Functional Materials for the Smart Community

Teiichi Inada
New Business Development Headquarters
Tsukuba Research Laboratory
Social Infrastructure-related Materials Development Center

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

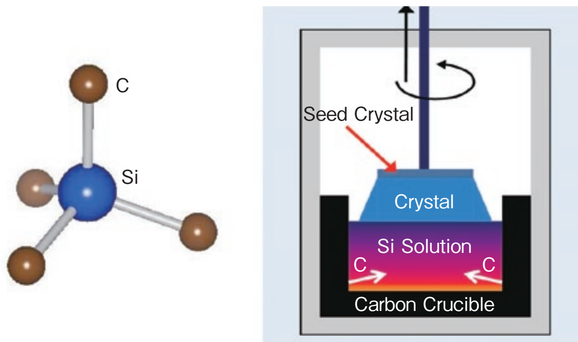


Figure1 SiC Structural Unit and the Method of Growing Single Crystal SiC from Solution

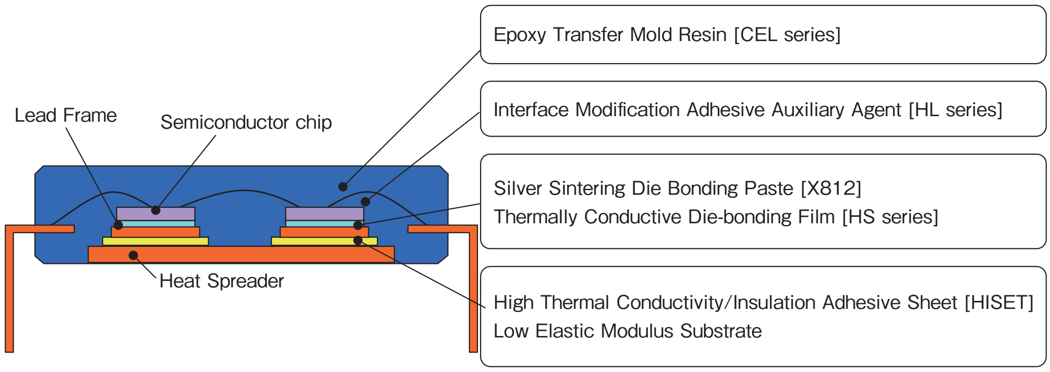


Figure 2 Hitachi Chemical's Technology for Power Module Package

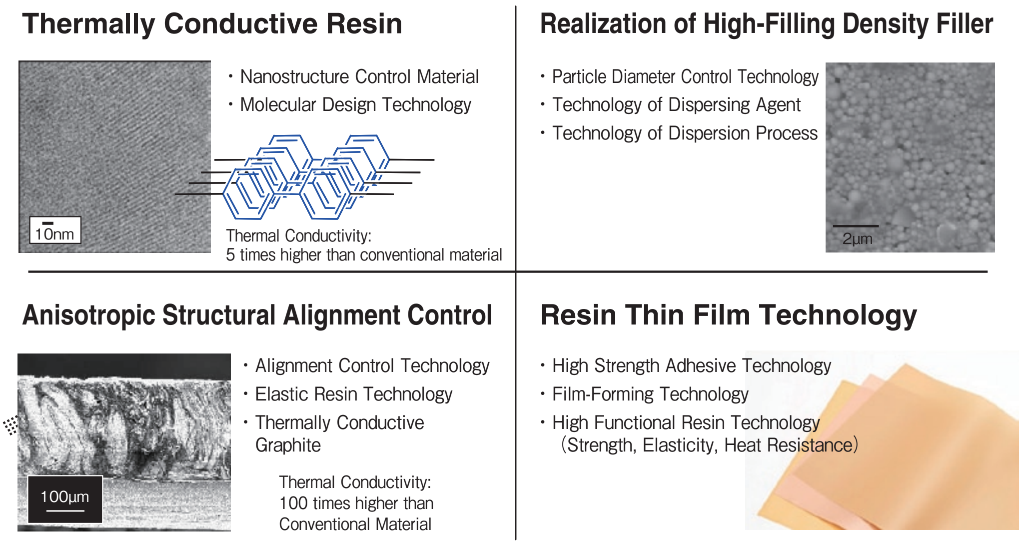
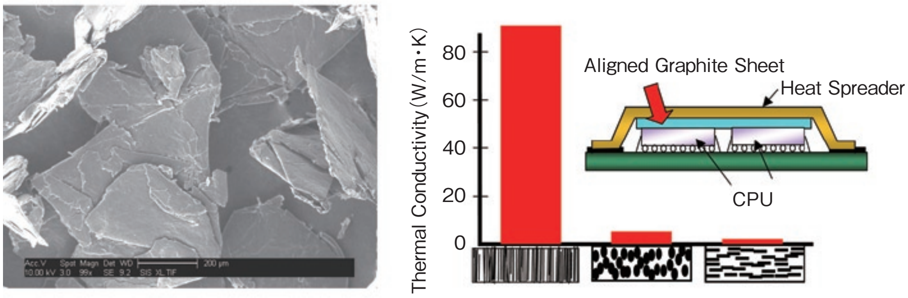


Figure 3 The Key Technologies of Hitachi Chemical

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

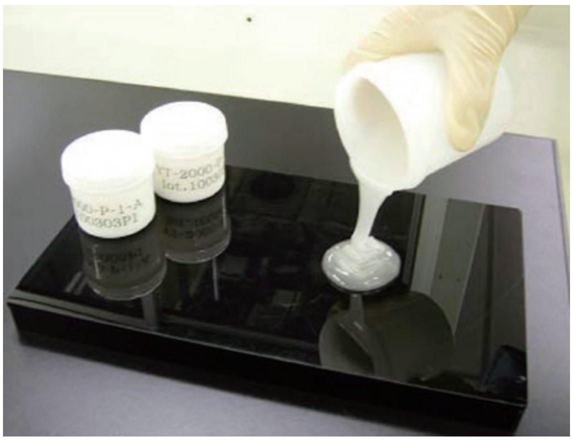
and insulation materials, etc., which are helpful in controlling heat.

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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