# TOSHIBA REVIEW

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## Special Reports

### Technologies Enhancing Efficiency of Discrete Semiconductors to Support Energy-Saving Society

**Toshiba Discrete Semiconductor Devices as Driving Force for Changing Our World**
KAWANO Tomohiro

**Latest Trends in and Future Outlook for Discrete Semiconductor Technologies**
NISHIWAKI Tatsuya / YOKOTA Makoto / YAMAGUCHI Masakazu
Severe global environmental and energy problems are driving demand for more effective utilization of electric energy in a broad range of fields including information and communication technology (ICT) systems, automotive and industrial systems, and electricity generation and transmission systems.
Toshiba Electronic Devices & Storage Corporation has been progressively developing and introducing a wide variety of discrete semiconductor products for electric energy conversion and protection applications ranging from small- to large-scale power systems, and is also making efforts to develop advanced technologies and commercialize products applying these technologies. We are committed to delivering various solutions to enable the efficient, stable, and secure handling of electric energy by means of our advanced discrete semiconductor technologies with the aim of realizing an energy-saving society.

**Low-Voltage Power MOSFET Technologies for Next-Generation Large-Capacity Communication Systems**
KAGANOI Keisuke / ARAI Masatoshi / KACHI Tsuyoshi
Commercial operation of fifth-generation (5G) mobile communications commenced in Japan in March 2020 in response to the increasing volume of contents requiring large-capacity and high-speed communication capability such as video streaming services. As increased data traffic volumes lead to a dramatic increase in the power consumption of base stations for mobile communications, it has become necessary to further improve the efficiency of power supply units in these base stations. Highly efficient low-voltage power devices with a drain-source voltage of 80 V or 150 V are required not only for AC-DC converters to convert the AC voltage fed from a commercial power supply into the -48 V DC reference potential used in base stations but also for DC-DC converters to convert the -48 V DC into the various voltages necessary for high-frequency amplifiers and system controllers.
Toshiba Electronic Devices & Storage Corporation has developed 80 V power metal-oxide-semiconductor field-effect transistor (MOSFET) products featuring superior on-resistance, gate charge, and reverse recovery charge characteristics by utilizing its proprietary U-MOS X-H process. We are also developing 150 V power MOSFET products based on the same device structure.

**IGBTs and IEGTs to Achieve Energy Saving in Various Applications from Home Appliances to Power Transmission and Distribution Equipment**
NAKAMURA Kazutoshi / HAYASE Shigeaki / KOBAYASHI Toshiaki / KOSAKO Shuji
Insulated gate bipolar transistors (IGBTs) are widely used in various applications ranging from home appliances including motor drive units for air conditioners, microwave ovens, and induction heating (IH) cookers to equipment for electric power transmission and distribution systems. Moreover, due to the expansion of renewable energy systems, attention is being focused on injection-enhanced gate transistors (IEGTs), which can play a key role in energy saving for high-voltage DC (HVDC) power transmission systems due to their lower power loss.
In response to these diverse needs, Toshiba Electronic Devices & Storage Corporation has developed the following products by optimizing the structures of the respective devices: (1) voltage-resonant type IGBTs that can operate at switching frequencies of several tens of kHz for equipment such as home appliances, and (2) press-pack IEGTs with a high breakdown voltage and reduced conduction loss. The newly developed voltage-resonant type IGBTs achieve a 26% reduction in switching loss while also reducing noise compared with our previous products. Inverter systems using the newly developed press-pack IEGTs achieve a 31% reduction in loss compared with systems using our previous press-pack IEGTs.

**1.2 kV-Class SiC MOSFET Equipped with Embedded SBD for Improvement of Reliability**
FURUKAWA Masaru / KONO Hiroshi / SANO Kenya
Silicon carbide (SiC) metal-oxide-semiconductor field-effect transistors (MOSFETs) are a key type of power device for power supply units because of the superior performance of SiC materials. However, improvement of the reliability of SiC MOSFETs is hindered by issues associated with low carrier conductivity as a result of increased crystal defects caused by the energization of pn diodes formed between the source and drain when a current is passed through them.
In order to rectify this situation, Toshiba Electronic Devices & Storage Corporation has developed a new device structure for 1.2 kV-class SiC MOSFETs that can improve reliability by means of an embedded Schottky barrier diode (SBD) located in parallel to each pn diode so as to prevent current flowing through the diode. We have confirmed the effectiveness of this device structure using embedded SBDs through the results of tests showing that it can suppress the generation of crystal defects, thereby improving the reliability of SiC MOSFETs.

**Low-Capacitance TVS Diodes for High-Speed Data Communications**
MATSUO Keisuke / SAI Hideaki
Although the need for electronic devices with higher performance and greater compactness continues to increase, the ongoing miniaturization of electronic components is accompanied by the risk of vulnerability to electrostatic discharge (ESD). The widespread dissemination of mobile devices has consequently led to growing demand for countermeasures against ESD generated by the frequent contact of such devices with the human body.
Toshiba Electronic Devices & Storage Corporation is actively focusing on the development of transient voltage suppression (TVS) diodes that can improve the reliability of electronic devices by protecting them against ESD. In order to support the development of high-speed data communication equipment, we are launching a lineup of low-capacitance TVS diodes that can be used in high-speed signal lines to improve performance while reducing the vulnerability of electronic components to ESD.

**eFuse ICs Enhancing Protection of Power Supply Lines in Compliance with IEC 62368-1**
YADOMARU Yutaka / HIKICHI Yusuke
In recent years, attention has become increasingly focused on the safety of various electronic devices worldwide. Particularly in Europe and the United States, IEC (International Electrotechnical Commission) 62368-1, a new safety standard for audiovisual and information and communication equipment, will be introduced in December 2020. In order to enhance the protection of power supply lines of such equipment in compliance with IEC 62368-1, which is a hazard based standard, demand has arisen for electronic fuse integrated circuits (eFuse ICs) offering higher protection performance compared with conventional protective devices, as typified by physical fuses.
Toshiba Electronic Devices & Storage Corporation has developed and released a lineup of eFuse ICs compliant with the IEC 62368-1 standard that provide various protection functions comprising inrush current suppression, overvoltage protection, overheating protection, and reverse current protection, in addition to a high-speed, high-precision overcurrent protection function.

**Miniaturization of Photorelay Packages Using Chip Stacking Technologies**
TAJIRI Naoya / YAMAMOTO Mami / TANAKA Kazuki
Relays that turn an electric circuit on or off in accordance with external commands are widely applied in the field of electric actuators. A trend toward the replacement of conventional mechanical relays with photorelays, which provide several advantages including smaller size, higher speed switching, longer lifetime, and lower power consumption, has recently been progressing in line with the introduction of photorelays offering more sophisticated and more efficient functions. However, as the rated current of photorelays is presently smaller than that of mechanical relays, it is necessary to overcome the trade-off between reduction of size and increase of rated current in such products.
Toshiba Electronic Devices & Storage Corporation has developed new photorelay products that achieve smaller size and higher rated current by utilizing its proprietary chip stacking technologies to attach photodiode array (PDA) and light-emitting diode (LED) chips to a metal-oxide-semiconductor field-effect transistor (MOSFET) chip, in addition to a package structure that dissipates the heat of parts more efficiently. These photorelays also contribute to higher density packaging of electric circuits by incorporating a small resistor chip into a package of the same size as that of conventional photorelays, which require an external resistor.

**IGBT Device Model Facilitating Highly Accurate Model-Based Development**
MIZOGUCHI Takeshi / IKEDA Yoshiko / TSUKAMOTO Naoto
With the progressive introduction of model-based development (MBD) processes utilizing simulation technologies into a broad range of system design work in the fields of power electronics and in-vehicle electronics, there is a need for circuit simulations to predict power efficiency and electromagnetic interference (EMI) noise with a high degree of accuracy. In particular, a device model to precisely represent switching characteristics is essential for high-voltage and high-current insulated gate bipolar transistors (IGBTs), which are widely used in high-power applications including power control circuits.
Toshiba Electronic Devices & Storage Corporation is promoting the development of device models of its discrete semiconductor devices for MBD. We have now developed an IGBT device model taking into consideration the dynamic flow of both electrons and holes in switching operations as a replacement for conventional models, in which the tradeoff between power efficiency and EMI noise prediction is a serious issue. We have confirmed that the new model achieves highly accurate reproduction of switching characteristics measured by an actual circuit with high convergence.

**Process Technology for MOS Type GaN Devices Offering High Channel Mobility and High Reliability**
KURAGUCHI Masahiko / KAJIWARA Yosuke / MUKAI Akira
Gallium nitride (GaN) power semiconductor devices are expected to contribute to the realization of small, low-loss power electronics equipment. In particular, metal-oxide semiconductor (MOS) type GaN devices are promising candidates for next-generation power devices that can achieve normally-off operation by themselves in addition to high-speed switching.
The Toshiba Group has developed a process technology for MOS type GaN devices that makes it possible to selectively control the crystallization of an aluminum nitride (AlN) film on the recessed gate structure. Through evaluation tests of prototypes fabricated using this process technology, we have confirmed that it has the potential to achieve high channel mobility at the gate as well as high reliability under high-temperature, high-drain-voltage conditions.

## Feature Articles

**Functional Structure Modeling Method to Extract Standard Modules from Software Specifications in Groups of Existing Products**
SUNAGAWA Eiichi / NAGANO Shinichi
Accompanying the progress of market segmentation, manufacturing industries have been increasingly moving toward high-mix, small-lot production in recent years. In order to improve the efficiency of development of products including software, there is a need to extract and prepare highly reusable software functions in existing products as standard modules. Due to the complicated relationships among these functions and the differences in prerequisites for specifications, however, it has been difficult to extract such standard modules from groups of existing products.
To solve this issue, the Toshiba Group has defined a functional structure model that represents the relationships among software functions to analyze the reusability of each function in groups of existing products, and systematized an ontology-based functional structure modeling method for the extraction of standard modules from specifications of software in groups of existing products. We have confirmed the potential of this method by means of feasibility studies using software specifications of existing products in the retail field.

**$CO_2$ Electrolysis Cell Operating at High Current Density for Power-to-Chemicals $CO_2$ Utilization**
KOFUJI Yusuke / MIKOSHIBA Satoshi / KITAGAWA Ryota
The recent heightening of awareness regarding global warming mitigation has led to the development of technologies aimed at achieving a decarbonized society by reducing greenhouse gas emissions. The electrochemical conversion of carbon dioxide ($CO_2$) into chemical feedstocks such as carbon monoxide (CO), ethylene, ethylene glycol, and so on using renewable energy has been attracting increasing attention as one of the promising candidates for economically reducing $CO_2$ emissions.
Based on the power-to-chemicals (P2C) concept, Toshiba Corporation has been working on the development of a $CO_2$ electrolysis cell with a catalyst electrode aimed at realizing a practical system for the rapid treatment of large volumes of $CO_2$ gas. We have now developed a new $CO_2$ electrolysis cell that overcomes several problems in conventional cells, such as their low reaction rate due to the limitation of $CO_2$ diffusion in an aqueous solution, large footprint, and high cost. The newly developed $CO_2$ electrolysis cell realizes a dramatic improvement in reaction rate through the direct electrochemical conversion of $CO_2$ gas and facilitates the diffusion of $CO_2$ gas in large volumes through the application of a porous cathode catalyst layer. As a result, the reaction rate is improved by approximately 450-fold compared with that of conventional cells.

**Robotic Inspection Technology Substantially Shortening Time Required for Turbine Generator Inspections**
KUWAHARA Hiroaki / MATSUZAKI Akihiro / ITO Kazuo / ARAI Yuya
Power plants in Japan and overseas are experiencing a pressing demand for improvement of operational efficiency by shortening the time required for periodic inspections of turbine generators, which currently entail disassembly and reassembly work, and prolonging the intervals between such inspections. A new technology is necessary to replace the conventional inspection method, in which a great deal of time and effort is expended in removing the rotor from the stator in order to perform a detailed inspection, followed by reassembly work.
The Toshiba Group has developed a robotic inspection technology for turbine generators that can automatically perform inspections without the need for rotor removal. This technology employs a system consisting of an inspection robot, an inspection robot station, and a management system. We have confirmed that the newly developed technology can shorten the inspection time to less than 50% compared with the conventional method.

**Automation of Piece-by-Piece Cargo Loading into Containers Using Vanning Robots**
HORIUCHI Haruhiko / MARUYAMA Osamu
In the logistics business field, the volume of cargo being handled both in Japan and overseas has sharply increased with the globalization of online shopping and the expansion of investment in facilities in developing countries. However, cargo handling on the truck deck and inside the container still depends on conventional manual operations, and the burden on workers is close to reaching a limit.
With this as a background, Toshiba Infrastructure Systems & Solutions Corporation is promoting the development of so-called vanning robots, which can automatically load cargo into a container. We have now developed a vanning robot that can load cargo into a container one piece at a time. The development of this robot was achieved through the application of our proprietary handling mechanism, an automatic orbital correction technique, and a remote monitoring technique.

**Color LED Luminaire with Six Color LEDs Offering Wide Color Gamut and High Color Rendering for UHDTV Shooting**
HANYUDA Yumi / HIGASHI Hirokuni / IDE Nagisa
Color light-emitting diode (LED) luminaires for ultra-high definition television (UHDTV) broadcasting at resolutions of 4K (3 840 x 2 160 pixels) and 8K (7 680 x 4 320 pixels) have begun to be introduced in recent years as an alternative to halogen luminaires. However, conventional LED luminaires have not fulfilled the requirements of videographers, particularly drama creators, and demand has been increasing for a wider color gamut in the case of chromatic lighting and higher color rendering in the case of white lighting.
In cooperation with Japan Broadcasting Corporation (NHK), Toshiba Lighting & Technology Corporation has developed a color LED luminaire for UHDTV shooting that incorporates red, green, blue, amber, cyan, and lime LEDs, making it possible to cater to this demand through the dimming and additive mixing of these six colors. From the results of experiments on UHDTV shooting using a newly developed high-saturation color chart with a wider color gamut than the Macbeth chart generally used for evaluating high-definition television (HDTV) systems, we have confirmed that this LED luminaire offers a wider color gamut for chromatic lighting and higher color rendering for white lighting than conventional color LED luminaires incorporating four color LEDs.

**Technologies to Digitalize and Analyze Team Communications in Hotel Businesses for Improvement of Both Hospitality and Productivity**
SONOH Satoshi / FURIHATA Kentaro / KAGAWA Koichi / IZUMI Shiro
In the hotel industry, demand has been increasing in recent years for high-quality hospitality to maximize customer satisfaction in response to diverse requirements. On the other hand, the need has also arisen to enhance productivity accompanying the shrinkage of the working population and the improvement of working conditions. In this context, attention is being increasingly focused on the optimization of hotel operations from the standpoint of teams consisting of personnel engaged in various operations in order to effectively deliver better services.
Toshiba Digital Solutions Corporation, in cooperation with a hotel company, is tackling the reform of hotel operations through the digitalization of team communications. Through the use of speech synthesis and speech recognition to realize swift team communications, the time required to issue instructions to personnel for guest room cleaning operations has been reduced by about 80%. The utilization of team communication analysis technology can also contribute to the visualization of evaluation indexes for business challenges facing the hotel industry.

## Frontiers of Research & Development

Software Update Method for Embedded Devices to Address Security Risks of IoT Systems
Deep Reinforcement Learning Method Allowing Selection of Automobile Driving Lane in 100-Millisecond Cycle