Fundamental and Advanced Technologies

Fundamental Technology
Advanced Technology

Outlook

Global competition is increasingly getting fierce with the expansion of emerging markets centered on Asia. Most Japanese companies are pressing ahead with the selection and concentration of their businesses, promoting structural reform by allocating research and development resources preferentially to product development, and trying to gain competitive advantages. On the other hand, too much focus on product development has raised concerns about sustained growth, such as a shorter research and development scope and insufficient investment in advanced studies. As a countermeasure, an increasing number of companies employ open innovation-style technology strategies to seek out external resources. Such strategies are also important to promptly and properly address customer needs for the technologies that were found to be nonexistent in the company as a result of the selection and concentration effort.

We at Fuji Electric have set power semiconductors and power electronics at the center of our core technologies and systematized these core technologies through instrumentation and control technologies to reinforce our efforts in electrical and thermal energy-related solutions. We are also actively involved in the fundamental and advanced technologies supporting these core technologies to contribute to continuing innovations and improving the quality of research and development. As open innovation efforts, we participated in a large-scale project of industry-government-academia cooperation to reinforce our core technologies such as a wide-band gap power semiconductor technology. We are also conducting joint research with universities and other external research institutions to refine our fundamental technologies and to seek prospective advanced technologies.

As for the advanced technologies for power semiconductors, we have developed a 1,700 V withstand voltage class SiC-Schottky barrier diode (SiC-SBD), a 1,200 V withstand voltage class SiC-metal-oxide-semiconductor field-effect transistor (SiC-MOSFET) and a 13 kV class ultra-high withstand voltage SiC-insulated gate bipolar transistor (SiC-IGBT) by conducting the joint research or by participating in a program of the National Institute of Advanced Industrial Science And Technology. When mounted on inverters or other power electronics equipment, SiC-SBDs and SiC-MOSFETs are expected to significantly reduce the power loss in the equipment. Ultra-high withstand voltage SiC-IGBTs are expected to be used for applications in fields requiring ultra-high withstand voltage such as power transmission/distribution equipment. To develop these devices it is necessary to control the interfacial properties between metal and SiC or an oxide film and SiC in a highly reproducible manner. Consequently, we have developed an analysis technology to compare the density distribution and binding state of atoms at a resolution level of several atomic layers by combining synchrotron radiation photoemission spectroscopy and analysis technique using transmission electron microscope.

In order to accurately predict losses that occur in the semiconductor devices in power electronics products, we have developed a loss prediction technology that uses a device equivalent circuit model. Moreover, we participated in IEC committee activities and promoted development of standard-conforming technologies to advance the global expansion of power electronics products.

As instrumentation and control technologies required for systematization, a high-speed database technology that can manage a large volume of measurement data simply and a virtual hardware application technology that helps reduce development person-hours for built-in software have been developed. A machine learning technology that lets a computing machine learn from a large volume of image data groups and generate algorithms automatically has been developed and applied to robot vision.

Power magnetic materials used in electrical equipment such as rotating machines or transformers have a great influence on the equipment performance because their magnetic properties change depending on their manufacturing and design conditions. By measuring the magnetic properties under environment simulating such conditions, we have developed a technology that can optimally utilize power magnetic materials.

As a component used for thermal energy solutions, we have developed a steam generating heat pump system utilizing warm water discharge from factories and conducted a field test at the Mie factory.

We worked on magnetic layer technology for heat assisted magnetic recording method that is expected to be the next-generation recording method for hard disk with areal density of 1.4 Tbits/in^2 or higher. We have developed a material that decreases the Curie temperature by 100 °C while keeping magnetic anisotropy energy that is twice as high as the level now in use.

A reactor concept using a modular high temperature gas-cooled reactor has been established. In the concept, the reactor can cool down by natural heat radiation during an emergency shutdown and has complete passive safety characteristics.

We have completed development of elemental technologies for a multi-analysis instrument that is capable of measuring PM 2.5 based on a combination of optical techniques and mass analysis techniques. It enables real-time measurement of component analysis, which took at least 8 hours with a conventional method.

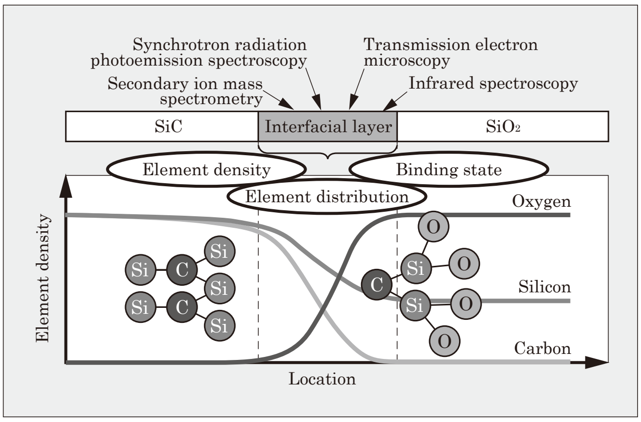
Fuji Electric will take on the challenge of developing advanced technologies that will lead to innovations in electrical and thermal energy technologies and instrumentation and control technologies, while making full use of the fundamental technologies that support such development to improve the quality of research and development in the future.

Fundamental Technology

1 Analysis Technology Supporting the Development of Next-Generation Power Devices

In order to improve the reliability of SiC-MOSFET, it is necessary to ensure good interfacial properties of a gate oxide film. As in the same way for Si, a gate oxide film is formed by thermal oxidation. However, a complicated structure is generated between the SiC substrate and oxide film owing to elements added to improve interfacial properties and carbon emitted during the formation process, which may interrupt the flow of electrons and decrease reliability. Fuji Electric utilized various analysis techniques including synchrotron radiation photoemission spectroscopy and transmission electron microscopy, and has established a method to evaluate the interfacial surface structure of a gate oxide film in terms of element density, distribution and binding state. As a result, we were able to acquire a deeper understanding of the relationship between the oxide film formation process and interfacial structure and improve the properties of the interfacial surface of a gate oxide film to increase the reliability of SiC-MOSFET.

Fig.1 Schematic diagram of density, distribution and binding state of interfacial elements

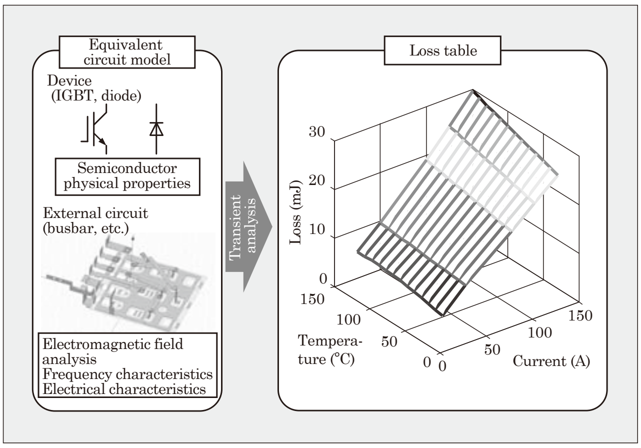


---

2 Equipment Loss Prediction Technology Using Device Equivalent Circuit Model

In the power electronics equipment, it is extremely important to accurately determine the losses that occur in semiconductor devices, in the design of equipment structures and heat sinks. These generated losses, however, vary depending on the operating conditions such as temperature or electric current, parasitic inductance resulting from equipment wiring and external circuits such as a gate drive circuit. Therefore, to determine such losses, repeated prototyping and measurement were required. Fuji Electric is developing a simulation technology to predict the generation of losses by combining a device equivalent circuit model and an external circuit model. The simulation technology enables the highly accurate analysis which is independent of the operating conditions because the device equivalent circuit model is based on the physical properties. Moreover, when the relationship between the losses and operating conditions are tabularized and combined with thermal analysis, the losses caused by the change in temperature can be predicted. Thus the simulation technology indicates the potential of a shorter period of equipment design review.

Fig.2 Loss table using an equivalent circuit model



---

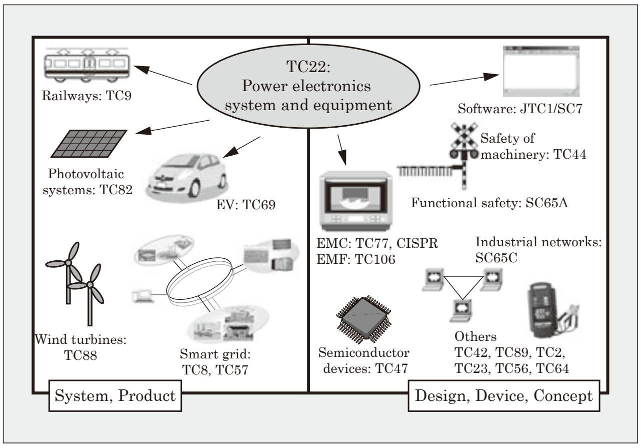
3 Conformance to Power Electronics-Related International Standards

In order to promote the global expansion of its primary product line of power electronics products, Fuji Electric has been involved in several technical committees of the International Electrotechnical Commission (IEC), especially in TC22 (power electronics), SC22G (drive) and CISPR (EMC), while developing technologies to ensure conformance to standards. The main achievements are as follows:

(1) Assumed the post of a project leader for the EMC standards for photovoltaicr power conversion systems and is leading the standard creation processes.
(2) Conducted a verification test for drive efficiency standards in Japan, presented views in standard review meetings and obtained the understanding of each country.
(3) Worked on the first draft of the EMC testing technologies for the functional safety standard that is under revision and made Japan's view reflect in it.

Fuji Electric will advance product development and standard creation simultaneously for the EMC standards about which more active discussion is expected, and for standardization related to system interconnection.

Fig.3 International standards related to power electronics



Fundamental Technology

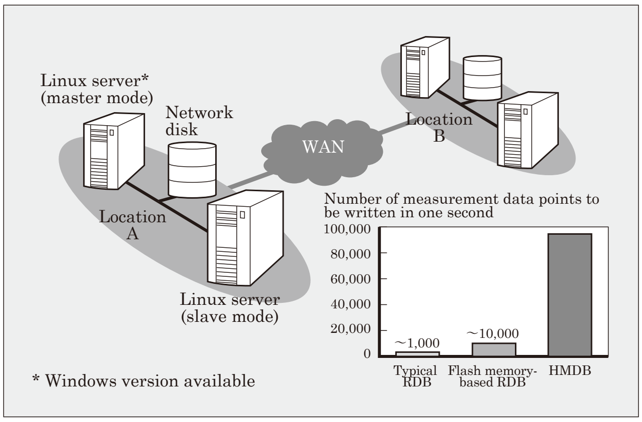
4 High-Speed Database Technology

Fuji Electric has developed a database called high-speed measurement database (HMDB) to enable simple and high-speed management of a large volume of data measured at a constant cycle such as smart meter readings in meter data management system (MDMS) or various energy values collected by the building and energy management system (BEMS) aggregators.

By specializing in measurement data storage, the database allows even a Linux server with a single configuration to store 30 million smart meter readings within six minutes.

It also supports high-reliability options such as a redundant system and dual location system, and can also be implemented as infrastructure middleware of an industrial/social system.

Fig.4 HMDB system configuration and number of measurement data points to be written



* Windows version available

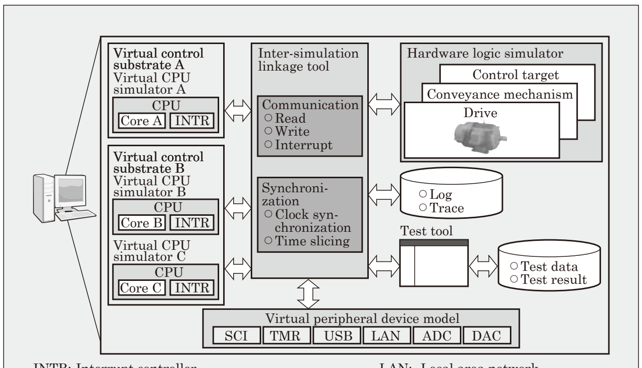
5 Virtual Hardware Application Technology for Development of Built-in Equipment

In order to reduce the development period (by 35%) and development person-hours (by 30%) for built-in software, Fuji Electric developed a virtual hardware development environment for built-in equipment that allows built-in CPU's binary codes to work on a PC without any modification.

This development environment consists of a virtual CPU simulator on which built-in programs are enabled to run, an inter-simulation linkage tool and simulators (virtual peripheral device model, hardware logical simulator and test tool).

The virtual peripheral device model can be used in common when it is connected with respective virtual CPU simulators via the inter-simulation linkage tool. Even a test of hardware abnormalities, which is normally difficult to make happen, can be automated in a virtual environment, resulting in improved reliability as well as reduced development person-hours.

Fig.5 Virtual hardware development environment



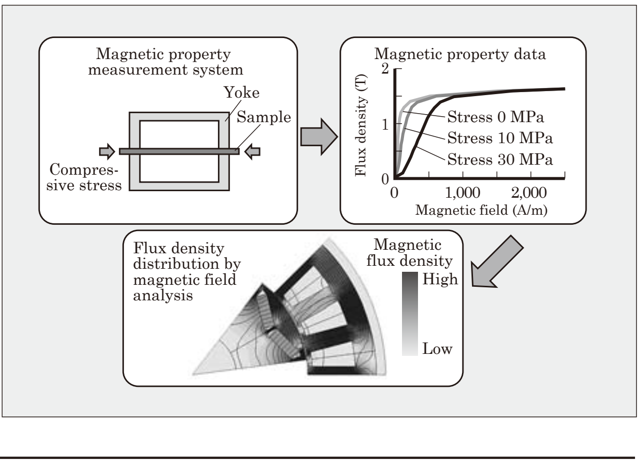
INTR: Interrupt controller
SCI: Serial communication interface
TMR: Timer
USB: Universal serial bus
LAN: Local area network
ADC: Analog to digital converter
DAC: Digital to analog converter

6 Technology of Optimum Utilization of Power Magnetic Materials

It is known that power magnetic materials used in electrical equipment such as rotating machines or transformers have a great influence on the equipment performance because their magnetic properties change depending on the product manufacturing and design conditions. Electrical steel sheets, in particular, have a strong tendency to show such properties. Consequently, there is a need to optimize electrical equipment based on a design method that takes into account the magnetic properties of the magnetic materials under the actual usage environment.

Fuji Electric has established a technology to optimally utilize power magnetic materials by obtaining the magnetic properties under an environment that simulates manufacturing conditions (e.g., fixed stress, press punching, inter-locking and welding) and design conditions (e.g., inverter excitation, flux leakage to surrounding structural materials and DC-biased excitation), and then applying them to magnetic field analysis. This technology is being used to improve product performance and to shorten design period by reducing the number of prototyping attempts.

Fig.6 Example of a design method that takes into account the magnetic properties under the actual usage environment

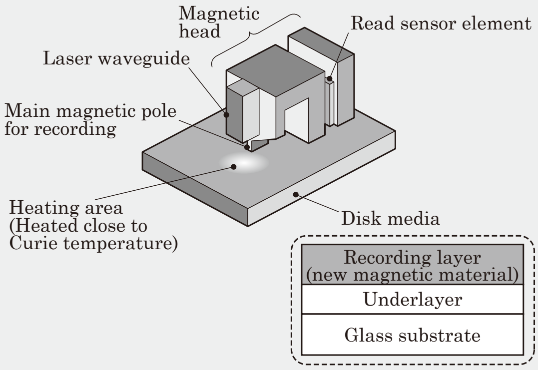


Advanced Technology

1 Magnetic Layer Technology for Heat Assisted Magnetic Recording

It is expected that the recording method will be shifted to heat assisted magnetic recording for hard disk drives (HDDs) with areal density of 1.4 Tbits/in^2 (1 TB per 65-mm disk) or higher. The recording layer must be made of a magnetic material having high magnetic anisotropy energy such as ordered FePt alloy; however, ordered FePt alloy has a high Curie temperature. Reducing the Curie temperature is desirable because limiting the heating temperature during recording and reducing the power of the heat source laser can improve reliability. Fuji Electric found a material that has about twice the magnetic anisotropy energy of the current material (1.6×10^7 erg/cm^3) and a Curie temperature of at least 100°C lower than that of ordered FePt alloy, and can maintain a fine granular structure. The recording layer using this material can be expected to reduce the laser power by 20% and improve reliability.

Fig.7 Structure of thermally assisted magnetic recording

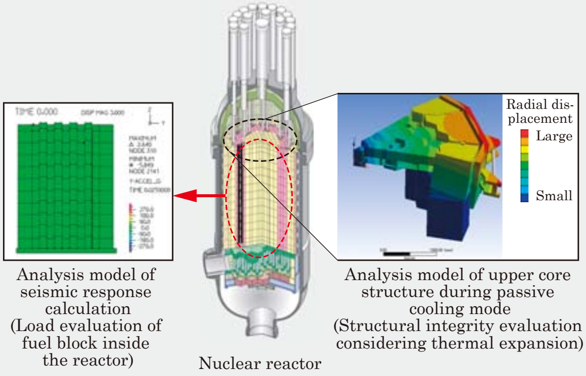


2 Modular High Temperature Gas-Cooled Reactor Featuring Complete Passive Safety Characteristics

High temperature gas-cooled reactor (HTGR) is a next-generation nuclear reactor that has features as follows: (1) it has fully passive safety features, such as that it can be cooled only by natural phenomena after an emergency shutdown; and (2) it can supply high temperature heat to realize various heat applications, such as high-efficiency gas turbine power generation and hydrogen production from water.

Fuji Electric is focusing research and development to establish a reactor concept which realizes complete passive cooling and is used to very high temperature reactor (VHTR) offering much higher temperature. The design technology for structural integrity evaluation of the reactor internals during passive cooling mode, the seismic response analysis technology of reactor core consisting of graphite blocks and the reactor core design technology supporting a higher burn-up operation have been developed. As a result, a basic concept of reactor structure adopting a metallic core restraint mechanism proven in a high-temperature engineering test reactor (HTTR), the first very-high temperature gas reactor in Japan has been established, which achieves complete passive cooling even in a VHTR reactor with an outlet temperature of 900°C.

Fig.8 Example of seismic response and structural analysis



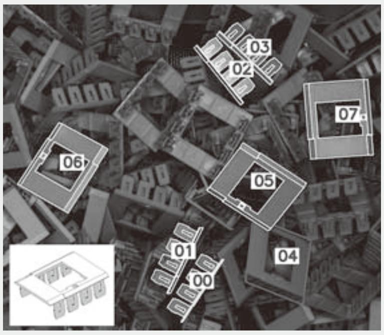
3 Application of Machine Learning Technology to Robot Vision

In the robot vision field, research and development work has been continued to help robots recognize the position and pose of randomly stacked parts and take out a specific component.

In the previous development approach, developers focused on shape patterns that were considered to be characteristic of individual parts and then built algorithms so that robots could recognize the position and pose of the parts. When the parts were changed, the development work had to be started over again.

The application of "machine learning" that takes an approach of letting a computing machine learn the characteristic patterns of the parts from a large volume of image data groups and generate optimum algorithms automatically has made it possible to greatly reduce the development person-hours required for new parts.

Fig.9 Result of part position and pose recognized by machine learning



Recognized parts: 00, 01, 02, 03, 05, 06, 07

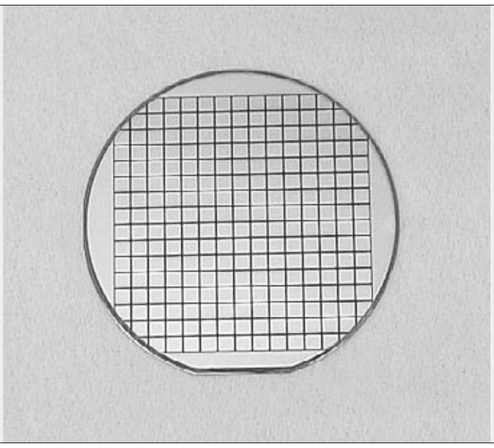
4 1,700 V Withstand Voltage Class SiC-SBD

To meet the further power-saving requirement of power electronics systems, free wheeling diodes using silicon (Si-FWDs) are being replaced with silicon carbide Schottky barrier diodes (SiC-SBDs).

Fuji Electric has developed 1,700 V withstand voltage class SiC-SBDs together with the National Institute of Advanced Industrial Science and Technology. By replacing Si-FWDs with these SiC-SBDs, we succeeded in reducing the power loss generated in the latest Si-IGBT module by 39%. These developed SiC-SBDs are enable to be operated at high temperature exceeding 200°C and have avalanche withstanding capability at least 10 times higher than that of Si-FWDs. Fuji Electric is planning to equip various types of next generation power electronics systems with these 1,700 V withstand voltage class SiC-SBDs.

➲Reference: FUJI ELECTRIC REVIEW 2013, vol. 59, no. 4, p. 218

Fig.10 1,700 V withstand voltage class SiC-SBDs within a wafer

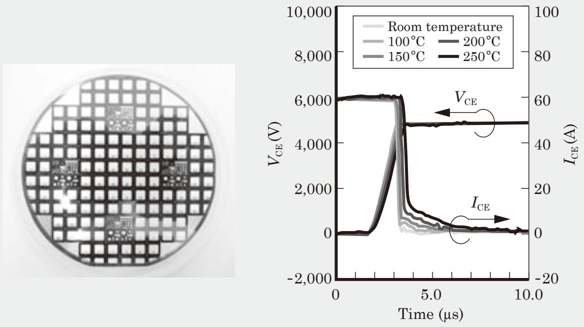


5 13 kV Class Ultra-High Withstand Voltage SiC-IGBT

Fuji Electric participated in the Funding Program for World-Leading Innovative R&D on Science and Technology (FIRST) led by the National Institute of Advanced Industrial Science and Technology, and has developed a 13 kV class ultra-high withstand voltage SiC-insulated gate bipolar transistor (SiC-IGBT). This device is expected to be used for applications requiring ultra-high withstand voltage such as power transmission/distribution equipment in a smart grid. Because of its higher withstand voltage and lower power dissipation than those of conventional silicon devices, this device allows energy savings as well as downsizing and weight reduction of equipment.

This device is characterized by the use of a high-quality flip-type wafer with all layers formed by epitaxial growth technique. The combination of the new oxidation technique and Carbon-face IEMOS structure has achieved good electrical properties. These technologies has realized properties of the highest level in the world, such as differential on-resistance of 11 mΩcm^2 and withstand voltage of 16 kV.

Fig.11 13 kV class ultra-high withstand voltage SiC-IGBT



(a) SiC-IGBT wafer (b) Turn-off waveforms

Fuji Electric

Innovating Energy Technology