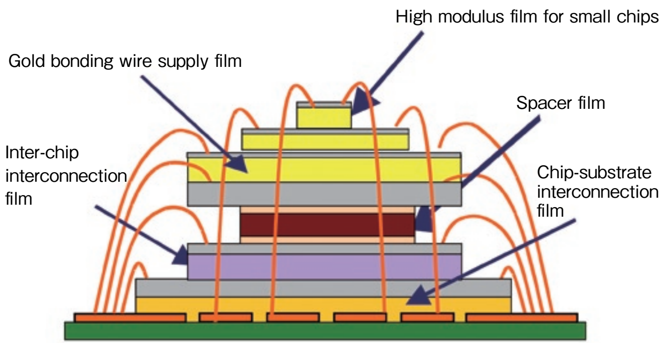

Figure 6 Application of Die-bonding Film in the Semiconductor Package

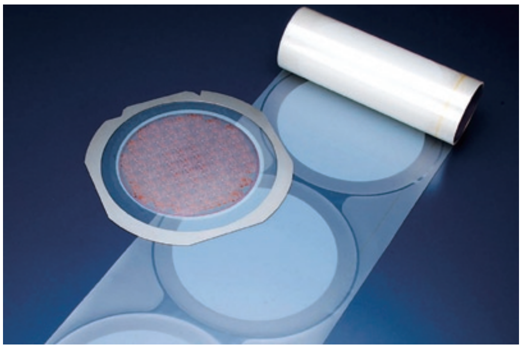
Figure 7 Appearance of Dicing/Die-bonding Double Functioning Tape

2.2 Future Development

More diversified DAF characteristics and technologies may be required according to changes in package structures and the growing demand for diversification in future:

1) Thick film (>50 μm) and thin film (<10 μm) production technology
2) Die bonding and dicing tape technology suitable for dicing processes
3) High heat dissipation (high thermal conductance) technology

The development of new fields includes:

1) Packages of new structures (e.g. TSV)
2) New bonding films for sensors, etc.

In addition to existing technologies, the development of new technologies for photosensitivity, etc. is required for achieving new fields. The development of various mounting materials, including adhesives for sensors, is also important.

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Technology Trends and Future History of Semiconductor Packaging Substrate Material

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The electronics industry has developed dramatically over the past half-century, primarily thanks to the semiconductor industry. Today, with increasing demand for smartphones and tablet computers, further high-volume, high speed, low power consumption LSIs and smaller/thinner semiconductor packages are strongly required. Meanwhile, the technical challenges involved in further fine pitch design shift the focus to assembly technology, which is considered the core technology required to achieve high-volume, high-integration semiconductor packages. Recently, the market for 3D semiconductor packages such as Package on Package (PoP), capable of stacking different IC packages such as memory and logic, is growing. Materials which have supported the development of such semiconductor packages include printed wiring board materials and semiconductor packaging materials. This report will introduce the history of printed wiring board materials and its technical trends in future.

1 Introduction

The electronics industry started with the commercialization of transistors in the 1950s, and has since grown into a ¥45 trillion market. Since personal computers (PCs) were introduced in the market in the late 1980s, the Internet and cell phones have become ubiquitous, and smartphones and tablet computers are recently growing markets. Electronic components and materials have supported the development of the electronics industry. Japanese semiconductors and electronic devices account for 20% of international markets, while the share of electronic components and materials exceeds 40%, reflecting the fact that the superiority of Japanese high-function materials is approved by the international community. The printed wiring board (PWB) is an electronic component incorporated in electronics, and comprising printed wiring board materials. Hitachi Chemical has developed advanced electronics technologies, and continuously marketed electronic materials that contribute to the electronic industry. This report presents the history, recent technical trends and future development of such printed wiring board materials.

2 What are Printed Wiring Board Materials?

The role of PWB is to transmit electric signals to electronic components such as semiconductor silicon chips incorporated into electronic equipment such as computers via copper circuits. **Figure 1** shows the hierarchical structure of silicon chips, semiconductor package substrates (“PKG substrates”), and PWB. The printed wiring board materials, including copper-clad laminate (core material), which is the base of PWB, photosensitive dry films for forming circuits and solder resist (**Figure 2**), compose the PKG substrate and PWB.

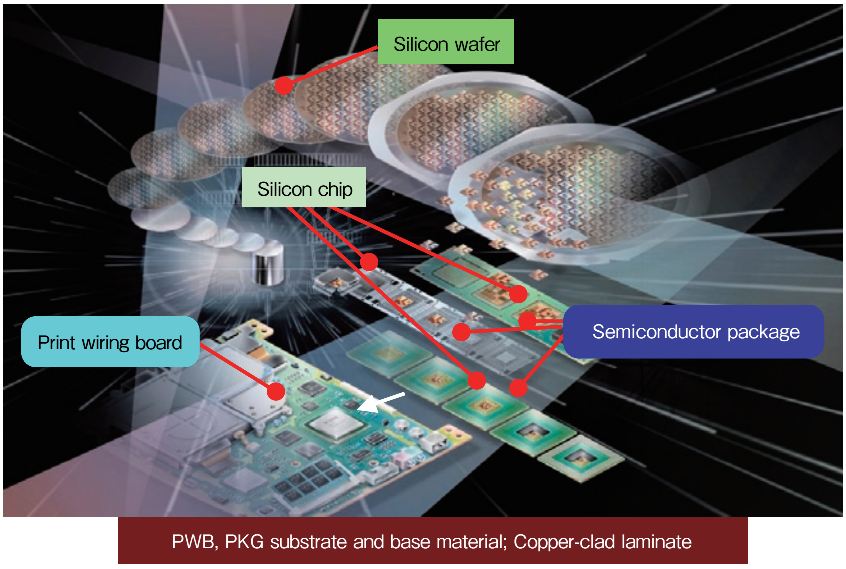

Figure 1 Hierarchical Structure of Silicon Chips, Semiconductor Package Substrates and Printed Wiring Boards

Copper-clad laminate

Photosensitive dry film

Solder resist

Figure 2 Printed Wiring Board Materials

3 Evolution of PWB

PWB was mainly developed in the United States during the 1950s. The etched foil method featuring chemical etching of copper foil on the substrate to formulate a circuit was mainly used for manufacturing PWB. In Japan, the first prototype paper phenol copper-clad laminate was manufactured in 1954, and about half a century later, technology has evolved into mass production of cutting-edge PKG substrates equipped with high Tg epoxy copper-clad laminates. These materials consist of a combination of a matrix layer of thermoset resin and basic material, and the structure is basically the same.

Circuits are wired onto these copper-clad laminates using a photosensitive dry film to produce PWB, which is classified according to the concept of "generation" depending on the materials and structures[1). **Table 1** lists the generations and associated materials. Due to evolution, PKG substrates are much denser than PWB, and a method known as a semi-additive process (SAP) is mainly used for formulating circuitry.

Table 1 PWB and PKG Substrate Generations, Respective Materials and Substrate Structures

Generation	1st	2nd	3rd	4th		
	1955～	1960～	1975～	1995～	1993～	1997～
Copper-clad laminate	FR-1	FR-4	FR-4	FR-4	FR-4, BT	High Tg FR-4 resin
Resin	Phenol	Epoxy			Multifunctional epoxy, BT	
Base material	Paper	Glass Cloth				
Printed wiring board	Single-sided	Double-sided	Multi-layer	Build-up	Multi-layer	Build-up
Wiring density (L/S)(μm)	250/250	200/200	200/200	100/100	30/30	15/15→10/10
Application	PWB				PKG substrate	

5th generation (2005 -); Component embedded PWB, 6th generation (2010 -); Electric and optic substrate

4 Evolution of Packaging Technology

Semiconductor PKGs for electronic equipment have grown with the development of packaging technologies required for higher density (with more pins), smaller and thinner chips. **Figure 3** shows the trends of semiconductor PKGs. A DIP (Dual In-line Package) was used for pin insertion packages, in which lead pins are inserted into the through-hole of the PWB and welded, by the first half of the 1970s. Subsequently, the QFP (Quad Flat Package), using solder reflow on the components mounted on the lands of the PWB, has become mainstream to meet the requirement for narrower pin pitch. In the meantime, FC-BGA (Flip Chip-Ball Grid Array) was proposed to deal with the increased number of pins for the logic semiconductor PKGs used in micro processing units (MPUs) as IO terminals and control signal terminals increased. This method, formulating solder ball at the back of PKG for area array packaging, has been widely used for major electronic equipment as a driving force for narrowing pitches and PKG miniaturization.

Ceramic PKG substrates were the main logic semiconductor PKG substrate, but the development of highly temperature-resistant copper-clad laminates and build-up wiring technology made organic PKG substrates available in around 1993 to meet the following three requirements:

1) Faster and higher clock frequencies
2) Fine-pitch wiring formation
3) Low costs

The low permittivity of organic materials facilitates the high-speed response in signal transmission. Accordingly, the MPU for computers is mounted on an organic FC-PKG substrate. Organic PKG substrates will continue to be developed as mainstream in future.

The recent rapid dissemination of smartphones and other mobile electronic terminals reflect the demand for faster, thinner and smaller products which are more compact and power-efficient. To meet these requirements, the SiP (System in a Package) technique is proposed, which integrates several semiconductor devices into a single PKG. A notable advance is achieved, particularly in 3D packing technique, for stacking different semiconductor PKGs and semiconductor chips.

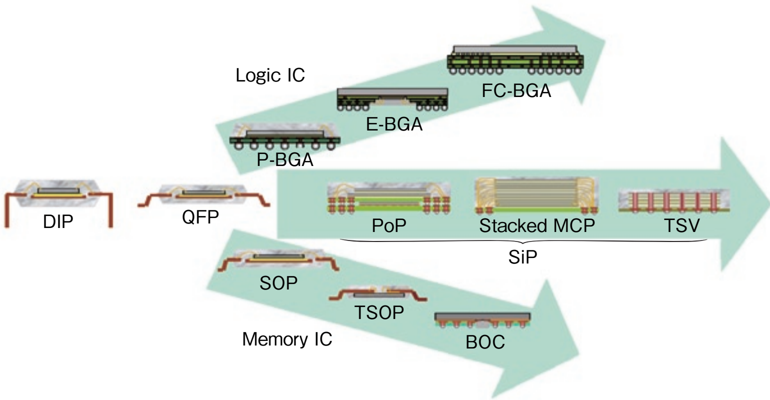

Figure 3 Trends of Semiconductor Packages

5 Issues and Development Trends of the FC-PKG Substrate

In addition to FC-BGA for MPUs, the FC-CSP (Chip Scale Package) is used for application processors. The FC-PKG substrate has some issues to be studied such as micro wiring formation, reductions in warp to meet the requirements for shrinking and multi-bump semiconductors.

5.1 Fine-Pitch Wiring Formation

The fine-pitch wring formation on PKG substrates is also an important issue to achieve high-speed processing of semiconductor chips. In the most advanced PKG substrate, Line/Space (L/S) = 10/10 μm was attained. The fine-pitch wiring forming method is a SAP method using plating technique. Here, a circuit is formed on the inter-layer materials (build-up materials) on the film, while laser-beam machining using CO_2, etc. is used for the inter-layer connection of materials. A micro through-hole of less than 80 μm is formulated between the layers, and copper plated to connect the upper and lower layers. In future, a pitch smaller than L/S = 5/5 μm (in 2015) and L/S = 3/3 μm (in 2017) are expected. To achieve these pitches, materials with good resolution, adhesion and development are required. **Figure 4** shows L/S = 5/5 μm dry film formation. Commercialization in this area has been steadily promoted.

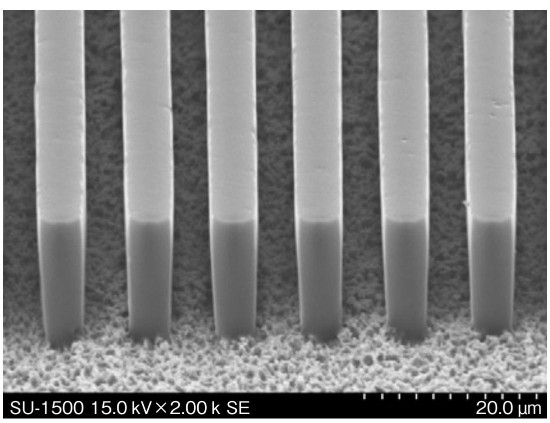

Figure 4 L/S=5/5 μm Dry Film Formation

5.2 Warp

The coefficient of thermal expansion (CTE) of silicon chips is 3 to 5 ppm/K, much lower than that of PKG substrates (16 to 19 ppm/K). The difference in their CTE is a big issue because of the production of a warp[2]. The semiconductor chip and PKG substrate are usually connected with a metal. Lead-free solder melts at 260 ˚C to connect the bump on the chip and the copper bump on the PKG. During the subsequent cooling process, however, the substrate shrinks more than the chip due to the difference in their CTE, causing a warp. If the warp of the PKG substrate is marked, the reliability of the secondary connection with the motherboard may be lost. To solve this problem, the CTE of the PKG substrate must be decreased, namely approximated to the CTE of the silicon chip. The PoP FC-CSP market will demand 0 ppm/K for the CTE of the base materials in 2015 to 2017.

6 Future Trends of PKG Substrates and Material Design Technology

As described in Section 4, 3D PKGs will be popular in future. Typical semiconductor PKGs using 3D packaging technology include PoP for stacking logic and memory ICs, MCP (stacked Multi-Chip Package) for staking multiple semiconductor chips, and CoC (Chip on Chip) for connecting two semiconductor chips directly.

A 3D packaging technology for stacking semiconductor chips, on which a through silicone via (TSV) is formulated, has been increasingly investigated for its potential as the next generation high-density packaging technique. As an example of these future technologies, a material design technology for PoP will be presented in this section.

6.1 PoP Trends and Technical Issues[3)]

The typical PoP stacks the memory PKG on the logic PKG, and is widely used for mobile information terminals such as smartphones. The flip-chip type FBGA (Fine-Pitch Ball Grid Array) is used for the lower PKG. The pitch will narrow and the PoP shrink in future.

Materials (core materials, build-up materials, solder resists) have become thinner according to the requirements for structural components, i.e. chips and PKG substrates, and narrower inter-PKG gaps[4)]. To meet these requirements, the over-mold type PKG structure shown in **Figure 5** was recently proposed[5)].

Changes in the PKG structure suggest issues to be tackled, such as increased PKG warp, connection reliability, reduced impact resistance, reflow resistance, and decreased cooling performance. The subsequent section introduces an example of reducing PKG warp and improving the reflow resistance of an over-mold type thin FBGA used in the lower PoP.

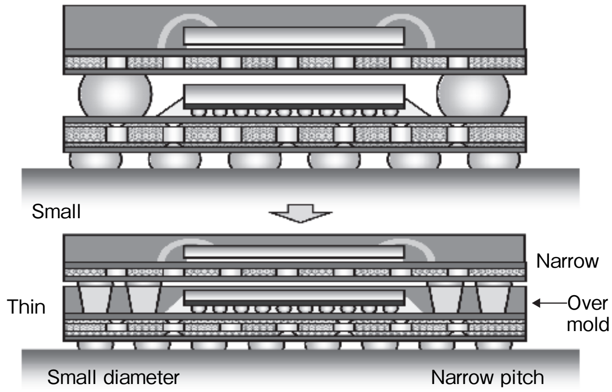

Figure 5 High-density 3D Semiconductor Package

6.2 Reducing PKG Warp and Improving Reflow Resistance

The FBGA is separated after semiconductor chips are mounted on the substrate and the substrate is encapsulated. **Figure 6** shows the external appearance of the PKG substrate with a typical post-encapsulation specification (pre-optimization). The substrate has already warped significantly at this stage, which may result in a fixed warp after separation, and significantly affect the conveyance and solder ball mounting processes.

Noting the core material and encapsulating material, which occupy a high percentage of volume in the substrate, the effect of material properties on the PKG warp was investigated using the analysis model in **Figure 7**.

First, the effect of properties of the core material on the PKG warp pre-encapsulation was analyzed, with the result shown in **Figure 8**. The PKG warp largely depends on the CTE of the core material compared with the modulus of elasticity, and lowering the core material CTE may reduce the warp.

Second, the effect of properties of the encapsulating material on the PKG warp post-encapsulation was analyzed. **Figure 9** shows the result. The PKG warp after encapsulation largely depends on the CTE of the encapsulating material compared with the modulus of elasticity, and unlike the core material, CTE optimization is required. For example, about 10 ppm/K is the optimum value in **Figure 9**.

To verify these analytical results, the warp and reflow resistance of the PKG pre- and post-encapsulation were evaluated by combining core and encapsulating materials with different CTEs. The result is shown in **Figure 10** and **Table 2**, showing good

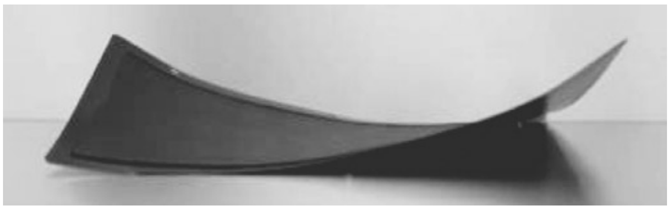

Figure 6 Example of thin FBGA post-encapsulation (pre-optimization)
Package size: 14×14×0.51 mm, Chip size: 8×8×0.12 mm
Substrate thickness PKG: 270 μm,
Thickness of core substrate: 100 μm,
Thickness of encapsulation: 240 μm

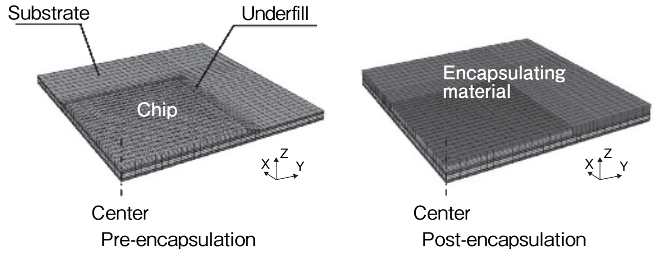

Figure 7 Package Warpage Analysis Model

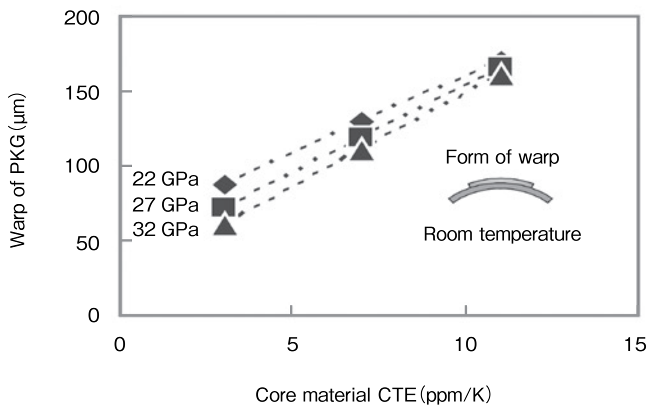

Figure 8 Influence of Substrate Material Property on Package Warpage

agreement between the analytical and experimental results. However, the pre- and post-encapsulation warps were not observed in material system No. 4, consisting of a core material with a small CTE and an encapsulating material with an optimized CTE respectively. **Figure 11** shows an example of post-encapsulation warp (after optimization), which was largely reduced compared with that of pre-optimization (**Figure 6**).

To analyze the high-temperature reflow resistance, encapsulating materials with low moisture absorption and effective adhesion (Nos. 3 and 4) suppressed the interfacial delamination, and improved reflow resistance.

Based on these results, combining the core material with a low CTE and encapsulating material with high adhesion and optimized CTE could reduce the pre- and post-encapsulation PKG warp, and improve the reflow resistance.

Structural components and materials other than the mentioned core and encapsulating materials (build-up materials, solder resist, underfill materials) have been analyzed as required to investigate the suitability of these components and materials in terms of the warp on PKG and reliability.

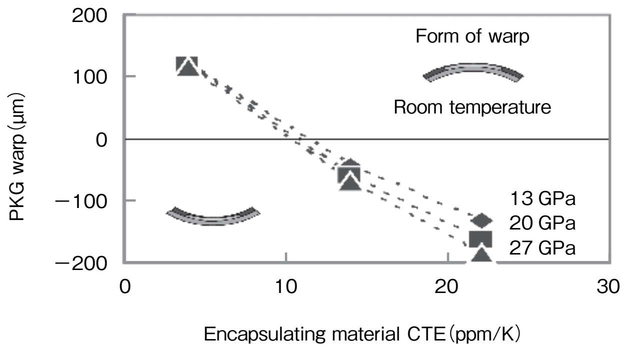

Figure 9 Influence of Encapsulation Material Property on Package Warpage

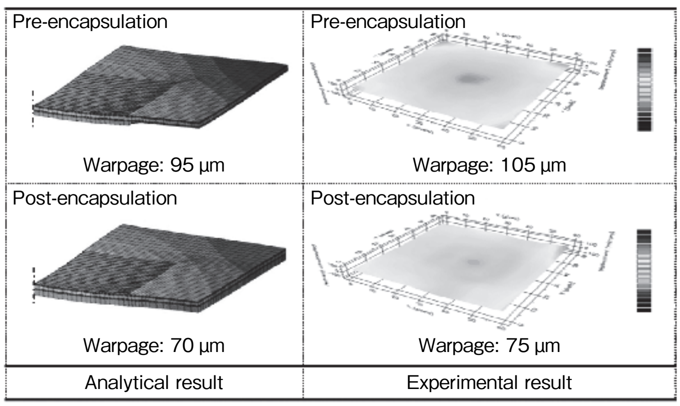

Figure 10 Comparison of Package Warpage Analysis and Experimental Results

Table 2 Package Evaluation Result

Material system		No. 1	No. 2	No. 3	No. 4
Core material	CTE (ppm/K)	9	3	3	3
Encapsulating material	CTE (ppm/K)	20	20	14	7
	Moisture absorptivity* (%)	0.5	0.5	0.3	0.2
	Adhesion with chips* (MPa)	0.1	0.1	0.9	1.0
PKG warp (μm)	Pre-encapsulation	180	105	105	105
	Post-encapsulation	85	135	120	75
Reflow resistance (defect rate)	Moisture absorption level 3	0/6	0/6	0/6	0/6
	Moisture absorption level 2	1/6	4/6	0/6	0/6
	Moisture absorption level 1	6/6	6/6	0/6	0/6

*Moisture absorption level 1

7 Changes in PKG Material Improvement Technologies and Unlimited Advance in Technology

In addition to improvements in epoxy resin for increasing Tg and decreasing the CTE in PKG substrates, various methods, including increases in the volume of inorganic filler to substrate materials have been discussed and their effectiveness presented[6]. The CTE lower than Tg is 80 ppm/K in the current epoxy resin. Submicron (about 500 nm) silica particles with smaller CTE (0.5 ppm/K) are generally processed with surface treatment by silane[7]. To further decrease the CTE when high-density filling of silica particles reaches the limit, a technology for the molecular design of resin with a higher-order structure has been applied, making 2.8 ppm/K available. To decrease the CTE to below 0 ppm/K, the molecular design of organic materials and a means of controlling silica filler volume are important.

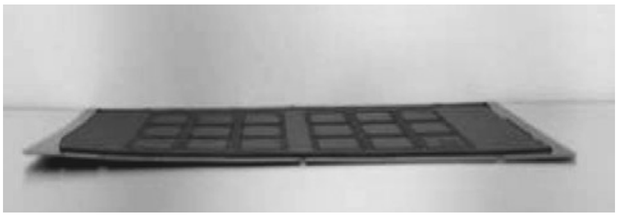

Figure 11 Example of Thin FBGA Post-encapsulation (post-optimization)

3D packaging technology is expected to be widely used in future in various areas such as mobile information terminals as electronics advance further. Combined with MEMS and optical packaging technology, system integration in various areas will be accelerated.

Packaging technology is key to achieving these targets, and the packaging materials supporting such technology must meet diversified and complex requirements. This means ever-greater importance of design and development encompassing multi-functionality.

8 Future Vision Focusing on Business 20 Years Out

Electronics technology will continue to progress as the base technology in various industries, including electronic equipment, automobile, medical equipment and robot. Its application and the form of end products will drastically change. This report traced the history of material technology over the past half-century. While end products have changed from televisions to computers and smartphones, material technology used for PWB and PKG substrates has developed based on the resin technology for matrix layers. Looking ahead two decades, the development of materials is still based on chemistry, and the following technologies may be required for developing materials:

1) Polymer synthesis technology based on molecular design
2) Interface control technology in molecular units (nanoparticles)
3) Bonding technology for organic, inorganic and metal materials, and hybrid materials made of different types of materials
4) Development of signal transmission technology (combination of electric and optical technologies)
5) Super-fine photosensitivity technology

In addition, with a lineup of packaging materials, Hitachi Chemical will strive to improve its material system solution (MSS) (**Figure 12**) that synchronizes the properties of materials, structural design, packaging and reliability evaluation by developing materials to create highly functional packaging materials and contribute to the development of society.

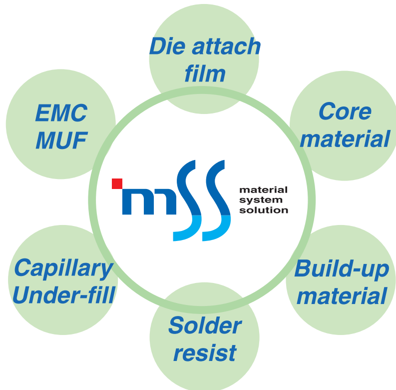

Figure 12 MSS of Package Substrate and Package Materials

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Printed Wiring Board Supporting Cloud Computing

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Cloud Computing became a familiar concept within our industry and personal use. And this gives us great convenience. The systems on which Cloud Computing is based include a network, server and storage, for which more high-speed signals must be used to send more data in a short time. The Printed Wiring Board fixes and connects LSIs and operates important functions for high-speed operation. This paper introduces the situation of the Printed Wiring Board for high-speed signals and future prospects.

The Multi Wiring Board (MWB®) is one of our products and suited for high-speed signals, because of its superior signal loss and signal delay properties. As a specific example to achieve high-speed operation, this paper introduces “High-Speed Signal MWB” and “Hybrid MWB” for networks and servers and an “Optical Waveguide” development for speed exceeding 25 Gbps, for which transmission by electrical signals is difficult.

1 Cloud Computing

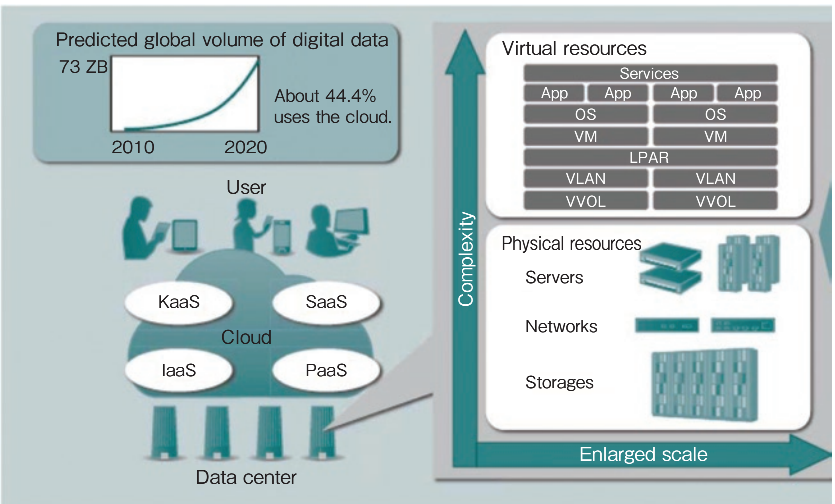
Unlike conventional independent computer systems, cloud computing proposed in 2006 connected multiple computers via a network like the Internet to offer services. Cloud computing users can obtain the necessary information or service any time without being conscious of computers. At the same time, service providers can expand or reduce their systems as required regardless of location. Its high cost performance has seen cloud computing rapidly gain popularity in recent years.

Cloud computing allows corporate users to share documents and data, and medical doctors to make immediate confirmation of cases, anytime and anywhere, through an information database at medical institutions. For private users, services include real-time downloads of news, music and video to their smartphones and tablets.

The data management facility in cloud computing is called the data center, which comprises servers for data processing, data storage, and networks for connecting the data center to the outside network.

As the cloud computing is used widely, the volume of operating data is increasing, and it is predicted that the total volume of digital data worldwide will increase to more than ten times and reach 73 ZB (Z = 10^{21}) by 2020[1]. High-speed signals have been required for servers, storages, and networks to deliver as much data as possible in a short time.

Printed wiring boards, used for servers, storages and networks, incorporate LSIs and other electronic components and transmits signals. Their development is therefore critical for high-speed signals, particularly servers at the center of data manipulation. We have set a signal speed target from the current 5 - 10 Gbps to 25 Gbps in 2015.



Note: Abbreviations ZB (zetta bytes), KaaS (Knowledge as a Service), SaaS (Software as a Service), PaaS (Platform as a Service), IaaS (Infrastructure as a Service), App (Application), OS (Operating System), VM (Virtual Machine), LPAR (Logical Partition), VLAN (Virtual Local Area Network), VVOL (Virtual Volume)

Figure 1 A Large-scale Cloud Data Center Operation and the Global Volume of Digital Data [1]

2 Multi Wiring Board (MWB®)

The Multi Wiring Board (MWB®) is one of the printed wiring board products of Hitachi Chemical, with a unique structure, in which wiring is formulated with insulated discrete copper wires attached to the insulating board. Conventional printed wiring boards makes circuits by selective etching of copper foil with chemical agents. **Figure 2** shows the surface and cross-sectional photos of the wiring layer on the MWB. Compared with conventional printed wiring boards, the MWB using copper wires with smooth surface has good high frequency properties with small propagation loss of high frequency signals. **Figure 3** shows a comparison of the propagation loss of a conventional multi layer wiring board and MWB. Because of using insulated wires and cross wiring, MWB has high insulation reliability and high density wiring.

Production of the MWB started in 1973, since which time the MWB has been used for supercomputers, LSI inspection systems, aerospace and various other industries and supported industrial development.

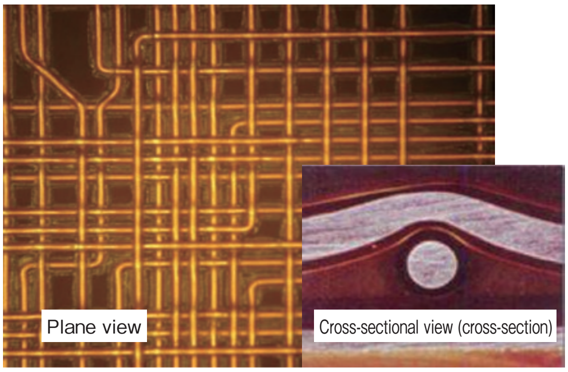


Figure 2 Wiring Layer for Multi Wiring Board

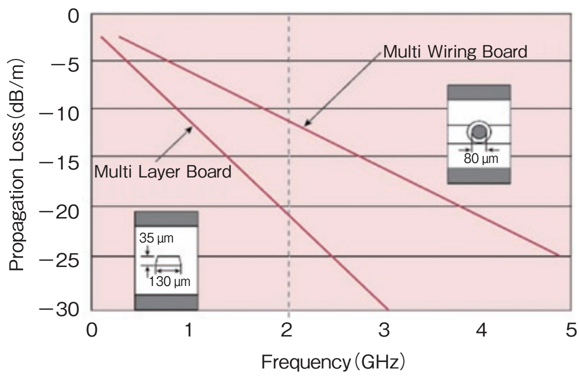
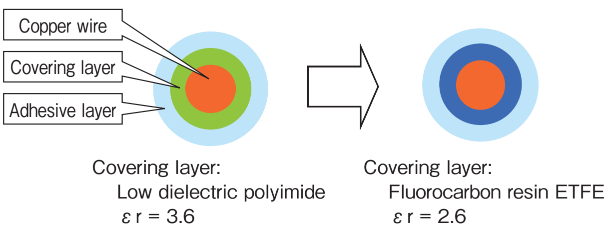


Figure 3 Comparison of Propagation Loss

3 MWB for High-Speed Signals (under development)

We set 25 Gbps as the target internal signal speed for next-generation servers by 2015 to respond effectively to a required communication speed of 100 Gbps, a hundred times faster than now. A printed wiring board with signal propagation loss of less than 0.6 dB/inch at 12.5 GHz is required to achieve this target. The target is also considered to represent the limit of electric signals in practical terms, since more electric energy turns to electromagnetic waves for attenuation with increasing frequency. **Figure 4** shows the cross-sectional structures of wires mounted on the MWB for high-speed signal transmission designed for achieving the target, and **Figure 5** shows the simulation results of signal propagation loss.

We have developed an MWB with configuration to improve signal propagation loss using ETFE featuring effective high-frequency properties as the insulated covering material of wires, and keeping high density wiring. The product will be marketed by 2014; targeting application as a back board with the longest transmission distance among the components of next-generation servers.



Note: Abbreviation: ETFE (tetrafluoroethylene and ethylene copolymer)

Figure 4 Improvement in Electrical Performance by Changing the Covering Material

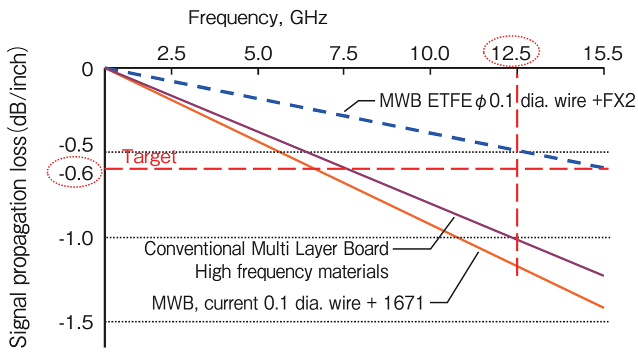


Figure 5 Signal Propagation Loss Simulation by Current and ETFE Wires

4 Hybrid MWB

Despite its effective electrical properties, MWB has relatively low productivity, since the insulated copper wires need to be attached to the insulating plate one by one using an NC machine. To improve productivity, we developed the Hybrid MWB Type 2, which comprises a conventional wiring board for general wiring and MWB for wiring high-speed signals. We also developed the Hybrid MWB Type 3, for which a fine-pitch circuit board is mounted on the MWB to achieve fine pitch assembly of surface mounted components. **Figure 6** shows example cross-sectional structures of Hybrid MWB Type 2 and Type 3.

Hybrid MWB Type 2 and Type 3 have already been mass produced in 2012, and applied to semiconductor inspection systems, servers and network equipment.

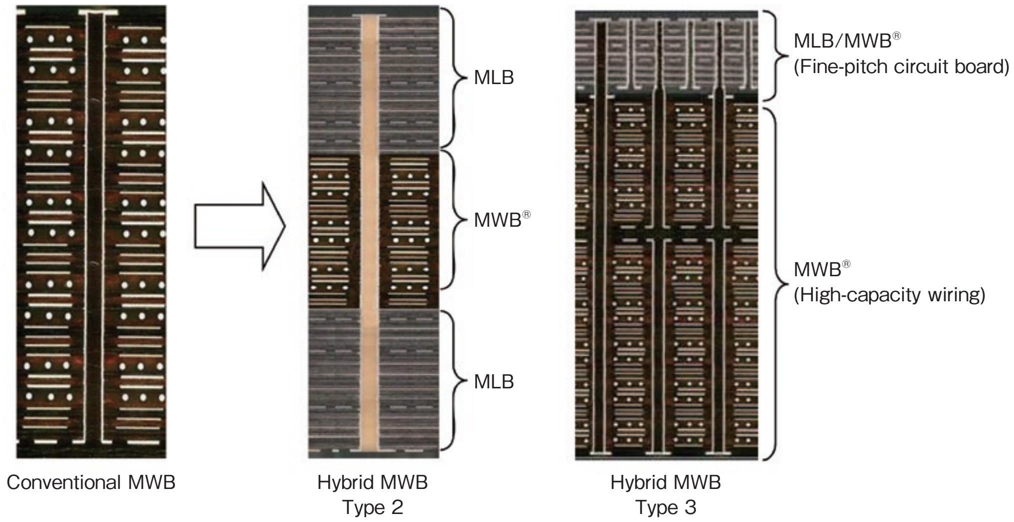


Figure 6 Hybrid MWB Cross Sections (Example)

5 Coaxial MWB, Optical Wiring Board (under development)

25 Gpbs is considered to be the limit of practically feasible electric signals due to propagation loss. To achieve signal speed exceeding 25 Gbps, we are developing Coaxial MWB using coaxial wires for electric signals and Optical Wiring Board using on-board optical waveguide for optical signals. **Figure 7** shows the relationship between signal speed and wiring capacity, and **Figure 8** shows an example of optical waveguide substrate under development. These products and technologies are under development to be used for next-generation cloud computing equipment such as servers and networks after 2016.

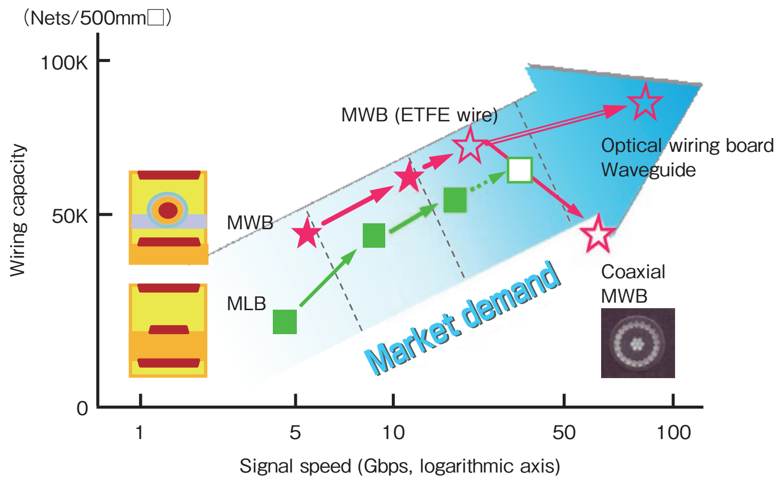


Figure 7 Improvement in Signal Speed and Wiring Capacity for Each Printed Wiring Board

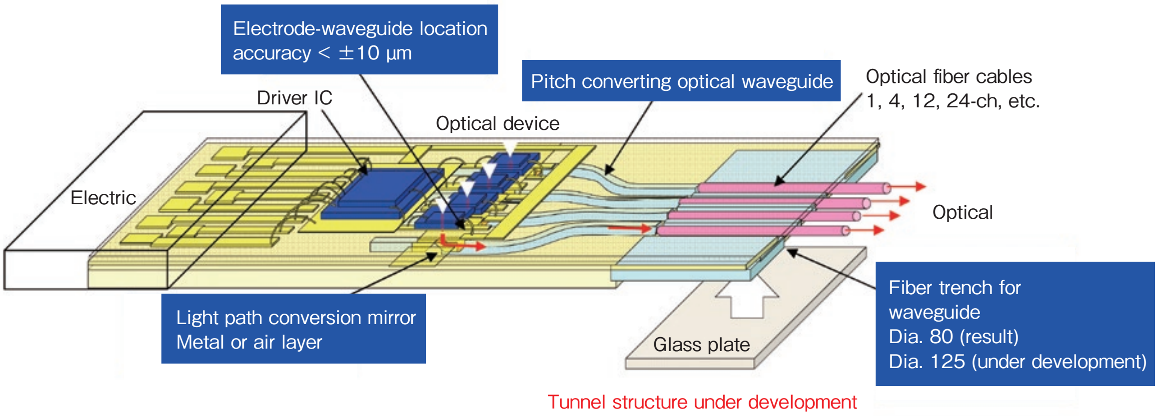


Figure 8 Developed Optical Waveguide Substrate Example

6 Conclusion

With the progress of cloud computing, we are in an age when big sized data can be used anytime and anywhere. The evolution of cloud computing is expected to accelerate in future, and the requirement for high speed signals in printed wiring board also accelerate. Hitachi Chemical will lead these movements by developing innovative technology and products based on MWB to meet customers' expectations.

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Nanomaterials

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Nanotechnologies, major fields of which include Nano manufacturing process, Nanomaterials, Nanodevices, and Nanomeasurement, are expected to become fundamental technologies for manufacturing in a wide range of industries. In this paper, Cu ink for Printed Electronics is introduced as a typical Nanomaterial with which Hitachi Chemical is familiar. The scope also includes our efforts to attain the international standard and cooperate with partners to overcome inconsistencies in advanced technologies. We, Hitachi Chemical, will apply those advanced technologies to applications in the near future, expanding next generation ICT (Information and Communication Technology) and other industries.

1 Introduction

R&D of nanotechnology has been accelerated worldwide since the U.S. announced its National Nanotechnology Initiative strategic plan in 2000. In Europe, the EU increased its budget for nanotechnology in the 6th R&D Program Framework, while in Asia, South Korea set up a 10-year master plan for nanotechnology in 2001. Japan has taken the lead in basic technology, for example, the discovery of Carbon NanoTubes in 1991, and producing an Atomic Force Microscope and Magnetoresistive Random Access Memory (MRAM) by the 10-year Atom Technology Project launched in 1992[1)].

Nanotechnology can be roughly classified into three categories. They are nano manufacturing processes, nanomaterials and nanodevices for new features of high performance, and nanomeasurement (**Table 1**). Hitachi Chemical deals with all of these technologies and nanomaterials in particular. Focusing on nanomaterials, this paper reports typical applications, general international standardization trends and future prospects.

Table 1 Technology Map of Nanotechnologies

Wealthy society	Safe and secure society	Sustainable society	Economical production
Energy, Information and Communication Technology, Environment, Life Science			

Nano manufacturing process (Precision manufacturing)	Nanoobject (Nanodevice, Nanomaterial)	Nanomeasurement (Measurement and evaluation equipment)
Nanoimprint Nanoetching Fine pitch inkjet	Nanodevice Quantum dot, Photonic crystal, Magnetoresistive Random Access Memory MRAM (Spintronics)	Electron microscope, Atomic Force Microscope, Radiation measurement
Self assembly Thin film technology Nanocoating	Nanomaterial Carbon nanotube, Graphene, Fullerene, Nanoparticle, Nanofiber, Nanowire, Nanocomposite, Nanocompound	Molecular dynamics, ab-initio method

Source: Created based on a Technology Map of Nanotechnologies 2009, METI

2 Nanomaterials, Applied Technologies and Products

The maximum size at least one direction of nanomaterial is defined as 100 nm in size in at least one direction[2), 3), 4), 5)]. A carbon nanotube (CNT) is a typical nanomaterial, comprising a hollow nanofiber formulated in the six-membered ring network composed of carbon atoms and featuring e.g. high mechanical strength, low electrical resistance and high thermal conductivity. Commercialization of multi-walled CNTs is underway for specific applications. Single-walled CNTs (SWCNTs) are in the basic study phase, and separation and refinement technologies have recently been reported.

The copper-clad laminates with low CTE (Coefficient of Thermal Expansion) for semiconductor package substrate are typical applications of nanomaterials commercialized by Hitachi Chemical. Copper-clad laminates are manufactured using nanosilica as fillers. The material is slurried after surface treatment with nanocoat technology, dispersed in epoxy resin varnish and sent to a common coating process[6)]. Nanomaterials such as CNTs, plate-like nanoparticles, nanofilms, and the conductive component of Cu ink for printed electronics (PE) are currently under R&D. CNTs and Cu ink will be described later in this report.

Hitachi Chemical has participated in the Nanotechnology Program, Innovative Material Creation Program, Nanotechnology and Advanced Material Commercialization Program, and Quantity Synthesis of SWNCT and R&D of Transparent Electrodes launched by the New Energy and Industrial Technology Development Organization (NEDO). Our CNTs synthesized using the Chemical Vapor Deposition (CVD) method are characterized by millimeter-long length and high purity exceeding 98% (**Figure 1**, **Table 2**)[7)]. Its application as an additive for functionalization is expected, in addition to the use for transparent electrodes. In Cu ink, a dense conductor layer with low volume resistivity of 2 to 4 μΩ･cm, equivalent to electroless plating wiring, can be formulated in gas-phase treatment under atmospheric pressure at a temperatures below 190 ˚C using a Cu compound with an average particle diameter of 70 nm as the conductive component (**Table 3**). Because no dispersant is used, the reactive conditioning temperature required to remove the dispersant can be kept low, and gas-phase treatment eliminates the liquid control and waste treatment processes[8), 9), 10), 11)]. Accordingly, the printing method using Cu ink is characterized by fewer processes and resources, and a more compact wiring space (**Figure 2**). PE meets the needs to break away from traditional technologies such as vacuum and photolithography processes, as well as thin semiconductor packaging and wiring on curved planes. Hitachi Chemical has participated in basic technology development projects to promote the commercialization of *Manufacturing technology for printed devices* and *flexible device technology* managed by the Japan Advanced Printed Electronics Technology Research Association, established in 2011, while striving to market PE for applications on next-generation information and communication equipment.

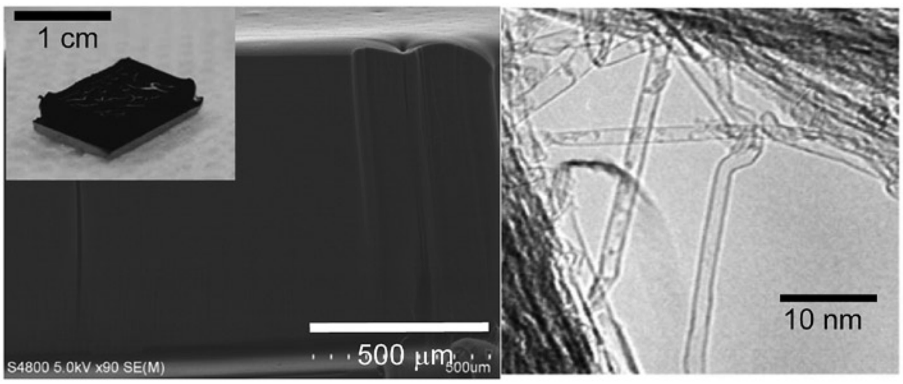
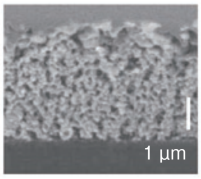
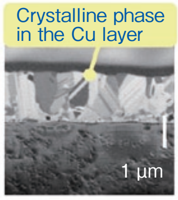
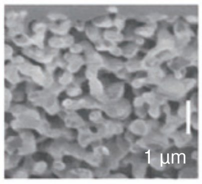


Figure 1 Electron Micrograph of CNT

Table 2 Comparison of CNT Properties by Various Synthetic Methods

Item	CVD method (Hitachi Chemical)	HiPCO method	CoMoCat method
Diameter	2-7 nm	1-2 nm	≒1 nm
Length	1-5 mm	2-3 μm	2-3 μm
Catalyst residue	＜0.1%	30%	10-20%
Purity	≧99.8%	≦70%	≦10%
Raw material	Hydro Carbon	Carbon monoxide	Carbon monoxide

Table 3 Dependence of the Reactive Conditions on the Cu Layer Structure

	Gas-phase treatment under reducing pressure (6 μΩ･cm)	Gas-phase treatment under atmospheric pressure (3 μΩ･cm)	Liquid-phase treatment under atmospheric pressure (100 μΩ･cm)
After reactive conditioning			
Cross-sectional SIM image			

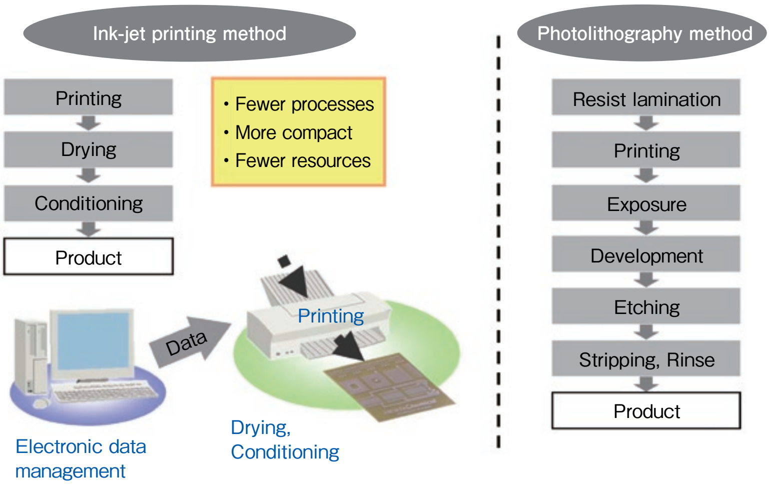


Figure 2 Comparison of the Manufacturing Process between Ink-jet Printing and Photolithography

3 Trends of International Standardization and Approaches of Hitachi Chemical

Prevention of inconsistencies, overlapped work, and uniformity of result tables, including terminology and evaluation methods, are part of the purposes for international standardization. Countries are striving to take the lead in standardization to gain competitive advantages. For the international standardization of nanotechnology, the International Organization for Standardization (ISO) launched a technical committee TC229 in 2005, while the Japanese Industrial Standards Committee (JISC) established the Japan National Committee for International Standardization of Nanotechnology[12]. The role of Japan in standardization is to characterize measurement and the safety of CNTs in particular. For the international standardization of PE, the International Electrotechnical Commission (IEC) established a technical committee TC119 in 2011, and Japan is expected to be active as the organizer of the material working group. JISC set up a PE International Standardization ad hoc Committee in the Japan Electronics and Information Technology Industries Association, which is currently negotiating with the U.S.-based IPC (former Institute for Printed Circuits) for smooth standardization. Hitachi Chemical has actively participated in these international standardization projects.

4 Future Prospects

Hitachi Chemical has focused on four business domains: information and communication, and display, environment and energy, automobile, and life science. The information and communication, and display domain includes not only functionalization and upgrading of conventional technologies, but also R&D of PE, as explained in Section 2, and the promotion of organic electronics with technological trends such as cloud computing, Internet of Things (IoT), big data and electronics. As electronic

devices transform, new business opportunities may open up. In the environment and energy domain, it seems to be the time for us to enter new businesses because the large-scale development initiatives involving renewable energy, and innovation for building the next generation society such as smart cities that improve energy efficiency, are underway. Nevertheless, such clear technological trends accelerate global competition, the demand for materials remains considerable. Competing power comes of differentiated capabilities for enhancing customer value is important, therefore, combining and optimizing technologies alone will be insufficient to maintain an industry leading position. Nanomaterials are useful for differentiation, but nano-level structural control may be equally critical. Technology to produce nanofilms by stacking components with opposite electric charges alternately, and the polymer brush that grafts functional groups are included in this category. Open innovation is effective to make these fundamental technologies available in the short-term. Our objectives are to bring up unique technologies that differentiate our products from others by establishing good relationship with our partners through society activities and technology exchanges.

5 Conclusion

Nanotechnology that creates atomic-level functionality deviates from the progress of existing technologies, which may hinder its commercialization. Cooperation with partners for added value is therefore critical and why we implement international standardization to share globalized technologies. We are in an era where good unique technology alone does not ensure success. This report presented the features of our Cu ink products for PE as an example of nanotechnology application. We believe such cutting-edge technologies exceed conventional technologies, and will be commonly used.

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Hitachi Chemical
Working On Wonders

Resin Technology

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New Business Development Headquarters
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Social Infrastructure-related Materials Development Center

Since the establishment of our business a century ago, resin technology comprising various kinds of resin has been used for many products. For products with high thermal conductivity and insulation, we have developed new epoxy resin with higher order structures and higher thermal conductivity. Moreover, thanks to our new analytical technique, we have clarified the thermally conductive property by revealing the interaction between the filler and resin, which has enabled us to design advanced products. Furthermore, the development of new analytical techniques, such as the detection of a minute amounts of accelerator in the thermosetting composite and analysis of the polymerization initiation mechanism of the UV curable resin system have also supported new product design. Recently, we have been studying biomass resin technology, including lignin resin for thermosetting materials, and silk fibroin for cosmetic applications. These resin technologies are expected to help develop our new business, providing new resin materials and new analytical techniques for the new era in future.

1 Introduction

We started research work into insulation varnish for Japan-made motors in a corner of the Hitachi Works of Hitachi Ltd., the birthplace of our business, a century ago (1912), which subsequently became the root of our resin technology.

Our research into resin material, initially focused on insulation varnish, has eventually progressed to include phenolic and epoxy resins used as materials for molding, printed circuit boards and encapsulation. The “molding” technology was the springboard for multiple new businesses and technologies, including molding material technology applicable to automobiles, FRP businesses and expanded polystyrene. Moreover, the functional capability of the “coating” insulation varnish was a catalyst for coating resin product lines and the acrylic resin technology eventually developed as a result became the cornerstone for research into photosensitive resins; used in photosensitive films for printed circuit boards. Conversely, the scope of the function to “adhere” has spread to include the development of alkyl phenolic and acrylic resins for bonding agents and adhesive compounds. Further, “coating” technology, an extension of photosensitive film coating technology, has come to materialize in the form of protective film for electronic equipment, electro-conductive anisotropic film for display terminals and optical waveguides, etc.

As just described, our history includes the use of various resins for our products. We believe the potential of our accumulated technologies in thermoset, photo-curable and thermoplastic resins will be invaluable in helping us expand our business into new fields in future.

2 Development of Resin Technology

Thanks to the following features, we introduce our current ventures involving the development of resin technology in new fields:

2.1 Control resin structure

The concept of high thermal conductive resin, which incorporates a self-aligning mesogenic structure we developed, is shown in **Figure 1**[1]. A high-order structure can be easily formed within this resin, which contains numerous highly ordered crystals at micro level. Furthermore, via a thermosetting reaction, this resin solidifies and stabilizes, randomly oriented at macro level and with isotropic thermal conductivity. Currently, attempts are being made to deploy newly developed epoxy resin for applications in electric/electronic devices in hybrid cars and LED lighting parts. However, high product performance cannot be accomplished simply by replacing existing resin with a new alternative. First of all, we must understand the structure of the resin itself. Moreover, it is also important to clarify the actual structural state in a product incorporating such resin and its effectiveness in boosting product performance. Accordingly, once the correlations between the resin structure and its characteristics are established, this paves the way for optimum product design and swift on-target improvement.

For example, although mixing a large amount of high heat conductive inorganic fillers requires a material using the resin with high heat dissipation and high insulation properties, as shown in **Figure 1**, these properties vary significantly subject to the selection of fillers, its dispersion or differences in the thermo-setting process.

Figure 2 shows the XRD (x-ray diffraction) analysis of mesogenic epoxy resin/ hexagonal boron nitride (hBN) crystal with high thermal conductivity (omnidirectionally 40 W/ m · K or higher) and insulation property (60 kV/mm or higher) [4].

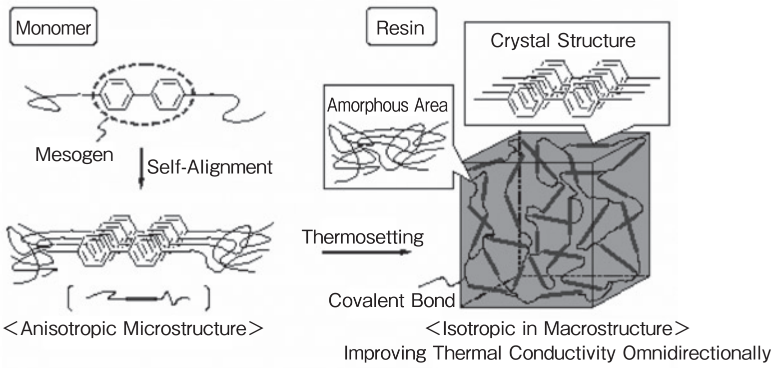


Figure 1 Concept of Thermal Conductive Epoxy Resin

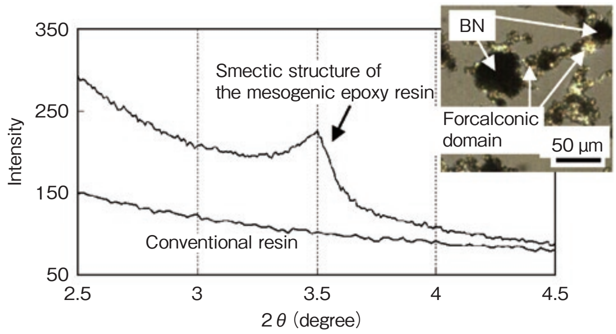


Figure 2 XRD Analysis of the Mesogenic Epoxy Resin / BN Filler Composite with High Thermal Conductivity

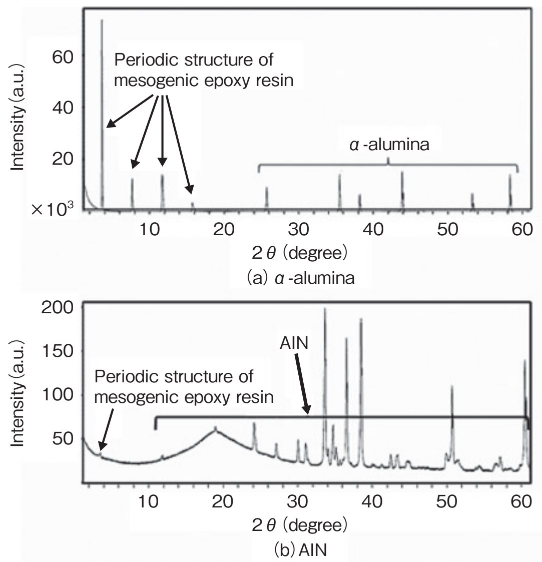


Figure 3 XRD Patterns of the Thin Mesogenic Epoxy Resin Layers Cured on (a) α-alumina and (b) AlN Plates

Observation of the high-order structure in the composite containing mesogenic epoxy resin is not possible using a polarization microscope or AFM due to the disturbance caused by added fillers. However, XRD analysis showed a peak of around 2θ = 3.5°; indicating a periodic structure and suggesting the formation of a high-order (smectic) structure in the resin. Furthermore, with the addition of fillers, its measured thermal conductivity of 0.45 W/m · K exceeded the 0.33 W/m · K of resin without fillers. **Figure 3** shows XRD analysis of the thin mesogenic epoxy resin layer cured on α-alumina and AlN plates [5]. α-Almina (a) showed strong high-order diffraction peaks due to the 2.2 nm pitch periodic structure; conversely, AlN (b) showed weak regularity of the periodic structure, suggesting AlN has difficulty in aligning mesogenic epoxy resin. In conclusion, it was clarified that alignment of mesogenic epoxy resin varies widely depending on the fillers used. By optimally exploiting analytical technology, the degree of interactions between epoxy resin and fillers can be converted to actual data. This allows us to directly access important information, which can then be utilized for product development, including the selective property of fillers and need for surface treatment.

2.2 Analytical Techniques Supporting Resin Technology

To develop a new resin, as mentioned above, as well as material composition, the type of functional groups, volume/amount, molecular weight and selection of modified materials, the application of resin technology backed by high level analytical technique is absolutely essential. We have been constantly engaged in developing new analytical techniques, which have boosted the progress of our new product development.

Here is an analytical example of UV curable resin. UV curable resin is used in a broad range of applications, including coating material, photosensitive film, OCA (Optical Clear Adhesive) for display, etc. **Figures 4** and **5**, and **Table 1** show the results of investigations into the initiation mechanism of polymerization by terminal group analysis using MALDI-TOFMS in the photopolymer systems of acrylic acid-2- phenoxyethyl acrylate (PEA), using highly sensitive oxime ester compound (OXIME-01) as a photo-polymerization initiator[6]. New findings confirmed that methanol,

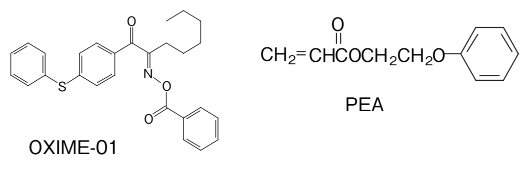


Figure 4 Structural Form of OXIME-01 and PEA

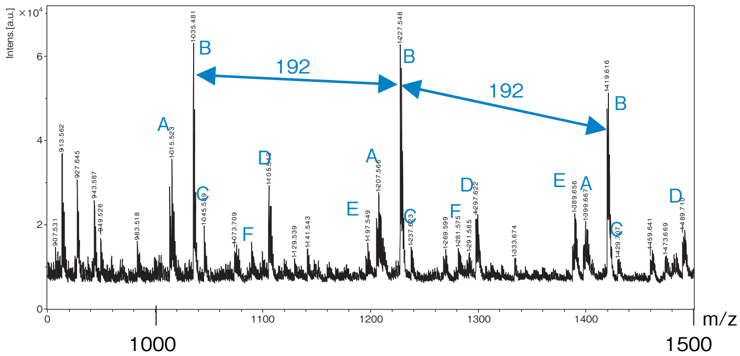
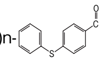
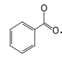
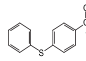
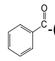


Figure 5 MALDI-TOFMS Spectra of PPEA

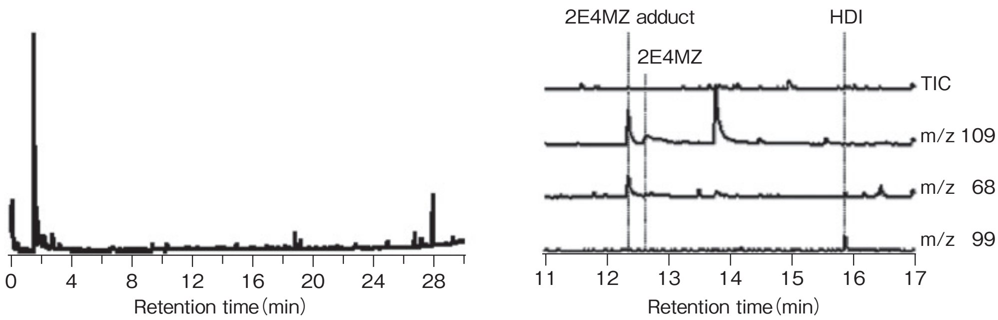
Table 1 Results of Terminal Group Analysis for OXIME-01

Peak group	Molecular Ion Peak	
	General formula	Assigned
A	32+192n	HO-CH_2-(PEA)n-H
B	244+192n	HO-CH_2-(PEA)n-
C	62+192n	HO-CH_2-(PEA)n-CH_2-OH
D	122+192n	-(PEA)n-H
E	214+192n	-(PEA)n-H
F	106+192n	-(PEA)n-H

a solvent, functioned as a chain transfer agent, that methylol radicals become initiation species, and also confirm the existence of benzoyloxy and benzoyl radicals. These findings clarified the magnitude of the impact on the reaction rate of various radicals and helped us when designing new products.

Also, developing a standout analytical technique which is capable in itself of manifesting our technologies at a high level, is effective in preventing unwarrantable counterfeit goods of our products, the development of which required strenuous efforts.

The example shown in **Figure 6** illustrates the analytical results of curing accelerators and modifiers used in a curing formulation for epoxy resin mounted on a printed circuit board and identified in the final cured product[7]. Since the amount of curing accelerator used is fractional and ends up included in the cured product, its type and content cannot be easily analyzed using existing analytical methods. However, detection and identification of imidazol curing accelerator was enabled using dynamic head space gas chromatography (DHSGC-MS). Such advanced analytical technique can help us prove illegal patent infringements by third party marketed products, which will eventually help enhance the competitive edge of our products.



(a) Total ion chromatogram (b) Total ion chromatogram and mass chromatograms

Figure 6 DHSGC-MS Results of Copper-clad Laminate Degraded at 300 ℃/15 min

3 Biomass Resin

Finally, we would like to introduce our approach toward biomass resin.

Resins, many of which are simply called “resin”, originally came from natural resources, but many today also come from petroleum. The trend to reduce dependence on petroleum and carbon dioxide emissions is intensifying, although the urgency to conserve fossil fuels has eased, with depleting petroleum resources in mind. Consequently, research into biomass has been flourishing year after year.

Polylactic acid, the raw material of which is lactic acid produced from carbohydrate by fermentation, and bio-polyethylene, made from bio ethanol, are well-known resins of plant origin. The starting raw materials for both polymers are edible plants such as corn, a natural product significantly affected by weather conditions.

We turned our attention to lignin, which constitutes about 25% of the total wood component. Lignin can be classed as a natural polyphenolic resin, to which we considered our thermoset resin technology, the basis of our technologies, to be applicable. **Figure 7** shows the evaluation results of the property of molding resin that used lignin as a curing agent of epoxy resin; the lignin was solvent soluble and obtained from steam explosion pretreatment. By utilizing the natural network inside lignin, it is clear that

lignin-based molded products show higher flexural strength and elastic modulus than those of phenol novolac resins[8].

Previously, approaches made to enhance the performance of resins basically focused on manipulating resin composition and the molecular structure and weight. In the case of biomass resin material such as lignin, our major challenge involves finding how to use these techniques effectively. Biomass resin does not differ from petroleum-based resin, simply because its environmental impact as determined by an LCA (Life Cycle Assessment) becomes equivalent to that of usual petroleum-based resins if biomass resin is subject to multiple resin modifications, meaning such resin eventually can no longer be considered a technology to reduce carbon dioxide emissions. Currently, we are striving to carve out various applications to exploit the benefit of natural material.

Next we introduce a case example using silk fibroin. This is a protein, a major component of silk, which can also be called an animal biomass material. In other words, this protein is a natural ultrahigh-molecular-weight polymer. By exploiting its distinctive characteristics, we foresee the potential to identify unique added value, which would otherwise be unobtainable in petroleum-derived materials.

We showed an example of our development, a sponge sheet made from silk fibroin in **Figure 8**, with a soft touch, high water absorption and heat resistance. We are currently considering its applications as decorative and/or medical materials[9].

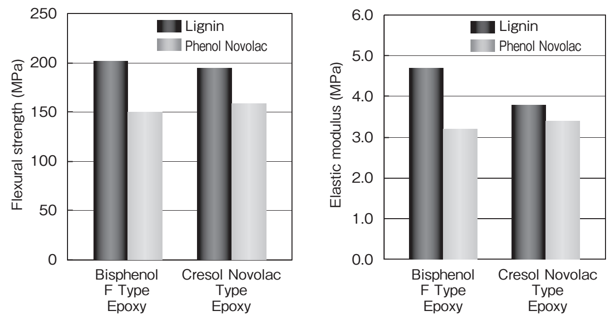


Figure 7 Flexural Strength and Elastic Modulus of Epoxy Resin Composite Using Lignin or Conventional Novolak Resin

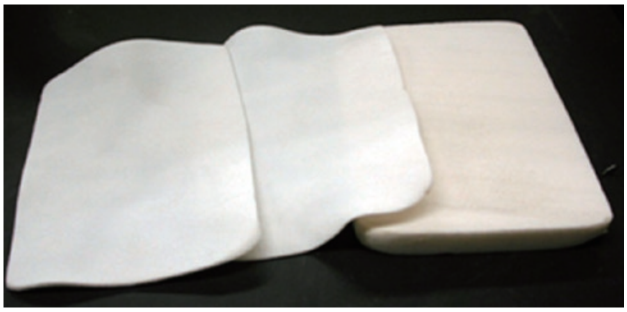


Figure 8 Example of Sponge Sheets Made from Silk Fibroin

4 Role of Resin Technology

As introduced in this report, it is now possible to obtain previously inconceivable resin properties by controlling the resin structure, further cross-linking and crystal structures. We are also striving to find a way to utilize the structure of natural products as they are. Further enhanced analytical technique not only supports the development of these resins but is also a powerful weapon to protect our proprietary technologies. Our resin technology overall is an integrated body of different technologies and by offering resin material and analytical techniques to meet contemporary needs, we are confident that we can contribute to the progress of our society and company.

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Development Trend of Inorganic Materials and Our Developments

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Advanced Core Materials Business Sectors
Inorganic Materials R&D Department

Inorganic materials such as single crystals, ceramics and glass have been used as key products and devices in semiconductor, automobile and life-science fields in recent years. Our GSO and LGSO single crystals are used as scintillators in PET medical imaging equipment, while our high-thermal conductive SiC ceramics and low thermal expansion ceramics are used as structural materials in lithography equipment. Our vanadium-based low melting glass paste is expected to have wide-ranging applications as a moisture-resistant sealing agent for electronic devices. Recent development trends in inorganic materials and our developments are described.

1 Introduction

Wide variation of characteristics of inorganic material can be attributed to the abundance of many types of constituent elements and the constitution of chemical bonds as mixed state of ionic and covalent bonds. Furthermore, inorganic materials can be classified into three categories, namely single crystal, ceramic and glass; based on the regularity of the 3D atomic alignment and crystalline state. In other words, a single crystal is a solid where the entire body comprises single crystals, whereas glass (amorphous material) is a solid, where atoms are randomly aligned. Conversely, ceramics is composed of multi-crystal with particle size of ranging from sub-micron scale to tens of microns. These inorganic materials have been used for key parts and devices in semiconductors, automobiles and life-science.

In our case example, GSO (Gd_2SiO_5: Ce) and LGSO ($Lu_{2-X}Gd_XSiO_5$: Ce) single crystals are used as scintillators in γ-ray detectors of PET (Positron Emission Tomography) medical imaging equipment, while high thermal conductive SiC and low thermal expansion ceramics are used as structural materials for semiconductor lithography equipment. Moreover, the use of vanadium-based low melting glass paste is expected to be used in wide-ranging applications as a moisture-resistant sealant for electronic devices. All these materials are melted or synthesized at high temperatures, hence we promote the development of inorganic products based on our upstream technologies, i.e. material and treatment technology at high temperatures. In this report, recent trends in single crystal, ceramic and glass materials are reviewed and our developments are noted.

2 Single Crystals

2.1 The Recent Trends in Single Crystal

The largest market for single crystal is semiconductor Si, the production of which exceeded 8,000 tons in 2010. Si is fabricated into a wafer, which is then used as a substrate for semiconductor devices. Si single crystals grown using the Czochralski (CZ) method are mainly shaped into wafers and used for semiconductor devices. The technical advancement of CZ-Si can be performed by enlargement of crystal diameter and currently 300 mm diameter single crystals are being mass produced. In future, the wafer size is going to be increased up to 450 mm in diameter in association with the trend of wafer-size enlargement for Si semiconductor fabrication process. Si, which is grown using the Floating Zone (FZ) method, is used in fields of power semiconductor devices where high purity and defect-free silicon is required, infrared optical devices, x-ray related parts and radiation detectors. The mainstream material, however, for rapidly expanding solar battery markets, is amorphous silicon.

The material second to Si in the single crystal market is quartz (SiO_2 single crystal). Due to its piezoelectric property, quartz is used in wide-ranging fields, such as frequency control devices, frequency-selective devices and various types of sensors. Recently quartz has been used for optical devices in cameras and pick up lenses in DVD due to its birefringence, polarization and optical rotation properties. Quartz is grown using a hydrothermal synthetic method. By future trend toward miniaturization and enhanced performance, high quality quartz is required continuously. $LiTaO_3$ (LT) and $LiNbO_3$ (LN) single crystals have a stable market also as piezoelectric crystals, which are used in SAW (Surface Acoustic Wave) devices for high-frequency filters in cellular phones.

The single crystal of next important market is compound semiconductors such as GaAs, GaP, etc. Traditionally, the horizontal BR (Bridgman) method and LEC (Liquid Encapsulated Czochralski) methods have been used to grow crystals for GaAs as optical devices and high frequency devices respectively. Recently, however, the VGF (Vertical Gradient Freeze) method has become mainstream. Recently, GaAs can expect significant market growth due to the expanding demand for high frequency devices used in smartphones and wireless networks, SiC single crystal, which is expected as a big market by replacing Si currently used in

power devices, are very active.

Sapphire (Al_2O_3 single crystal) is used as a substrate for GaN growth, which is necessary for blue LED and white LED and demand for sapphire is in rapid expansion in parallel with the market growing for LED. Methods used to grow sapphire crystals are Bernoulli, Kyropoulos, CZ and HEM (Heat Exchange Method). The plane direction and diameter of sapphire single-crystal wafer varies depending on its application; for example, 2- to 4-inch diameter, C-plane wafer is used for LEDs and 6-inch diameter, R-plane wafer is used for SOS (Silicon on Sapphire) devices. In the future, the trend toward enlarged wafer size will continue.

2.2 Single-Crystal Scintillator for Radiation Detectors

PET (Positron Emission Tomography) medical imaging diagnostic equipment has become popular rapidly, ever since it was approved for health insurance coverage in Japan and demand for the scintillator material used in PET is growing. Many years ago, we produced BGO ($Bi_4Ge_3O_{12}$) scintillation single crystals for PET on a commercial scale for the first time in Japan and newly proceed to develop GSO. GSO as a world first practically applied scintillator which has the luminescence center of Ce. The Ce luminescence center enables high-speed compared to conventional NaI:Tl, and BGO, and the realization of high performance PET.

LSO (Lu_2SiO_5: Ce), LGSO and LYSO ($Lu_{2-X}Y_XSiO_5$: Ce) are used in the latest TOF-PET (Time of Flight PET)[1]. By doping Ce as the luminescence center of the scintillator, an excellent timing resolution is realized. A photo of our ϕ90-LGSO single crystal is shown in **Figure 1**.

Triggered by market expansion of PET, new single-crystal scintillators are developed aggressively. We developed GPS (Ce-doped $Gd_2Si_2O_7$) single crystal scintillators jointly with Hokkaido University. GPS excels in energy resolution due to its high light output and short decay time with 50 to 100 ns. Since GPS contains no radioactive isotopes, it is expected to be used in a wide range of applications such as SPECT (Single Photon Emission Computed Tomography) medical image diagnostic equipment[2].

Other scintillator applications include various types of survey meters, radiation detectors for oil wll loggings and detectors for physics research. Regarding a recent topics linked to the discovery of the Higgs particle by CERN (The European Organization for Nuclear Research), contribution of around 80 thousand PWO($PdWO_4$) scintillators placed at the CMS detector facility in CERN must be pointed out[3].

Figure 1 ϕ90-LGSO Single Crystal

2.3 Future Evolution of Our Single Crystal Material

These days, the development of earth-conscious materials, such as SiC single crystal for power devices and sapphire single crystal for LEDs are attracting attention. We wish to contribute to society by developing new environmentally friendly single-crystal material. Also, to put single crystal to practical use, we will actively promote resource saving and resource circulation by conserving natural resources and recycling in the fabrication/manufacturing process.

3 Ceramics

3.1 Trend of Ceramic Material

Presently, ceramics can be deemed an essential industrial material, like metal materials such as iron and organic materials such as plastics. In general, ceramics based on polycrystalline, with strong chemical bonds formed by ionic or covalent bonds, can be characterized by its high melting point, high chemical resistance, high strength, high hardness and good stability. However, ceramics is generally brittle.

Main industrial ceramics include simple metal oxides such as SiO_2, MgO, Al_2O_3 and ZrO_2; complex oxides such as $BaTiO_3$ and PZT (PbO-ZrO_2-TiO_2 system); carbides such as B_4C and SiC and nitrides such as AlN, Si_3N_4 and BN. Many of these materials comprise elements with large Clark numbers, which are thus deemed environmentally friendly.

The performance and characteristics of ceramics composed of polycrystallines may vary depending on differences in microstructure, additives and sintering conditions. By exploiting such characteristics, special featured ceramics called fine ceramics are manufactured by well-controlled chemical composition, microstructure, shape and production, etc. The fine ceramics can be roughly classified into two groups, namely functional ceramics and structural ceramics. The fine ceramics has a wide variety of application as a most advanced parts and products in the field of IT, automobile, biotechnology, energy and so on.

As one example, our developed ZrO_2-toughened Al_2O_3 ceramics is a material with excellent fracture toughness better than conventional Al_2O_3 ceramics. Moreover, its superiority in both impact and wear resistance means it is employed in various types of consumable parts for grinder mill and wearing parts. Further, our SiC ceramics have high hardness, high thermal conductivity and are used as pump seals for cars. The unique combination of hard SiC and soft carbon forms liquid layer on sliding surface and enhances the lubricative property.

3.2 Ceramics for Semiconductor Device Manufacturing Equipment

Semiconductor devices are used in electronic equipment such as PCs, cellular phones and gaming machines and their use is expanding in parallel with progress in IT technology in automobile and home appliance fields. Integration density of semiconductor devices increases annually according to design rules, and productivity enhancement also rises due to increasing silicon wafer size. A substantial quantity of ceramics is used in semiconductor manufacturing equipment by exploiting their high stiffness and thermal conductivity, low thermal expansion and superior chemical resistance.

For example, ceramics with high specific rigidity and low thermal expansion are required for semiconductor manufacturing equipment to enhance its positioning accuracy and improve throughput. To meet such requirements, we have optimized chemical composition, sintering aids and additives, and developed ceramics with a coefficient of thermal expansion (CTE) of which becomes zero at around room temperature. Our low-CTE ceramics and thermal expansion data are shown in **Figures 2** and **3** respectively. For practical application of the low CTE ceramics, it will be important to measure CTE with high precision and high reliability[4] to require the stability and reproducibility of CTE. Accordingly, AIST (National Institute of Advanced Industrial Science and Technology) and we have jointly developed a measuring method of CTE applicable to such low CTE ceramics with ease and #####. Consequently, we can constantly supply low-CTE ceramics with less than 20 ppb/K, thus enhancing the precision of semiconductor lithography.

Figure 2 Low CTE Ceramics

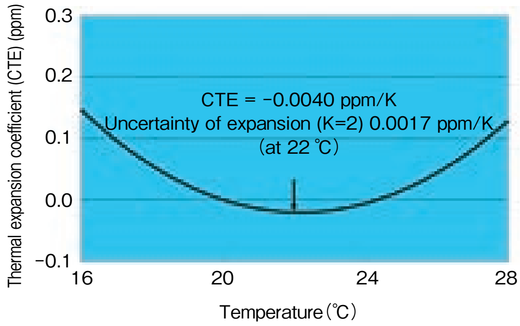

Figure 3 Thermal Expansion for Low CTE Ceramics

3.3 Evolution of Our Ceramic Material in Future

As mentioned above, we have been engaged in developing our ceramic materials; focusing on fabricated ceramics tailored for specific structural applications. Henceforth, we plan to fabricate the surface of ceramics chemically or to make hybrid of resins to add new function for the development of new applications. Further, we want to promote Global Environment Friendly Manufacturing by improving manufacturing technology, e.g. near-net shape technology, to reduce manufacturing waste and low-temperature sintering technology to reduce energy consumption.

4 Glass

4.1 Trend of Glass Material

Glass material shows glass-transition phenomena. In other words, glass has a unique feature to change itself from a solid state to a viscous fluid at glass-transition temperature or higher; allowing it to be shaped into various forms. Also in general, glass shows certain characteristics such as transparency and insulation, does not bend or rust, but is brittle. Such characteristics mean glass is used in everyday domestic items, such as windows, cups and bins, fluorescent bulbs, TV screens and automobile windshields. Recently glass has also been used in many industrial fields such as electronics, optics, display, storage and energy thanks to its freedom of composition, moldability, high strength and functional additionality as well as the aforementioned basic properties. These types of high-performance glass are called “new glass”.

Areas in which new glass can play active roles include optics, specifically transmission via optical fibers, optical amplifiers and non-linear optical glass in industrial fields. Synthetic quartz and fluoride glass varieties with distinguishable UV light transmission are used in IC photo masks and projector lens. The demand for glass in the display field is increasing alongside expanded liquid crystal applications. Thermal barrier super-insulated multi-layered glass, dimming glass and UV cut glass in automobile and construction areas, substrate glass in thin film solar batteries and glass film of fuel batteries in the energy field are already being practically applied.

4.2 Low-melting-point Glass

Electronic parts such as crystal oscillators, IC ceramic packages, MEMS (Micro Electro Mechanism Systems) and semiconductor sensors often employ hermetic sealing at 400 ˚C or less, using glass melting at low temperatures and containing significant poisonous lead or expensive Au/Sn solder. Lead-based low-melting-point glass contains fluorides to lower the melting point and cannot be used for vacuum sealing, given the tendency of fluoride to vaporize. In general, lowering the melting point of glass tends to reduce its reliability, due to moisture resistance and other factors. Conversely, Au/Sn solder is a highly reliable material, with the impact on environmental load in mind. Also, since it can be hermetically sealed, it has been employed as a low-

temperature sealing material for electronics parts requiring enhanced performance and reliability. With this background in mind, new high-performance and reliable sealing material allowing low temperature sealing at 400 ˚C or less, further miniaturization with environmental impact and cost in mind was needed. With that, we developed vanadium-based low-melting-point glass that can be sealed at 350 to 400 ˚C and contains no poisonous lead nor any other controlled substance jointly with Hitachi Research Laboratory, Hitachi, Ltd.

Conventional glass containing significant V_2O_5 has layer structures resembling V_2O_5 crystal and there were problems of structural disorder, whereby the grinding atmosphere or water molecules contained in the solvent was prone to penetrate between the layers to weaken the adhesion between them and leading to structural disorders. Accordingly, in this development work, we changed its structure to one of a 3D network, which was effective against water molecules penetration by controlling the ionic valency of vanadium. Further we could also successfully lower the melting point, preventing crystallization and significantly enhancing reliability, e.g. in terms of moisture resistance, by incorporating many elements with a large ionic radius and low-melting-point into the intermediate spaces of the network structure. The exterior appearance of our developed glass is shown in **Figure 4**, and the relations between sealing temperatures of various glasses and CTE are shown in **Figure 5**. Conventional lead-, bismuth- and tin-based glasses tend to increase CTE alongside decreasing sealing temperature. Moreover to date, bismuth- and tin-based glass have not been sealable at 400 ˚C or less.

Samples of the environmentally friendly vanadium-based low-melting-point glass we developed are shipped as pastes or powders and the property of the developed product is shown in **Table 1**. Because the CTE of the developed glass can be controlled over a wide range and is compatible with ceramics, glass, metal and semiconductors, we anticipate applications to various electronics parts in future.

Figure 4 Samples of V-based Glasses

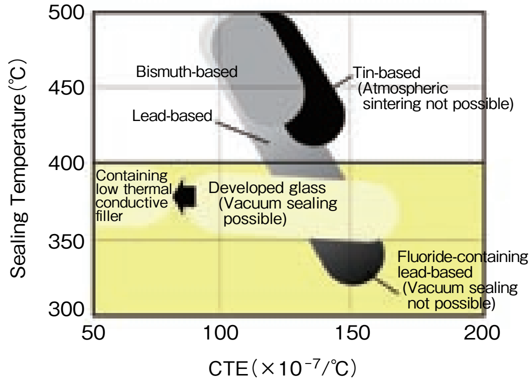

Figure 5 Relationship between CTE and Seal Temperature for Low Melting Glasses

Table 1 Properties of V-based Low Melting Glasses

Glass product number	VP−1175	VP−1176	VP−1177	VP−1179
Standard sintering condition	370 ℃−10 min	380 ℃−10 min	390 ℃−10 min	400 ℃−10 min
Color	Black	←	←	←
Specific gravity	4.0	3.7	3.8	3.7
CTE*1 (×10^{-7}/℃)	160	105	75	60
Standard average particle size (μm)	3	←	←	←
Moisture proof resistance: PCT*2	Good	←	←	←
Acid resistance*3 (%)	<1	←	←	←

*1：25–250℃
*2：Saturation-Type Pressure Cooker Test (PCT：120 ℃−100%Rh−202 kPa)
*3：Dissolution in dilute nitric acid

4.3 Evolution of Our Glass Material in Future

The vanadium-based low-melting-point glass we developed not only features a reduced environmental load but can also be heated by light sources such as various lasers. This means the glass area alone can be heated and glued without heating the whole body, including the elements with low heat resistance and substrate. Henceforth, by exploiting these featured characteristics, we plan to use our glass for partial heating, sealing and adhesion of elements and metals, while preventing thermal degradation.

5 Summary

The development trends of inorganic materials, including single crystals, ceramics and glasses as well as our products, are reviewed. In recent years, these inorganic materials have been considered indispensable for key parts and devices in semiconductors, automobiles and life science equipments. We continue these developments, in the hope that our inorganic materials may benefit humankind and preserve the earth environment.

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Automotive Parts for "Environment, Safety and Comfort Performance"

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A century has elapsed since the first Ford T was produced in 1908. Since then, the strong economic growth of emerging countries, especially the BRICs, has sparked a global explosion in automotive demand. In 2010, motor vehicle production reached 74 million units and is expected to continue growing, with a production total forecast of 140 million vehicles by 2020 and 165 million by 2030.

Conversely, to deal with growing environmental issues such as declining energy resources, global warming and air pollution, automotive makers have recently been focusing on improving existing gasoline engines by enhancing fuel efficiency and reducing emissions-while developing commercially viable next-generation electric and fuel cell vehicles (HEV/EV).

In this report, we will present our latest technological developments to meet the requirements of these next-generation vehicles in sectors of safety, comfort and environmental performance.

1 Introduction

In future, automobiles must meet personal demands from users, including elements of social responsibility such as safety, comfort and support for the trend toward a low environmental-burden hydrocarbon society as well as meeting requirements to improve basic functions to drive automobiles, such as running, turning and stopping. For example, saving weight in engine-driven automobiles, downsizing engines or equipping automobiles with turbochargers may become crucial to meet and improve safety standards while positively supporting the low hydrocarbon society, and meeting the requirements of high power output and fuel efficiency while maintaining traditional drivability.

Conversely, in parallel with the increasing popularization of hybrid vehicles (hereinafter referred to as "HEV") and electric vehicles (hereinafter referred to as "EV"), the escalating performance requirements of motors, inverters and batteries mean the need to develop upgraded parts and materials for the same is intensifying to an ever-greater extent[1].

In this report we introduce the development status of auto parts promoted via fusion of technologies owned by our group.

2 Our Automotive Parts to Achieve Environmental Protection, Safety and Comfort

From an environmental protection perspective, we have achieved an enhanced environmental performance level for our brake pads (hereinafter referred to as "pads"), one of our representative products, thanks to non-asbestos pad, as well as improving safety performance, e.g. with traditional good braking and long service life.

Moreover, in HEV and EV fields, the popularization of which we expect to continue, our IPM (Intelligent Power Module) housing (hereinafter referred to as "housing"), where IPM constitutes the heart of the inverter unit, which is a crucial control system for driving 3-phase motors, and the battery module case are being received favorably in the market.

One of the recommended means of improving environmental performance is weight saving. Accordingly, our group is commercially manufacturing engine peripherals made of resin, including resin gears[2] and resin rear door modules having replaced steel exterior parts. Rear door modules help save weight as well as contributing to safety issues e.g. through high stiffness and strength, vibration durability and collision safety.

Regarding the internal room comfort, our light-control film used for dimming glass can seamlessly control light transmission, since the particles inside the film can align and let light pass through when voltage is applied, meaning our film can effectively save energy. Currently our film is used in the sun roofs of high-grade European automobiles-an example of unique and one-of-a-kind products.

3 Environmentally Responsive Materials

3.1 Abrasion Material

The history of changing regulations governing chemical compounds used in automotive brake pads in North America is shown in **Figure 1**. Due to regulatory limits restricting the use of copper in motor vehicle brake pads[3)-5)] effective post-2012, we

foresee copper-free NAO (Non-Asbestos Organic) materials becoming mainstream from now. Conversely, brake pads capable of suppressing vibration and offering reduced drag resistance to limit brake squeal and boost fuel efficiency are required. We established technology to replace the copper and suppress the vibration, then developed a next-generation pad.

(1) Copper-free NAO material

Copper with high thermal conductivity and superior flattening property is used in the form of a fiber or powder to maintain the wear resistance and friction coefficient. Accordingly, we regularly investigated the improved functional property of friction materials due to the use of copper, and developed copper-free NAO material by compensating the lost function and replacing it with multiple metal- and inorganic-based materials. The friction property of copper-free NAO material is shown in **Figure 2**. The developed material clearly has a service life and friction coefficient equivalent or superior to conventional materials.

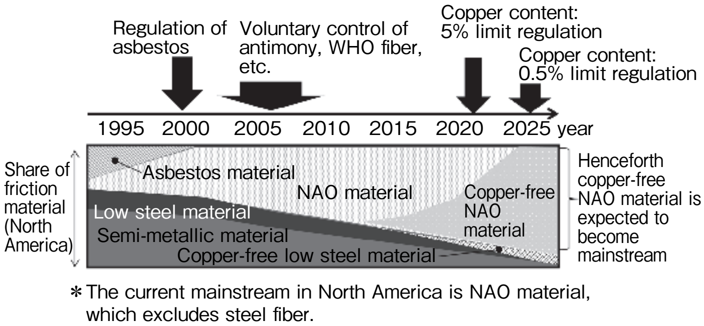

Figure 1 Change in the Regulation of Chemical Substances for Brake Pads

(2) Low-Compression Deformation Change and High Vibration-Suppression Material Using Vibration-Suppression Treatment

We successfully improved the vibration-suppression property and reduced the compression deformation using a high-vibration-suppressive elastomer and incorporating a new manufacturing process. The developed material, as indicated in **Figure 3**, showed a higher friction coefficient (tan δ) from a low to high temperature range and vibration-suppression property outperforming conventional rivals, meaning virtually no brake squeal. Conversely, the lack of compression deformation and drag torque reduction is considered to help improve fuel efficiency and can be applicable electric parking brakes, which generate high hydraulic pressure when the brake pedal is pressed. Henceforth, we will further enhance the stability of the friction coefficient and improve its applicability to controlled brake systems such as brake control/regenerative-friction brake coordination systems.

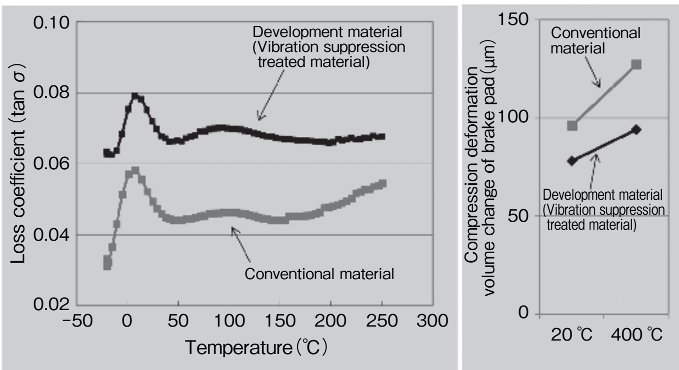

Figure 2 Friction Properties of the New NAO Friction Material without Copper

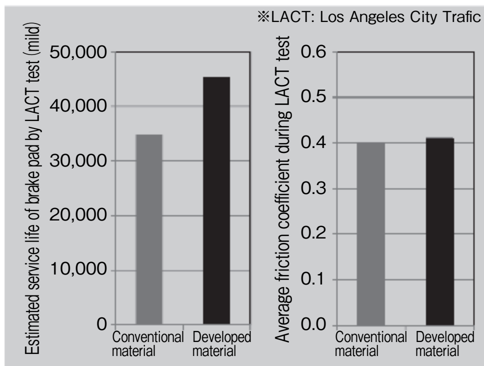

Figure 3 Damping and Compressive Properties of the New Friction Material

3.2 Metal-Insert-Molded Product for HEV and EV

To drive a three-phase AC motor, direct current from a battery is converted to AC via an inverter unit. We have been involved in the production of housing that constitutes the electric power circuit[6] of an inverter unit for one decade (**Figure 4**). The housing is constructed from a bus bar circuit that connects electrical power supplied from an IGBT (Insulated Gate Bipolar Transistor), a key inverter component and from insulation materials. The housing must have sufficient heat resistance and electrical properties to withstand the high temperature and humidity in the engine room. Accordingly, the basic technologies required to build housing cover a broad range from the design/fabrication of bus bar/molds, CAE analysis, insert molding and process control right up to quality assurance technologies. In particular, because housing molding, which involves placement of a metal insert, requires thermoplastic resin to be filled under high temperature and pressure using an injection molding machine, we must prevent flash generation in the clevis clearance between mold and metal inserts such as bus-bars and nuts and also any deformation that occurs during the cooling stage. When joint mating, we thus estimate the dimensional accuracy in advance, the flow path of the thermoplastic resin and the deformation change by CAE analysis, and use those results to optimize mold design and injection molding conditions. Also, as shown in **Figure 5**, we actually performed 3D cross-sectional observations and confirmed that both the resin and bus bar adhered to each other uniformly and a good finish was obtained as designed.

The battery case for EV, as shown in **Figure 6**, incorporates glass filament-reinforced thermoplastic resin and a metal insert,

because it was suspended under a car body and its impact resistance and joint strength with the car body frame were crucial requirements.

Backed by progressive infrastructure toward a low carbon society and enhanced comfort and convenience, we anticipate further growth in demand for EV and HEV. In response, we promote material performance improvements using new materials, for example, of the high heat dissipation-type as well as developing molded products with electromagnetic interference shielding metal inserted.

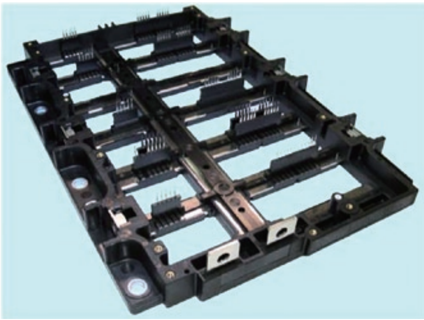

Figure 4 Housing made of a Bus Bar Circuit and Thermoplastic Resin

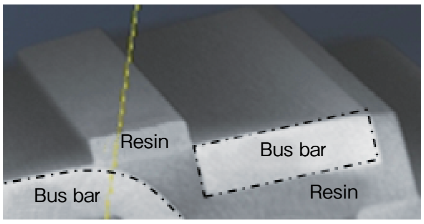

Figure 5 3D Cross Section View of the Bus Bar Area

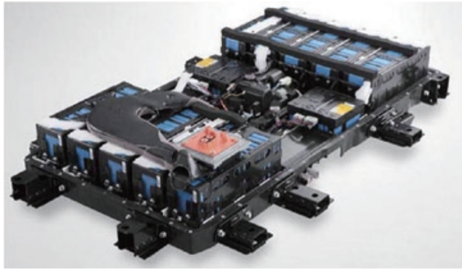

Figure 6 Battery Case for EV

4 Lightweight/Energy-Saving Material

4.1 Interior and Exterior Materials

The component ratio of resin parts in an automobile is 10 to 12 wt%, while interior/exterior and engine-peripheral parts are molded plastic. We commercialized interior parts such as instrument panels, console panels, and exterior parts such as the bumper, front grille, front lid of the truck, spoiler and rear door module. We used a gas-injection-molding method to retain rigidity while preventing shrinkage through the cross-section of a thick part. We also used slash molding and vacuum molding methods to improve the exterior finish and tactile sensation of the console box, and reduced the parts count via a vibration welding method.

Conversely, the rear door module shown in **Figure 7** offers the advantages of low weight, freedom of shape and a reduced parts count, hence we commercialized the rear door modules ahead of rival manufacturers. The structure of this module features inner and outer shells glued together, and meets the required specifications in terms of vibration durability, crash safety and exterior visual quality, thanks to structural optimization through CAE analysis and using high-strength glass fiber-reinforced thermoplastic resin[7].

Henceforth we promote the development of heat-resistant thermoplastic resin used for horizontally placed parts such as trunk lids and sunroofs, as well as developing high-functional parts material to improve the noise barrier property and in-car environment.

Figure 7 Plastic Rear Door Module

4.2 Light-Control Materials

Light-control materials have attracted attention in automobile, aircraft and construction material fields thanks to the privacy protection function by controlling light transmission as well as the energy-saving functions from thermal insulation and light and heat shielding[8)-10)]. We started the commercial production of light-control emulsion and films using our own polymer synthesis and film coating technologies developed based on SPD (Suspended Particle Device) technology licensed by Research Frontier Inc. in the U.S. The drive principle and a case example of the light-control film are shown in **Figure 8**. This is an active-type light-control film, where the deep blue color becomes transparent by applying AC voltage to adjacent transparent electrodes and orienting light-control particles along the directions of an electromagnetic field[11)]. The cross-sectional structure of the light-control glass is shown in **Figure 9**, where light-control film is placed between paired glasses via an adhesive layer. The ability to control visible light transmission by adjusting the AC voltage supplied via terminal electrodes of the light-control film, free control of visible light and heat ray energy and UV light not transmitting via glass, depending on the structure of paired glass[12)], mean applications of light-control glass to roof and rear-side glass are emerging.

The results of a simple simulated sunlight radiation test to measure the thermal management effect of a roof equipped with sunlight-control glass are shown in **Figure 10**. When it is transparent after an electric voltage was applied, the surface temperature on the black paper with an image of head hair was lower by 10 ˚C compared to that of conventional transparent glass. When the

voltage was turned off, however, the surface temperature decreased further. Accordingly, we believe applying such light-control glass to vehicle roofs should improve comfort and energy saving. The color of the developed light-control material is formulated to deep blue while the voltage is turned off. However, since the need for next-generation light-control film with achromatic black/gray color, which can match the room interior design, has emerged, we are actively promoting its development.

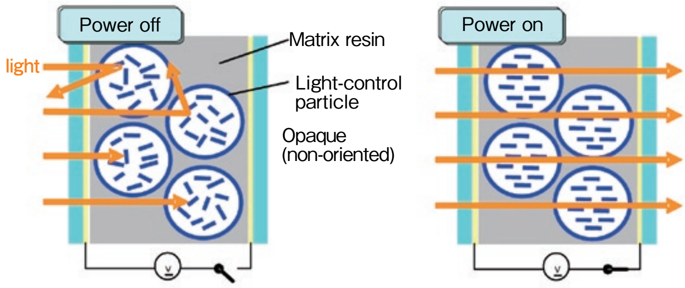

Figure 8 Fundamental Driving Mechanism of Light Control Film

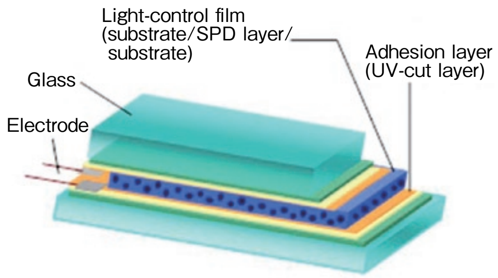

Figure 9 Structure of SPD Glazing

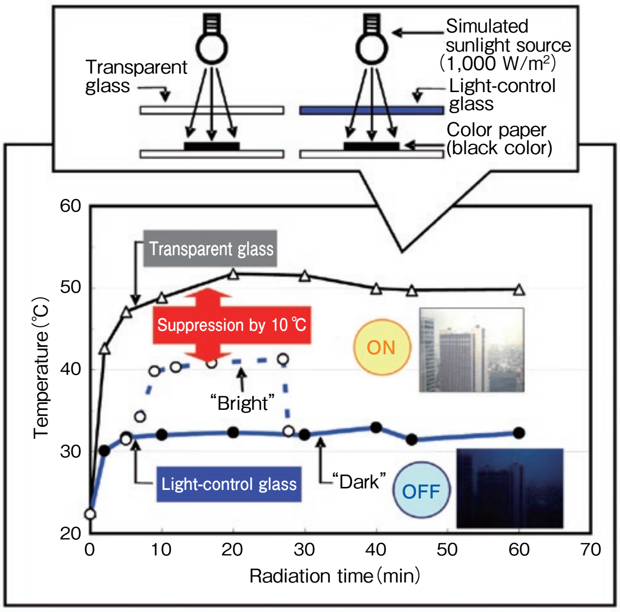

Figure 10 Surface Temperature of Black Paper during the Sunlight Simulator Test

5 Summary

Despite ever-changing social environments around automobiles, promoted by environmental assessments of natural resource-saving on a global level, anti-global warming efforts and new concepts introduced to our social system, such as HEV, EV and the smart grid, we are convinced that automobiles will continue to play mainstream transportation and delivery roles. In this context, new performance requirements for automobile parts are required and their importance has been more keenly recognized.

Our group will continue offering the aforementioned technologies, products and new automotive parts that demonstrate "Environmental Protection, Safety and Comfort Performance" ahead of other manufacturers, thus contributing to our society through the development of the automobile industry.

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Trends in Environmental and Energy-saving Technology for Automobiles and Corresponding Developments in Powder Metallurgy

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The motorization of society in China, India, Southeast Asia, and other emerging nations is driving a global increase in demand for primary energy. In 2030, this demand is predicted to be 40% greater than at present, with 60% of petroleum consumption predicted to be for automobiles. To decrease the environmental burden and minimize fossil fuel consumption, automobile makers are accelerating the development of environmentally friendly and fuel-saving automobiles. In response, more and more of our powder metallurgy products are supporting our customers' development of environmentally friendly automobiles. This report briefly reviews overall trends in the automobile industry and efforts by automobile makers to create environmentally friendly automobiles, while in the second half outlines examples of Hitachi Chemical powder metallurgy products that support these efforts.

1 Introduction

The popularization and development of automobiles have provided us with a means of transportation and delivery and made our lives more convenient and affluent. Conversely, automobiles consume vast amounts of fossil fuels, are a major source of carbon dioxide causing air pollution in urban areas and a greenhouse gas, and significantly impact on the global environment. In Japan, efforts to reduce atmospheric carbon dioxide as a countermeasure to global warming started in 2008, targeting a 6% reduction compared to the 1990 level pursuant to The Kyoto Protocol. Moreover, each country is mandated to establish a reduction target toward 2020 from 2013 onward.

17% of the total atmospheric carbon dioxide in our country comes from vehicle emissions, meaning measures to counter carbon dioxide from automobiles become more important than ever.

According to the "World Energy Outlook 2010" [1] report prepared by an international energy organization, global primary energy demand will increase 40% by 2030 if appropriate energy-saving actions are not undertaken, mainly propelled by increased petroleum consumptions in emerging countries, especially China, India and Southeast Asia, where motorization is rapidly expanding. In this case, petroleum consumption by automobiles is estimated to account for 60% of the total.

Under such circumstances, auto manufacturers are accelerating efforts to develop a technology for environmentally friendly automobiles to ensure their own survival in the international market.

2 Changes in the Automobile Market

2.1 Polarization of Automobile Markets and Accelerating Growth

Trends of the global automotive market show that 13.79 million automobiles were sold in China in 2009, where the automobile market surpassed that of North America. Automobile sales in Japan at the time went under than 8 million. Although little increase in vehicle sales is forecast in Europe, Japan and North America henceforth, sales are set to soar in China, India and other emerging markets alongside the growing polarization in automobile sales between developed and developing countries. In terms of passenger car sales, figures of 58 million cars in 2010, 72 million in 2020 and more than 100 million in 2030 are forecast thanks to increased sales in emerging countries[2].

2.2 Changes in Power Source for Automobile Propulsion

Japan targeted a 25% greenhouse gas reduction by 2030 compared to the 1990 level pursuant to the recently agreed Copenhagen Accord (COP15). The price of fossil fuel also soared after the Lehman Shock in 2008, while the subsequent breakdown of atomic power plants during the earthquake on March 11, 2011 further intensified Japan's energy dependence on thermal power generation, explaining the continuing high price of automobile fuel. Concerned by such situations, automobile manufacturers have accelerated the development of hybrid cars (HV, HPV), fuel cell cars (FCV) and electric cars (EV); conversely, renewed efforts to lower the fuel consumption of fossil fuel engines are still attracting attention, more than before. It is amazing to see that there is still room left to improve fuel efficiency given the long history of automobile development; 130 years for the gasoline engine and 90 years for diesel.

3 Trend of Environmental and Energy-Saving Automobile Technologies

In recent years, developments in energy-saving automobile technologies have been focused and simultaneously promoted in the following areas: (1) Enhancing the fuel efficiency of the traditional combustion engine, (2) Developing next-generation powered vehicle such as EV, HV (including PHV) and FCV for compatible energy-saving and environmental protection. **Table 1** shows the trend toward technological improvements in fuel efficiency and corresponding powder metallurgy products[3]. The key technology includes weight-saving, low-friction, heat-/wear-resistant, thermally insulated and magnetic parts with low loss/high efficiency; corresponding powder metallurgy products contribute to the development of environmentally friendly automobiles.

Table 1 Technology Trend of Fuel Economy Improvement in the Automotive Industry

Relevance ◎Strong ○Weak

Automotive System	Technology to improve the environment and fuel consumption	Targeted Automobile				Main targeted powder metallurgy product
		Gasoline	Diesel	HPV (including PHV)	EV	
Engine System	Reducing friction	○	○	○		Full range of structural parts
	Multi-valve (4 valves)	◎	◎	○		Valve guide, valve seat
	Variable valve train	◎		◎		Parts of the variable valve train
	Solenoid valve train	○				Wear-resistant parts, Sintered magnetic parts
	Direct fuel injection	◎				High-efficiency injector parts
	Multi-stage fuel injection		◎			High-efficiency injector parts
	Mirror cycle system	○				
	Exhaust gas recycling (EGR)		◎			Heat-resistant material (bush)
	Thermal management (reducing cooling loss)	◎	◎	◎		Porous heat insulation metal parts
	Thermal management (thermoelectric waste heat regeneration)	○	○	◎		Thermoelectric conversion module (system)
	Downsized-turbo	◎	○			Heat-/wear-resistant material
	Lightweight parts	◎	◎	◎		High strength thin-walled parts, metal-resin composite parts
Auxiliary Engine System	Electric power steering	◎	◎	◎	◎	Motor/core soft magnetic composite (powder core)
	Charge control	○	○	○	○	
Drive System	Idling neutral control	○	○	○		
	Automatic transmission (AT) multi-step	◎	◎	○		Internal gear, Planetary gear mechanism parts
	Automatic transmission (AT) lock-up	◎	◎	◎		
	Continuously Variable Transmission (CVT)	◎	○	◎		Internal gear, Planetary gear mechanism parts
	Automated Manual Transmission (AMT)	◎	◎	○		Synchronized mechanism parts
	Dual Clutch Transmission (DCT)	◎	◎	○		Friction material, Clutch material
Fuel System	Alternate fuel (biomass fuel)	◎	○			Anti-wear material (valve seat), Fuel pump bearing
	Idle stop	◎	○	○		Long life low-friction bearing, High fatigue strength gear
EV, HV Motor	Low-friction, High efficient motor			○	◎	Low loss motor rotor
EV, HV Power Source Control System	High efficient inverter, Low loss magnetic parts			◎	◎	Low loss magnetic parts (reactor)

4 Responses by Powder Metallurgy Technology to Environmentally Friendly Automobiles

4.1 Improvement in Fuel Efficiency of Traditional Internal-Combustion Engine for Automobile (Fossil Fuel)

• Parts for Turbocharger (Downsizing Turbo)

Downsized engines are increasingly popular thanks to applications of the turbocharger (hereinafter referred to as T/C) as an optional piece of automobile technology in response to environmental challenges. T/C parts require wear resistance under high temperature operating conditions, so the main materials used are steel-based with high Cr content, such as stainless steel. It is also possible to further enhance performance with sintered materials thanks to its higher scope of design freedom. A new high-Cr content material was developed anticipating use in an even hotter environment. **Figure 1** shows the metallographic microstructure of high-Cr-sintered material EW-50. EW-50 is a steel-based material with 20% chromium content, which is finely and uniformly dispersed with Cr carbide (30% area ratio), and shows remarkable wear and oxidation resistance, even at temperatures of 700 ˚C or more. We are now promoting EW-50 for T/C parts[4].

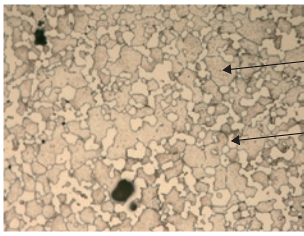

Figure 1 Microstructure of High Cr Content Sintered Material "EW-50" with High Heat and Wear Resistance

• Compact/Lightweight Parts

It has become possible to manufacture thinner-walled products thanks to the improved strength of sintered material, which can also contribute to miniaturization and weight-saving. We enhanced the mechanical property by adding alloys with high sintering performance and optimizing the addition method for the alloy. Developing a new additive element requires sufficient considerations of safety, recycling efficiency and cost. Accordingly, we are promoting the development of a new and more economical Cr-based material which replaces the current Ni-based materials. Also, sintered material with strength equivalent to conventional wrought steel was practically applied. **Figure 2** shows automobile parts using high strength material[5].

Figure 2 Sintered Products Applied High Strength Material for Automobiles

• Low-Friction Sintered Bearing (ISS starter bearings)

The number of automobiles mounted with idling stop systems (ISS) is expanding. The idling stop is a system stopping the engine when the driving speed declines to a certain level and then restarting it when the accelerator pedal is pressed. Accordingly, starter motors must be more durable than those currently used and the noise when restarting has to be suppressed. To improve these starter motor qualities, we developed a Cu-based

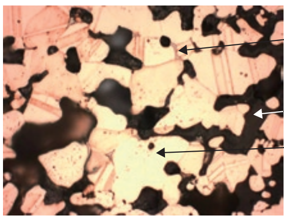

Figure 3 Microstructure of Low Friction Bearing Material "KCR-1"

sintered bearing, the material of which was dispersed with solid lubricants, whereupon the friction coefficient and squeals generated from sliding surfaces were reduced. The metallographic microstructure of the sintered oil-impregnated bearing (KCR-1) in the starter motor is shown in **Figure 3**. This material contributes to reliability and noise reduction[6].

• Magnetic Parts for Diesel Engine Injector (Clean Diesel)

To clean exhaust gas from a diesel engine, a high-precision and high-speed mechanism to open and close fuel injection valves is required, for which we use a soft magnetic composite (powder core) (hereinafter referred to as SMC) for solenoid magnetic parts (stator core). The SMC core is prepared by compacting magnetic powder of about 100 μm in diameter, the surface of which is electrically insulated. It is used without sintering and can reduce iron loss (thermal loss) in the AC magnetic field. **Figure 4** shows the structure of the SMC. Although iron loss of widely used magnetic material (soft ferrite) is small in the high frequency range, its magnetic flux density is low, hence the size of the magnetic parts increases. The magnetic flux density of the magnetic steel sheet is also high, but since its iron loss is also high in the high frequency range, it is not applicable to magnetic parts. The SMC can compensate for defects in both magnetic materials. **Figure 5** shows a stator core, which is made from the SMC of a solenoid valve for the injector of a common rail system for diesel engines[7].

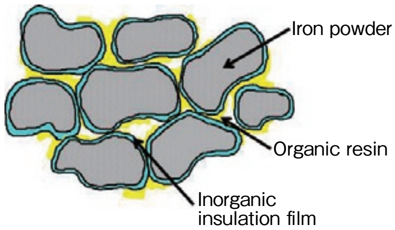

Figure 4 Schematic Structure of Soft Magnetic Composite (SMC)

Figure 5 Fuel Injector Stator Core of Diesel Engine

• Valve Train Parts for FFVs

FFV (Flexible Fuel Vehicle) engines use bio-ethanol, which is a replacement for gasoline, and natural gas and offers clean combustion. However, it has a tendency to adhere and wear due to the high frequency of metal contacts between the valve seat and valve, meaning the valve seat requires high wear resistance. **Figure 6** shows the microstructure of the valve seat material EH-51H developed for FFV, for which the anti-adhesion property was improved thanks to optimization of dispersion hard particles in substrate and added amount, also by the dispersion of solid lubricants. It also shows superior wear resistance[8].

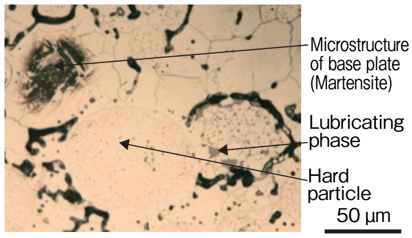

Figure 6 Microstructure of Valve Seat Material "EH-51H" for FFV

• Porous Metal Parts for Engine Heat Insulation

In recent years, various thermal management materials have come into focus to enhance automobile fuel efficiency. We developed a porous metal with ultra-high porosity, exceeding all levels achieved by traditional powder metallurgy to date. **Figure 7** shows an example of the SUS 316L (austenitic stainless steel) porous metal. It is characterized by a fine porous binary structure and a maximum porosity level of 95% can be set. The open-pore type with continuous coarse-scale pores and the closed-pore type with independent closed pores can be used as materials for heat exchangers and insulation respectively. The latter closed-pore type can help retain heat inside a combustion engine, leading to highly efficient combustion.

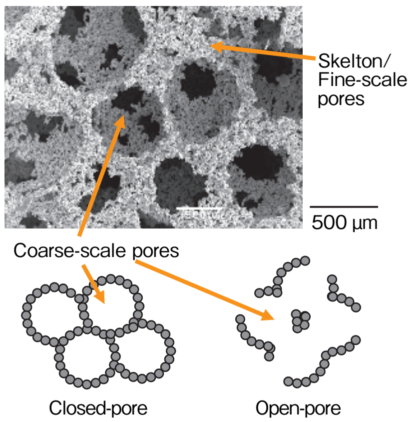

Figure 7 Dual Porous Structure Containing Coarse and Fine Pores of Porous Metal

4.2 Response to Next-Generation Powered Vehicles

• Magnetic Parts for HV and EV (motor core)

Since magnetic parts prepared by powder metallurgy method include a unique feature to facilitate the construction of 3D magnetic circuits, they are optimally suited to meet needs in response to vehicle electrification. The direct current magnetic property of sintered material is mainly defined by the material composition, the density of the sintered material and crystal particle size. Sintered pure iron shows a high magnetic flux density strongly related to the purity and density of iron, while high density sintered material using high purity iron powder can obtain high magnetic flux density. **Figure 8** shows the motor rotor core of HV with a sintered magnetic core of pure iron formed along the outer peripheral section. Since the inner peripheral section requires high strength to deliver motor torque to the shaft directly, an Fe-Ni-Cu-C based material is used and unified via a method of sintered diffusion bonding[9].

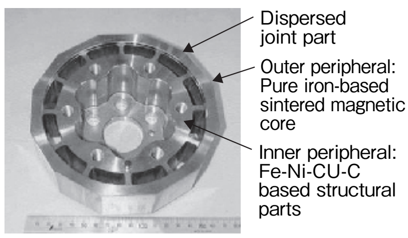

Figure 8 Motor Rotor Core for HV

• **Magnetic Parts for HV and EV (power source reactor)**

The reactor core for inverters in HV/EV with a voltage-increasing function must be made of material with low hysteresis loss. Eliminating residual stress inner raw material by heat treatment under high temperature is an effective solution, and the heat-resistant resin for the coating of the surface of the raw material requires stability at high temperature. **Figure 9** shows the exterior appearance of a reactor core used in HV. This core, combining both high magnetic flux density and low hysteresis loss, can be mounted in power inverters of not only HV/EV but also solar power, hot-water supply system using heat pump and wind power generation. Accordingly, a wider applicable scope covering more automotive and non-automotive fields is expected.

Figure 9 Reactor Core for In-car Inverter System Using Heat-resistant Film

• **Thermoelectric Conversion Module for a Waste Heat Regeneration System**

Thermoelectric conversion technology capable of directly converting thermal energy to electric energy is anticipated as a promising form of waste heat regeneration technology for automobiles and industrial furnaces due to its structural simplicity and ease of installation. By using a powder metallurgy method to manufacture this module, reduced thermal conductivity (phonon scattering) is enabled via micronization of crystals, helping improve the performance of thermoelectric materials. We are trying to make a thermoelectric conversion module with environmentally friendly materials such as SiGe, Mg_2Si and $Mn_{1.8}Si$ and develop a thermoelectric element of ZT=1.0 or higher, which is a performance index criterion suitable for actual use. **Figure 10** shows an encapsulated thermoelectric conversion module. By decompression-sealing the encapsulated module, the thermal contact resistance between the module and contacting case can be reduced to an extent that underlines the potential for use within high-temperature and corrosive environments. It is therefore expected to be a technology capable of regenerating electricity from waste heat from automobiles and improving fuel efficiency[10)-11)].

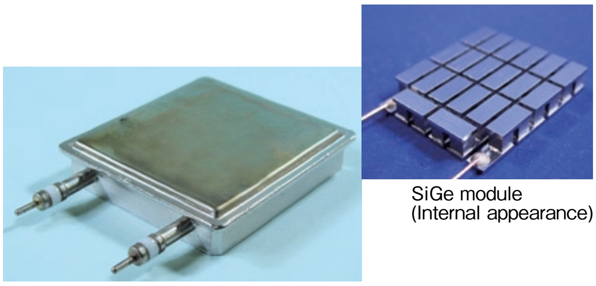

Figure 10 SiGe Thermoelectric and Encapsulated Modules

5 Summary

The market for automobile has expanded, weathering multiple challenges throughout its long history. We envision the future path of automobile over the next 20 years as follows:

The automobile market will continue alongside growth in emerging markets while manufacturing sites and manufacturing processes change. Improved fuel-efficient technology for fossil fuel automobiles will be pushed to the limits, and the era of a switch to next generation powered vehicles is upon us. We intend to develop new products as an automotive parts supplier, remembering the keywords: “comfort and rapidity”, “safe and at will” and “earth-friendly”, swiftly responding to “the needs for automobile technology development”.

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The Business Trend of In-Vitro Diagnostics: MAST CLA and Seratestam

Takeshi Sawazaki
Medical Business Unit

Antigen-antibody and enzyme reactions are basic technologies used for in-vitro diagnostics. The antigen-antibody reaction has high sensitivity and measurement specificity; for example, the concentration of pg/mL is expected as a detection limit. The enzyme reaction technology enables rapid measurement based on a simple principle, which also means the design of the instrument can be kept simple. Medical Business Unit of Hitachi Chemical is developing allergy and POCT (Point-of-Care Testing) businesses as two cores. We are currently marketing the Mastimmunosystems ("MAST CLA") for the allergy business and Seratestam for the POCT business respectively. MAST CLA is an immunological diagnostic capable of measuring 33 allergens simultaneously with 200 μL of serum. Seratestam is a biochemical diagnostic capable of measuring 22 items with information on a two-dimensional bar code, which records measurement parameters etc. A skilled laboratory technician is not needed to operate the Seratestam. The current business of in-vitro diagnostics is aligned to the trend among patients for QOL (Quality of Life) improvement. The future goal is to expand sales of current products and become a company that spreads diagnostic reagents, not only domestically, in Europe and the America but worldwide within the next 20 years.

1 Diagnostic Reagent

Diagnostic reagents can be classified into two categories, namely in-vivo diagnostics that are directly administered to the human body and in-vitro diagnostics that analyze components in blood, urine, etc. Although both diagnostics can be effective auxiliary methods of diagnosing diseases, Hitachi Chemical lines up only in-vitro diagnostic reagents for our products and our R&D activity is dedicated to in in-vitro diagnostic reagents only.

Japan's Pharmaceutical Affairs Law defines a diagnostic reagent as a "medicinal product not administered directly to humans or animals of medicinal products used solely to diagnose diseases". Accordingly, diagnostic reagents are legally classified as medicinal products and strict rules must be observed when developing, manufacturing and controlling the same. Our medical business unit abides by these rules and laws, having obtained international standard certification (ISO 13485) in 2005 as well as a license granted under Japan's Pharmaceutical Affairs Law.

2 Technology Used for Diagnostic Reagents

Diagnostic reagents are required to measure trace components accurately. The most basic elemental technology enabling this is a technology based on an antigen-antibody reaction. For instance, if the human body is infected with bacteria, it produces an antibody and by measuring this antibody, we can indirectly determine whether it is infected or not. When developing diagnostic reagents, we built an antigen-based measurement system (in this case, protein derived from bacteria) as a material that reacts specifically with the targeted antibody for measurement. Conversely, if we want to measure a specific substance in-vivo, we prepare an antibody in advance that reacts specifically with the targeted substance for measurement and use it as testing material. Since the sensitivity and specificity of the antigen-antibody reaction is very high; as an example of sensitivity, concentration at a level of pg/mL can be measured.

Conversely, another measurement system uses specific enzyme and substrate reactions. For instance, when measuring enzymatic activity in-vivo, one method uses an enzyme-specific substrate. Although the sensitivity of this method is not as high as that of antigen-antibody reactions, the measurement process simply requires mixing of enzyme and substrate, hence does not take long. Moreover, the progress of the reaction is accompanied by color changes, meaning a spectrophotometer suffices as a detector and allowing simplified design of the measurement instrument.

Other elemental technologies include PCR (Polymerase Chain Reaction), which is a method of amplifying genes (DNA segments) that can detect minute amounts of genes and is mainly used for assays of bacteria and viruses.

3 Market and Trends of Diagnostic Reagents

The main market segment for diagnostic reagents in Japan is that for testing infectious diseases: 60 billion yen annually, followed by immunological investigations (tests using immune responses, e.g. allergy tests) and biochemical examinations (measuring levels of enzymes, lipids and electrolytes inside the body e.g. liver function test): at 56 billion yen each and tumor markers at 23 billion yen annually. (Statistics 2010, Japan Association of Clinical Reagents Industries)

In recent years, the POCT market has been expanding rapidly, already reaching USD 90 billion in the U.S. and exceeding 100 billion yen in Japan.

POCT is a collective term for tests performed near patients e.g. at the office of medical practitioner. It is attracting attention as a test which helps enhance the quality of diagnoses as clinicians can judge and give patients medical attention promptly based on test results, give follow-up observations and monitor patients' prognosis.

4 Diagnostic Reagents of Hitachi Chemical

Medical Business Unit is involved in allergy and POCT businesses as two key sectors. The former lines up allergy diagnostic reagents and MAST CLA as core products; the latter currently lines up 22 items as Seratestam.

4.1 The Mastimmunosystems ("MAST CLA")

MAST CLA is a diagnostic reagent used to investigate allergy by measuring the IgE antibody in serum (**Figure 1**). Allergy and IgE are closely related; for example, a specific IgE to the cedar allergen can be found in the serum of a patient with the pollen allergy.

The most remarkable feature of MAST CLA is the capability to test 33 items of an allergen-specific IgE simultaneously. 33 types of allergen are immobilized in the solid phase of a specialized reaction container, whereupon an allergy test is completed about 6 hours after the serum is dispensed[1].

The measurement principle is shown in **Figure 2**. The first step involves reacting the allergen that is immobilized in the solid phase and the allergen-specific IgE in serum. The second step is to react the enzyme labeled anti-human IgE antibody to form a complex of "allergen"-"specific IgE"-"enzyme labeled antibody". Finally, dispense luminescent reagent (luminol, hydrogen peroxide) and measure the degree of luminescence using a specialized Luminometer.

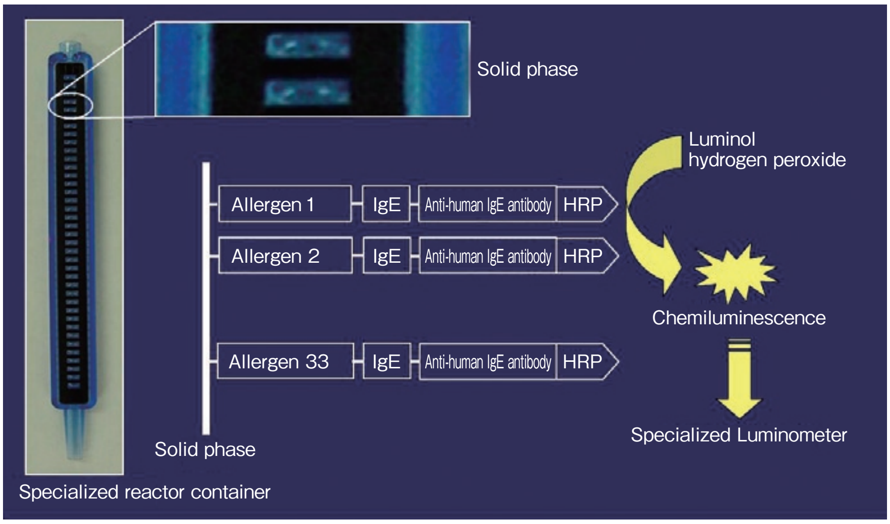
MAST CLA uses the 33 types of allergen listed in **Table 1**. Because extraction and purification methods differ for each of the 33 allergen types and the immobilization methods vary, MAST CLA preparation requires numerous technologies and know-how. We also have full-filling serum libraries that are essential for product development, quality maintenance and which offer us a major advantage when operating the allergy business.

MAST CLA has another feature-namely that a mere 200 μL of serum suffices to measure 33 items. This is especially advantageous for measurement in infants as the volume of blood required for sampling is very limited. We envision the development of new reagents used for additional items targeted at certain medical departments for diagnosis and treatment e.g. pediatrics.

Figure 1 The Components of MAST CLA
(Left : Luminometer; Specialized Measurement Instrument
Right : Reagents)

Table 1 The Measurement Items of MAST CLA

No.	Test Item Name	No.	Test Item Name
1	Mite f	18	Aspergillus
2	House Dust	19	Latex
3	Cat Dander	20	Buckwheat
4	Dog Dander	21	Wheat
5	Timothy Grass	22	Peanut
6	Sweet Vernal	23	Soybean
7	Orchard Grass	24	Rice
8	Ragweed Mix	25	Tuna
9	Mugwort	26	Salmon
10	Japanese Cedar	27	Shrimp
11	Japanese Cypress	28	Crab
12	Black Alder	29	Cheddar Cheese
13	White Birch	30	Milk
14	Penicillium	31	Beef
15	Cladosporium	32	Chicken
16	Candida	33	Egg White
17	Alternaria		



HRP : Horseradish Peroxidase

Figure 2 The MAST CLA Measurement Principle

4.2 Seratestam

Seratestam can currently be used to measure 22 test items, basically in the biochemical field in Japan (**Table 2**). Eight of the 22 test items are listed as key measurement items for "special health checkups" and "special health guidance" as set forth by law, allowing clinicians to obtain critical information to diagnose lifestyle-related diseases.

Another feature of Seratestam is its compatibility with large analyzers as it uses the same liquid reagents used for large automated analyzers and is easy to handle as it is filled in specialized compact cartridges. Also, a 2D bar code is labeled on cartridges and once a sample and diagnostic reagent are set up in the clinical analyzer, testing starts as soon as the 2D bar code is automatically read, eliminating the need for an experienced laboratory technician to operate the clinical analyzer (**Figure 3**).

One example of the measurement principles is given in **Figure 4**. Here, the first step is to dispense serum into a reaction cell, followed by pouring the diluent into the reaction cell and diluting the serum. Next, the reagent that reacts with the target substance in the serum is dispensed into the same reaction cell and the absorbance that increases (or decreases) in proportion to the concentration of the target substance is measured. The measuring time required is about 15 minutes. Seratestam is designed to ensure effective mixing of diagnostic reagents, even if mechanical stirring is not separately available, meaning measuring equipment can be kept simple.

Since the 2D bar code records measuring and calibration parameters, etc., the operator need not configure parameters him/herself, can skip calibrations and keep operations simple. Although the majority of measurement items are currently biochemical-related, sales of Seratestam have already started in Europe and we are preparing to launch sales in the U.S.; three electrolytes - Na, K and Cl - have been newly developed and lined up.

Table 2 The Measurement Items of Seratestam

No.	Name of Item	
1	ALP	Enzyme
2	γ-GTP	
3	LD	
4	GOT/AST	
5	GPT/ALT	
6	AMY	
7	CK	
8	GLU	Blood sugar and lipid
9	TG	
10	T-CHO	
11	HbA1c	
12	HDL-C	
13	LDL-C	
14	CRE	Protein including nitrogen
15	BIL	
16	BUN	
17	UA	
18	TP	
19	ALB	
20	CRP	
21	CA	Electrolyte
22	IP	

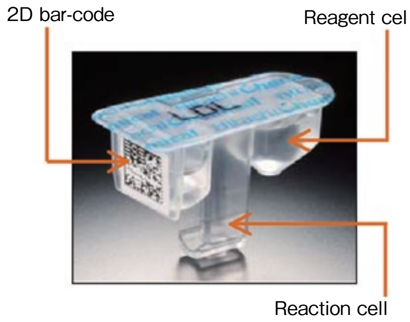


Figure 3 The Components of Seratestam
(Left : Clinical Analyzer; Specialized Full-Automatic Analyzer Right: Reagents)

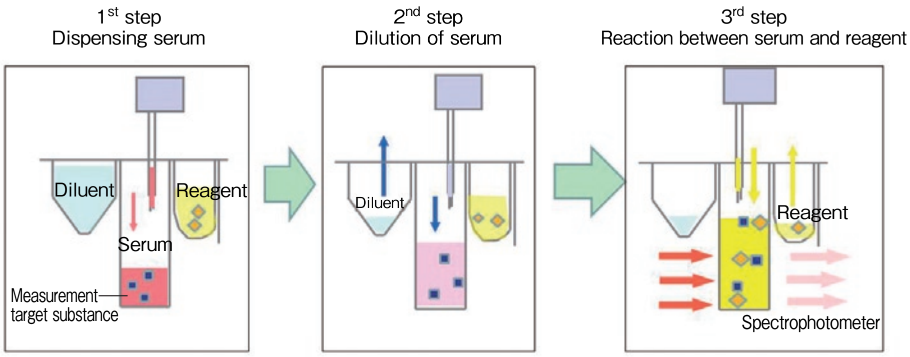


Figure 4 The Measurement Principle for Seratestam

5 Diagnostic Businesses to Come 20 Years After

The improvement of QOL will be a keyword for medical service in future. The early discovery and confirmation of disease is considered increasingly crucial and further enhanced basic performance parameters e.g. sensitivity, specificity and speed will be required.

Today, diagnostic reagents are used as one of the options to identify illness. Soon, however, healthy individuals may self-administer their own health. If a preventive health check function is added to diagnostic reagents, we expect a new market to emerge. Henceforth, tailor-made medical services may become important. Once each home is linked online to healthcare providers, patients can receive measurement results and medical practice at home.

Hitachi Chemical is pondering the next actions to meet the needs for QOL improvement in patients. In the allergy business sector, we plan to develop a fully-automated instrument for MAST CLA and market it worldwide while running the current business model built on clinical laboratories. Currently MAST CLA can measure IgE in blood. Subsequently, we will challenge the next allergy diagnosis, including measurement of sample in urine and saliva by substantially enhancing reagent sensitivity.

In the POCT field, we plan to develop and expand unique measurement items, mainly targeting lifestyle-related diseases. Although Seratestam currently measures only biochemical measurement items, we plan to add immunological measurement items, downsize the Seratestam clinical analyzer and target rapid testing. We hope to develop a compact Seratestam clinical analyzer suitable for home-use and enter a new market of preventive diagnostics with appropriate specifications usable for individual health control.

In 20 years, we will become a company operating diagnostic reagent businesses not only in Japan, Europe and the United States but also globally, by expanding the sales of current product lines.

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Editor's Note

In the preceding vol. 54 issue, we announced a change to our editorial policy and paper space layout. However, the current vol. 55, in commemoration of the 50th anniversary of our company's spin-off from Hitachi Ltd., has been edited differently from what we announced last time. In the "commentary" section from Mr. Tanaka, company CEO; we placed his pledge and message. His strong will to continue our R&D activity constantly and achieve our corporate philosophy backed by a spiritual backbone, namely the three genes inherited within our company group, is reflected. The topics of all articles were extracted from our key business fields and focused business areas for the future, while the main topics concern the current picture of our approach in each business field and our future undertakings. This time we tried to make each article easy for readers to understand the outline of our company R&D activity and its future trajectory. Accordingly, the content of each article is more like a technical review in each R&D field rather than an academic technical paper on individual R&D themes. Your understanding is appreciated.

This year our company celebrates 101 years since the start-up and 51 years from the spin-off and will start a new step forward toward the future. As before, our company continues striving to realize its corporate philosophy that states, "Contribution to Society through New Products and Technical Advancements to Open Up the Era of the Next Generation" and through R&D activity, "Creation of New Value ahead of its Time". It is our pledge to continue publishing accomplishments realized through all these activities. Finally, we will be more than happy to receive any comments you may have.

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