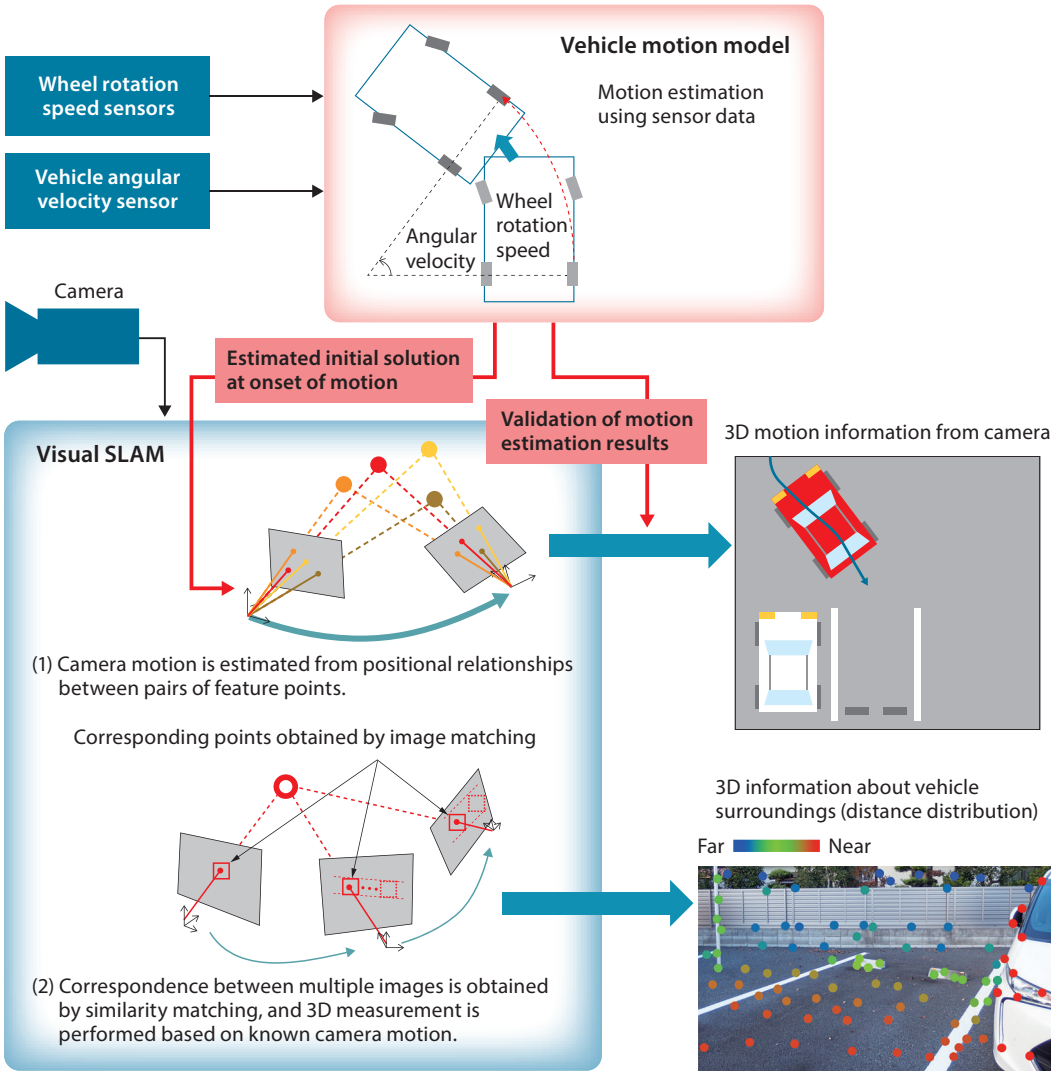
7. Electronic Devices and Storage

7.1 Visual SLAM Technology to Improve Motion Estimation for Vehicles Traveling at Ultralow Speed



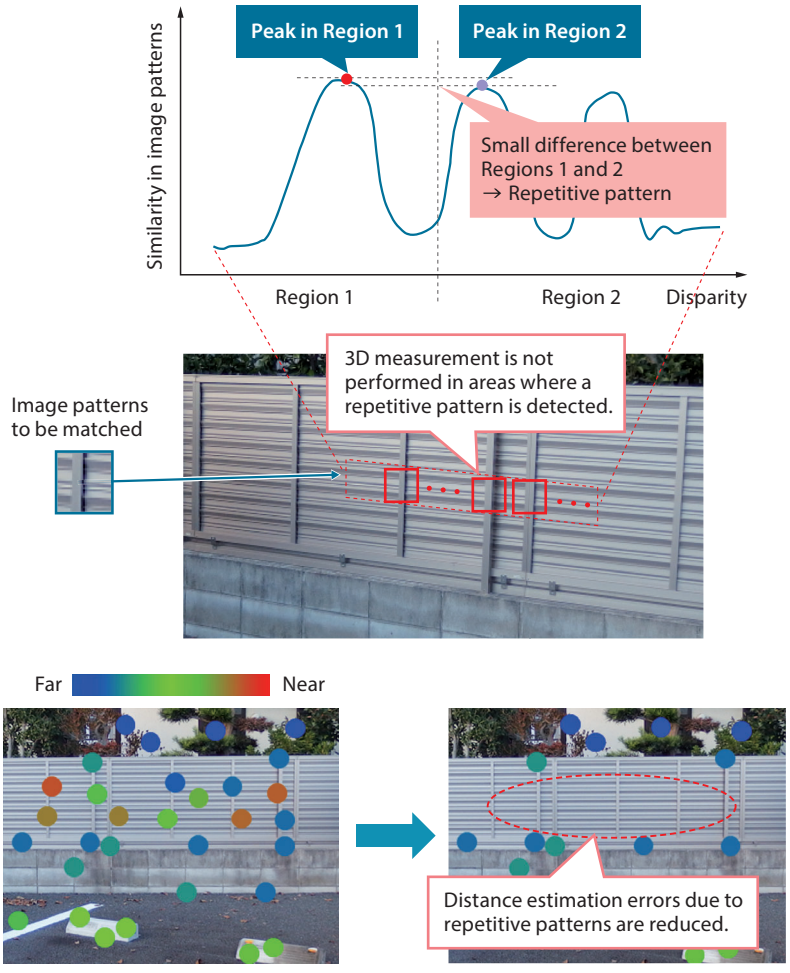
Improvement in accuracy of visual SLAM system by means of in-vehicle sensor data

Visual simultaneous localization and mapping (visual SLAM) is a technology to estimate the three-dimensional (3D) motion of a camera and the 3D topology of its surroundings using time-series images. It is used for vehicle motion estimation and obstacle detection in advanced driver assistance systems. Visconti4 and subsequent image recognition processors provide monocular visual SLAM capability with high speed.

Toshiba Electronic Devices & Storage Corporation has developed a new motion estimation technique that combines the data from wheel rotation speed and vehicle angular velocity sensors with camera images. This improves the accuracy of visual SLAM in situations where the vehicle is moving at very low speed. The newly developed technique predicts a motion value based on the sensor data and a vehicle motion model. The predicted value is used as an initial solution for motion estimation when the vehicle starts moving. It is also used for validating the

motion estimation results. When a vehicle is moving at ultralow speed, the accuracy of camera-based motion estimation tends to be degraded as the apparent motion of the camera images becomes small. To achieve accurate and stable estimation, the new technique also uses external sensors for motion value prediction.

Moreover, when a vehicle is driving at very low speed, multiple similar patterns tend to repeatedly appear in the camera images. Since visual SLAM performs 3D measurement based on similarity matching of image patterns, repetitive patterns lead to erroneous matching, causing an error in obstacle distance estimation. In order to prevent estimation errors, we have also developed a technique to determine the existence of repetitive patterns based on similarity distribution. This technique does not perform 3D measurement in the areas where repetitive patterns appear, but performs distance measurement in other areas. In this way, we have succeeded in improving the estimation of distances to detected obstacles.



Repeated-pattern detection from similarity distribution in images when traveling at ultralow speed

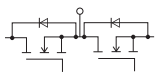
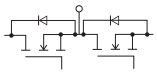
7.2 SiC Modules in Industry-Standard Package Incorporating Third-Generation SiC MOSFETs

Reducing power consumption in the field of power electronics can make an important contribution to the mitigation of global warming. To date, the semiconductor industry has reduced the power consumption of power devices by improving the performance of silicon (Si) power semiconductors. However, Si power devices are approaching their performance limit. Under these circumstances, silicon carbide (SiC), a wide-bandgap semiconductor, is attracting considerable attention.

Toshiba Electronic Devices & Storage Corporation commenced the mass production of SiC Schottky barrier diodes (SBDs) in 2013, followed by the mass production of hybrid single-package modules consisting of injection-enhanced gate transistors (IEGTs) and SiC SBDs in 2014. These products contributed to reducing the size and power consumption of traction inverters for railway applications. Thereafter, we developed SiC metal-oxide-semiconductor field-effect transistors (MOSFETs) in 2018 and 1.2 kV- and 1.7 kV-class SiC modules composed of third-generation SiC MOSFETs in 2020.

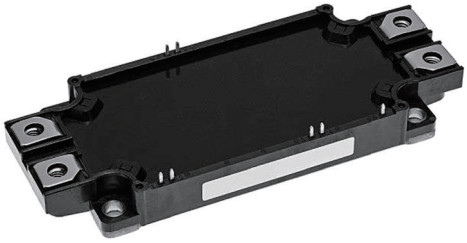
The SiC MOSFET exhibits a unique phenomenon in which on-voltage increases due to an increase in stacking faults when a reverse current flows through a parasitic diode (bipolar operation). In order to prevent bipolar operation of a parasitic diode and thereby suppress increases in on-voltage, we have formed an SBD region in the third-generation SiC MOSFET. The SiC modules incorporating these MOSFETs are housed in an industry-standard package, so they are suitable not only for new system applications but also for the replacement of Si modules in existing systems. The 1.7 kV-class SiC module delivers reductions of about 78% in switching loss, 40% in conduction loss, and 98% in reverse-recovery loss, resulting in a reduction of about 80% in total power loss compared with conventional insulated-gate bipolar transistor (IGBT) modules consisting of IGBTs and Si diodes. These new SiC modules are contributing to both energy and space saving.

Lineup of SiC module products

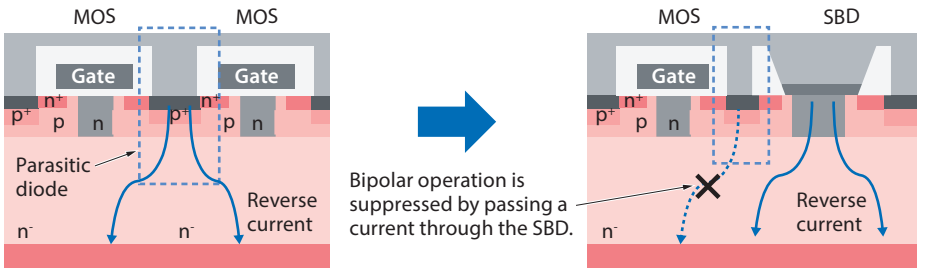
Part number	Absolute maximum ratings		Internal circuit	Structure	Package
	V_{DS} (V)	I_{DS} (A)			
MG600Q2YMS2	1 200	600		SiC-MOS 2-in-1	E3D
MG400V2YMS2	1 700	400		SiC-MOS 2-in-1	E3D

V_{DS}: drain-source voltage I_{DS}: drain-source current

152 (depth) × 62 (width) × 20.5 (height) mm



E3D package for SiC modules

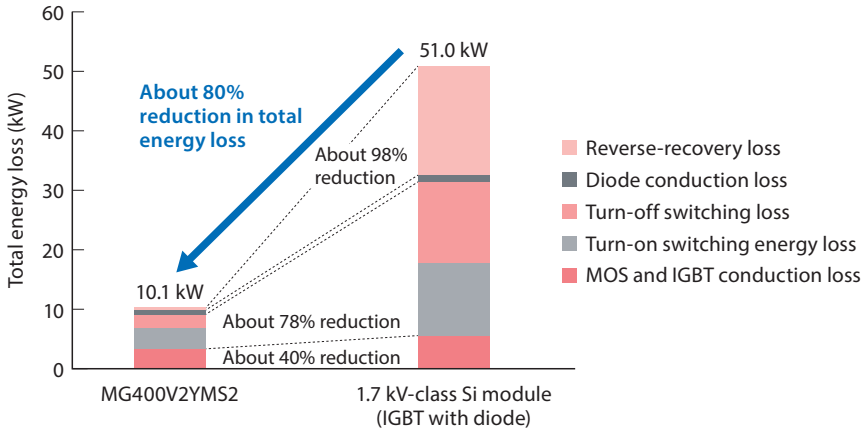


Structure of conventional MOSFET

Structure of newly developed SiC-MOSFET

p: p-type semiconductor
n: n-type semiconductor
p^+: p-type semiconductor with high impurity concentration
n^+: n-type semiconductor with high impurity concentration
n^-: n-type semiconductor with low impurity concentration

Structure of SiC MOSFET to suppress increases in on-voltage compared with that of typical MOSFETs



Calculated using data simulated at a channel temperature of 150°C
Test conditions: Two-level inverter circuit, 7.2 kHz carrier frequency, 50 Hz output frequency
Output current: 180.4 Arms, DC voltage: 1 087.5 V, modulation index: 0.74

Comparison of total energy loss of conventional and newly developed 1.7 kV-class SiC modules

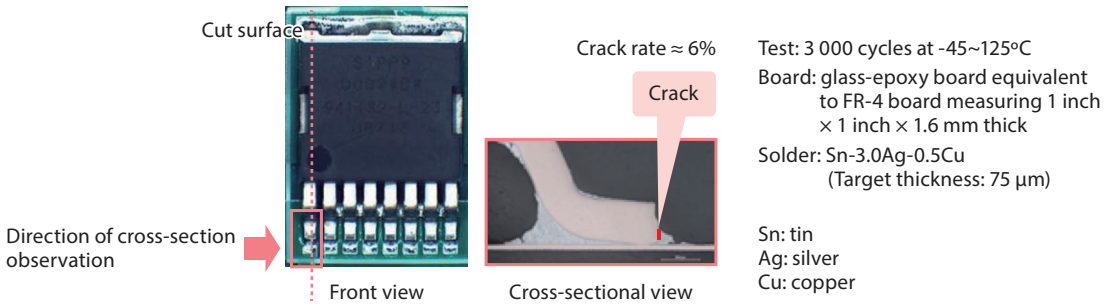
7.3 High-Current, Thermally Enhanced TOGL Package for Automotive Applications

	Conventional package		New package*1
Package	TO-220SM(W) 		TOGL 
Part number	TKR74F04PB		XPQR3004PB
I_D (A)	250	Mounting area: about 10% reduction Drain current: 1.6-fold increase Power dissipation: 2.0-fold increase $R_{DS(ON)}$: 59% reduction	400
P_D (W)	375		750
$R_{DS(ON)}$ (mΩ) max	0.74		0.3
V_{th} width (V)	1.0		0.4*2
Package dimensions (mm)	10 × 13 × 3.5 (mounting area ≈ 130 mm^2)		9.9 × 11.8 × 2.3 (mounting area ≈ 117 mm^2)

*1: Tentative specification
*2: Can be packed with a V_{th} width of 0.4 V

I_D: drain current P_D: power dissipation $R_{DS(ON)}$: drain-source on-resistance V_{th}: gate threshold voltage

Comparison of rated specifications of conventional TO-220SM(W) and newly developed TOGL packages for automotive power MOSFETs



State of soldered joint of TOGL package mounted on board after 3 000 temperature cycles

Toshiba Electronic Devices & Storage Corporation has developed a high-current, thermally enhanced transistor outline package with gull-wing leads called TOGL for the XPQR3004PB power MOSFET, which is designed for application as a high-current auxiliary battery switch and as an assist motor driver for mild hybrid vehicles.

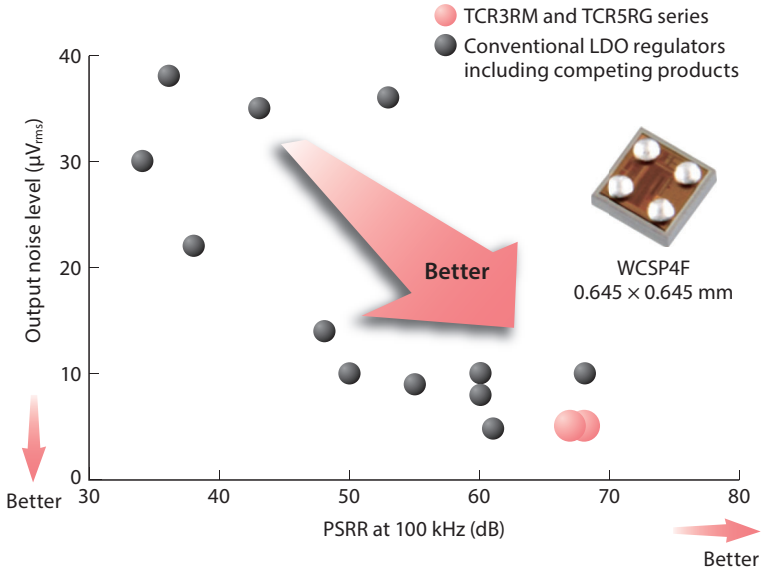
The newly developed TOGL package has seven source leads to reduce the heating of leads during high-current operation. These source leads are directly connected to the internal chip in order to accommodate a drain current (I_D) of 400 A. In addition, because of its thick plate frame, the TOGL package provides double the heat dissipation performance of the conventional TO-220SM(W) package.

Furthermore, the XPQR3004PB power MOSFET is designed to have a narrow gate threshold voltage (V_{th}) width to reduce current imbalance when a large number of XPQR3004PB devices are connected in parallel in high-current applications. The package leads are formed in a gull-wing shape to ensure solder joint reliability in high-load environments.

As a result of these features, a high-current switch composed of the XPQR3004PB device is expected to be smaller and have a longer life than mechanical relays. For assist motor applications with ever-increasing output power, the XPQR3004PB helps to simplify parallel connections and reduce the parts count in comparison with the conventional device in the TO-220SM(W) and other packages.

While we prepare for the mass production of the XPQR3004PB, we will consider developing variants of this device including those with a sensing function.

7.4 Low-Noise TCR3RM and TCR5RG Series Linear Regulator ICs for Image Sensors



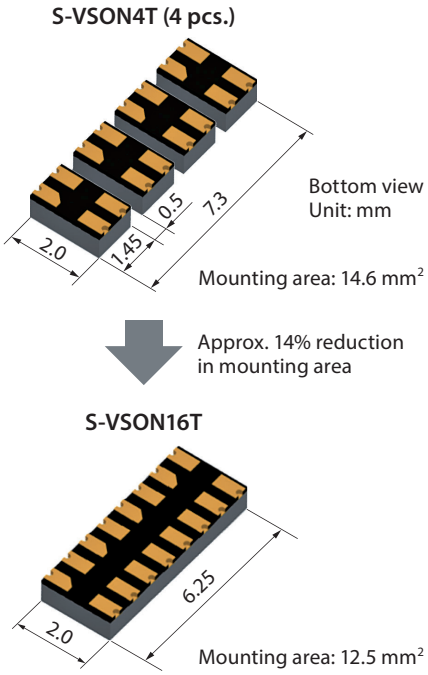
Lower noise and higher PSRR achieved by TCR3RM series and TCR5RG series linear regulator ICs for image sensors compared with conventional products

The ever-increasing dissemination of camera-equipped Internet of Things (IoT) devices and multi-camera smartphones in recent years has been driving demand for camera modules. Since the image sensors of cameras are extremely sensitive to power supply noise, there is a growing need for low-noise linear regulators designed to suppress unwanted battery ripple, operate for a long time on battery power, and supply large current to the image sensor.

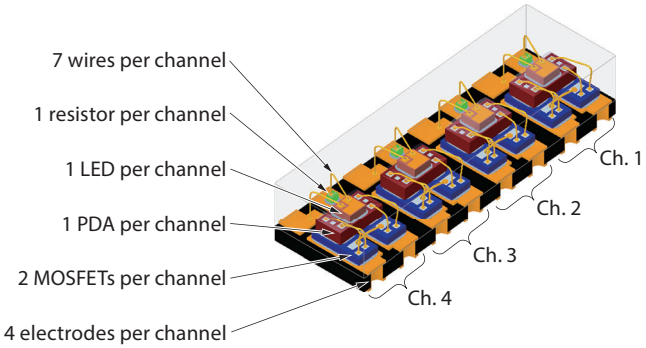
Featuring the lowest-class noise and the highest-class power supply rejection ratio (PSRR) in the industry(*), the TCR3RM and TCR5RG series of linear regulator integrated circuits (ICs) for image sensors help to derive the maximum performance from an image sensor and thereby obtain high imaging quality. In addition, these low-dropout (LDO) regulators automatically change the operating mode according to the electrical load level, achieving both low current consumption and fast transient response to load changes that have a trade-off relationship with each other. The TCR5RG series is also suitable for modern high-density designs as it is available in the industry's smallest-class WCSP4F package(*) and has a rated output current of up to 500 mA.

(*) As of October 2020 in comparison with existing products (as researched by Toshiba Electronic Devices & Storage Corporation)

7.5 Small Four-Channel Photorelays Ideal for Semiconductor Tester Applications



Comparison of photorelay mounting area when using four S-VSON4T packages and S-VSON16T package



Internal structure of S-VSON16T package

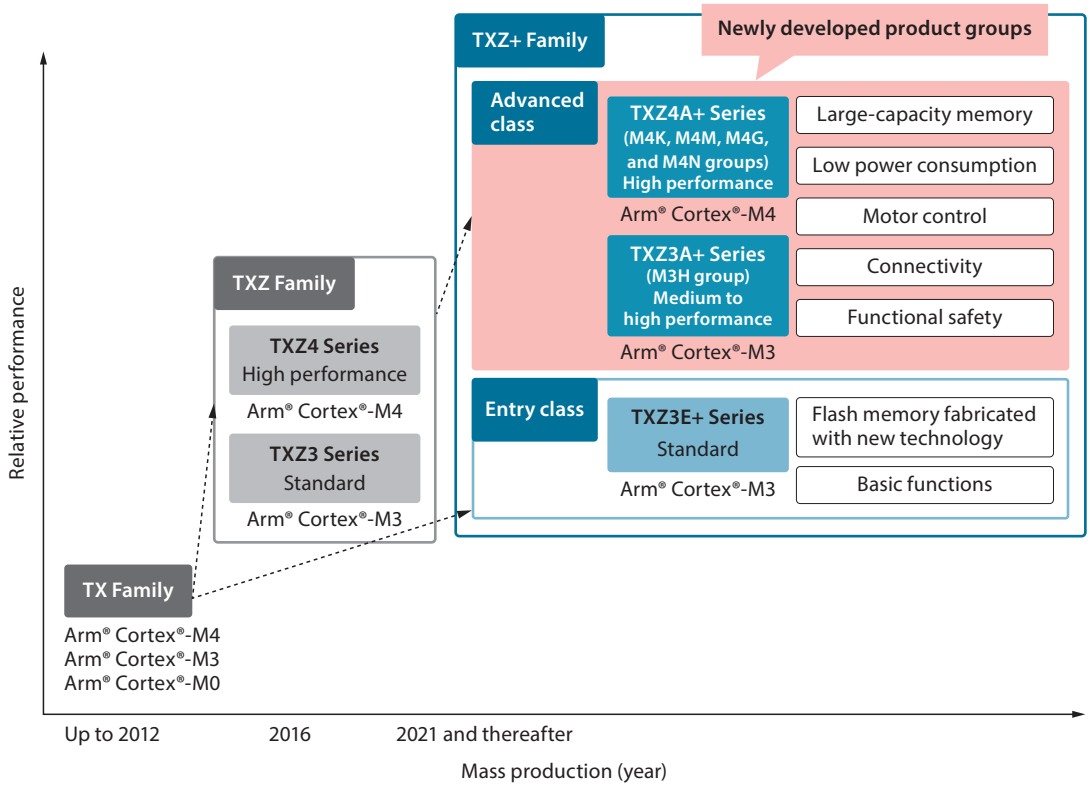
Semiconductor testers incorporate hundreds to thousands of photorelays mounted on a single printed circuit board in order to switch signal and power supply lines to be measured. As a result of an increase in the number of simultaneously measured lines, the number of photorelays in semiconductor testers is rising, driving the need to reduce the size of photorelays.

Toshiba Electronic Devices & Storage Corporation has already commercialized the S-VSON (Shrink Very Small Outline Non-leaded) 4T package that is assembled using a newly developed chip stacking technique, achieving a 60% reduction in mounting area compared with the existing USOP (Ultra Small Outline Package).

As the next step, we have now developed the TLP3407SRA4, TLP3412SRHA4, TLP3475SRHA4, and TLP3406SRH4 compact four-channel photorelays in the S-VSON16T package, which integrate light-emitting diodes (LEDs) and current-limiting resistors. Housed in the S-VSON16T package, these four-channel photorelays eliminate the dead space that was previously required between single-channel photorelays in the S-VSON4T package, resulting in a roughly 14% reduction in mounting area. Since the new four-channel photorelays also eliminate the need for external LEDs and current-limiting resistors, they provide a total board space saving of about 36%.

Furthermore, the TLP3407SRA4, TLP3412SRHA4, and TLP3475SRHA4 support an extended operating temperature of up to 125°C, making them suitable for high-temperature testing system applications.

7.6 New Additions to Lineup of TXZ+ Family Microcontrollers



Roadmap of TXZ+ Family motor control microcontrollers

Toshiba Electronic Devices & Storage Corporation has developed five groups of microcontroller units (MCUs) as new additions to the TXZ+ Family. Fabricated using a cutting-edge process, the new MCUs provide a maximum operating frequency of 200 MHz and require a roughly 30% lower operating current than the conventional TXZ Family. In line with the latest MCU portfolio, the TXZ+ Family now includes the following groups of MCUs for industrial applications in addition to those for consumer and home appliance applications:

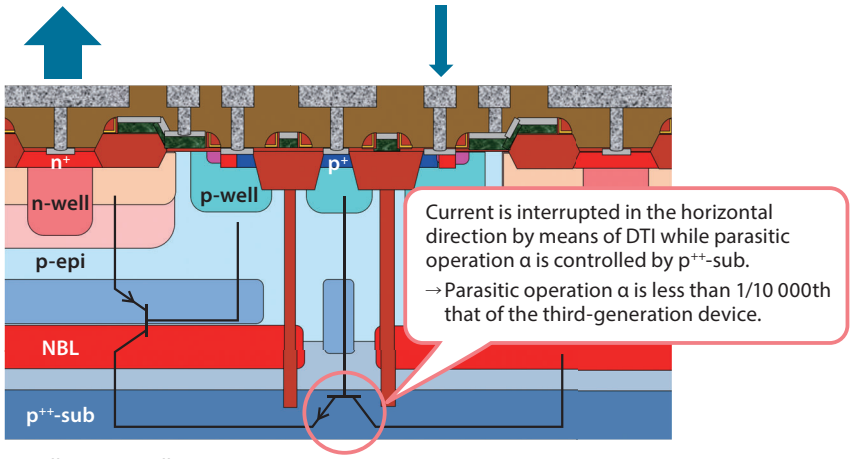
(1) The M4K and M4M groups incorporate the functions required for motor control such as advanced vector engines and high-precision analog circuits.

(2) The M4G and M4N groups incorporate a high-speed 12-bit analog-to-digital converter (ADC), large-capacity memory, and various peripheral functions such as a motor control circuit, timer, and serial interface.

(3) The M3H group of standard MCUs combine low power consumption and high functionality, incorporating large-capacity flash memory, a motor control circuit, digital liquid crystal display (LCD) driver, etc.

We are currently evaluating these MCUs, with mass production scheduled to begin in 2021. We will continue to expand the lineup of high-performance MCUs with large-capacity memory.

7.7 Fourth-Generation Analog IC Process



n-well: n-type well
p-well: p-type well
p-epi: p-type epitaxial layer
NBL: n-type buried layer
p^{++}-sub: p-type substrate

Cross-sectional structure of fourth-generation analog power IC

Demand is increasing for high-voltage, high-current analog power ICs, making it essential to develop low-cost manufacturing processes to increase their competitiveness.

Under these circumstances, Toshiba Electronic Devices & Storage Corporation has developed the BiCD(*1)-0.13G4 process, a fourth-generation analog IC process using (1) local oxidation of silicon (LOCOS) for the field plate(*2) to smooth the current flow, (2) deep-trench isolation (DTI) for device separation to achieve current cut-off in the horizonal direction, and (3) a heavily doped substrate to suppress parasitic bipolar coupling with adjacent elements.

The BiCD-0.13G4 process exhibits about 40% lower on-resistance (i.e., higher DC current capability) than the third-generation process, reducing parasitic bipolar action(*3) to one ten-thousandth or less. This process helps to reduce the size of and the spacing between elements, making it possible to develop competitive analog ICs.

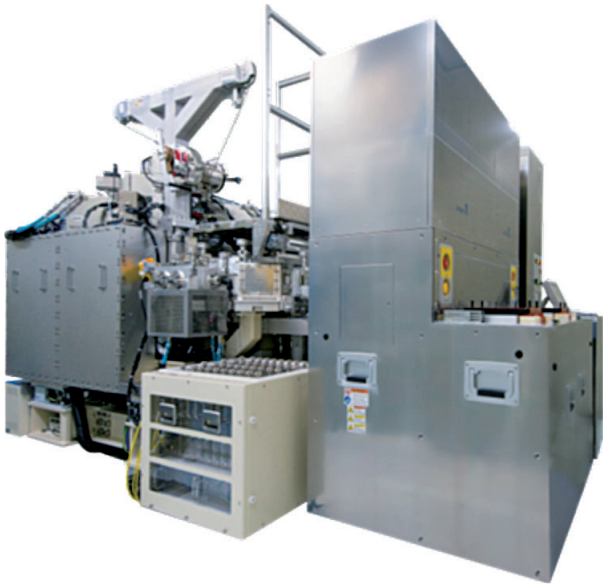
At present, we are developing motor control drivers (MCDs) fabricated with the BiCD-0.13G4 process, which are scheduled for mass production in 2021.

(∗1) A mixed process consisting of bipolar, complementary metal-oxide semiconductor (CMOS), and double-diffusion MOS (DMOS) processes

(∗2) A structure to increase the withstand voltage by decreasing the electric field at a point where it concentrates (i.e., a weak point)

(∗3) A current amplification factor of a parasitic bipolar transistor. The amplified current flows to the adjacent elements, causing them to generate heat and malfunction, leading to their destruction.

7.8 EBM-9500PLUS and EBM-8000P Electron Beam Mask Writers



EBM-9500PLUS/EBM-8000P electron beam mask writer

An electron beam mask writer is used to produce photomasks for semiconductor lithography with high accuracy. NuFlare Technology, Inc. has now developed the EBM-9500PLUS and EBM-8000P electron beam mask writers.

The EBM-9500PLUS features a high patterning speed achieved by unparalleled beam brightness (1 200 A/cm^2). It provides a critical dimension of 1.3 nm (3σ) and an image placement accuracy of 1.8 nm (3σ) by compensating, in real time, for resist sensitivity changes due to heat during patterning and the charging effect of the electron beam. The EBM-9500PLUS is being used for the mass production of ICs at the 7 nm+ technology node as well as for the development of ICs at the 5 nm technology node.

The EBM-8000P series is a reproduction of the discontinued EBM-6000 and EBM-8000 models. We have released the EBM-8000P series in response to strong demand from our customers. The EBM-8000P/M model is targeted at the 45 to 20 nm technology nodes whereas the EBM-8000P/H model is intended for the 16 nm and 14 nm technology nodes. We have designed their electron optical system on a unified platform to reduce the manufacturing lead time and cost. The EBM-8000P/M provides three times the patterning speed of the EBM-6000 while maintaining the same patterning accuracy.

7.9 18 Tbyte 3.5-inch Nearline HDD Applying FC-MAMR Technology

MG09ACA18T 18 Tbyte 3.5-inch HDD for nearline storage applications

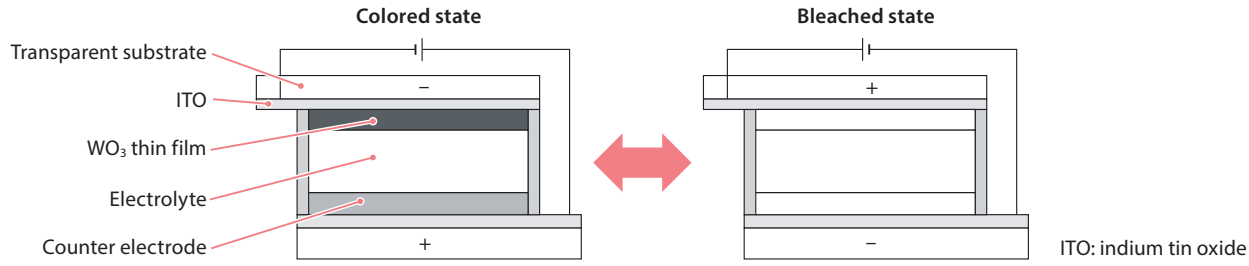
With the widespread dissemination of cloud services, social networking services (SNS), online shopping, etc., demand is increasing for large-capacity hard disk drives (HDDs) for data center and other applications.

Under these circumstances, Toshiba Electronic Devices & Storage Corporation has commercialized the MG09 series of 3.5-inch nearline HDDs applying flux control microwave-assisted magnetic recording (FC-MAMR) technology. The MG09ACA18T HDD in this series, our third-generation helium-filled conventional magnetic recording (CMR) model, provides a storage capacity of 18 Tbytes(*), representing a 12.5% increase compared with that of the conventional 16 Tbyte MG08 series.

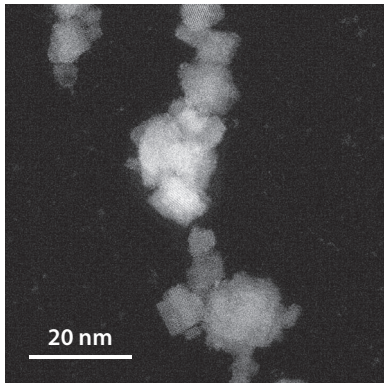
The FC-MAMR technology does not require a dedicated recording medium as it controls the head magnetic field so as to increase the recording magnetic field, making it possible to reduce the head core width. We also succeeded in increasing the track density by improving the head positioning accuracy. Furthermore, as solutions to increase the recording density, we changed and optimized the material for the recording medium to improve the read signal quality and modified the head to reduce spacing variations between the head and the medium.

(*) Definition of capacity: Toshiba Electronic Devices & Storage Corporation defines a terabyte (Tbyte) as 10^{12} (1 000 000 000 000) bytes.

7.10 Coatable WO_3 Nanoparticles for Electrochromic Devices



Cross-sectional outline of ECD



Transmission electron microscope (TEM) image of WO_3 nanoparticles

An electrochromic (EC) device (ECD) is a device constructed using an EC material that exhibits a change in optical transmission as a result of reduction/oxidation (redox) reactions, resulting in a discolored state. This property enables the ECD to be used for such applications as building and car roof windows for energy-saving and aesthetic purposes.

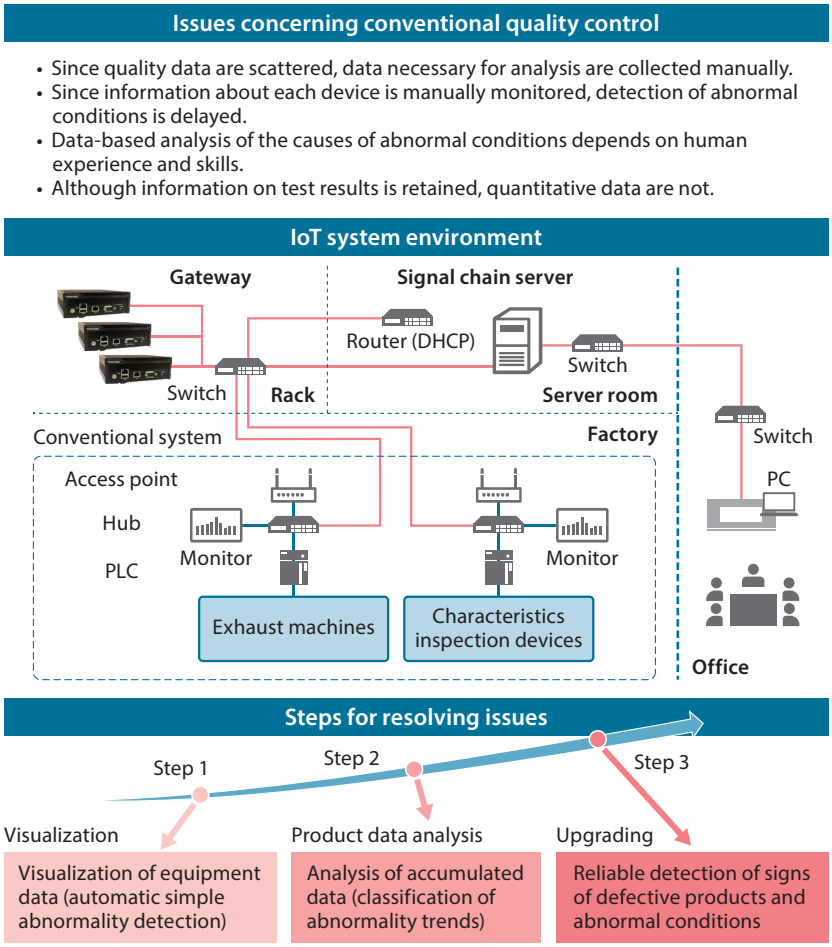
Tungsten trioxide (WO_3) has the highest coloration efficiency(*) among all EC materials. However, since WO_3 requires sputtering, vapor deposition, or other vacuum processes to form a thin film, WO_3-based ECDs are expensive.

Toshiba Materials Co., Ltd. has succeeded in developing an EC material with high coloration efficiency using a less costly coating layer formation process by controlling the size of WO_3 nanoparticles. It was found that the coloration efficiency of the WO_3-based ECD increased as the particle size was reduced. An ECD with a WO_3 particle size of 10 nm or less exhibited a coloration efficiency of 70 cm^2/c, as against the 50 cm^2/c obtained by typical vapor deposition layers.

This study is being conducted by a consortium of four enterprises in cooperation with the National Institute of Advanced Industrial Science and Technology (AIST) of Japan. At present, the consortium is developing a WO_3-based ECD with a view to launching it commercially.

(*) Amount of change in absorbance per unit of injected charge

7.11 Development of IoT System to Improve Reliability of Magnetron Manufacturing Process



PLC: programmable logic controller
DHCP: Dynamic Host Configuration Protocol

Improvement of reliability of magnetron manufacturing process utilizing existing data and IoT system

The requirements for magnetrons for microwave ovens and other consumer products include not only general performance metrics such as output power and efficiency but also output stability and reliability.

Toshiba Hokuto Electronics Corporation has been utilizing equipment to inspect emission and other quality-related characteristics during the manufacturing process. However, there were various issues to be resolved in relation to quality control in terms of data collection, abnormality detection, analysis, and data storage, and pass/fail determination was generally based on the performance of each production lot.

Under these circumstances, we developed an IoT system that collects data from exhaust machines and characteristics inspection devices, which play a key role in ensuring product quality, and issues an alarm in the event that a defect is predicted. This IoT system was realized

by utilizing gateways and a signal chain server without changing the specifications of any of the existing equipment.

We will employ the new IoT system to further improve the reliability of the magnetron manufacturing process. Specifically, it will be used to select key parameters that are important for product quality management, automatically collect data to visually monitor the equipment status, and formulate measures for preventing defects and maintaining high quality from the results of data analysis.