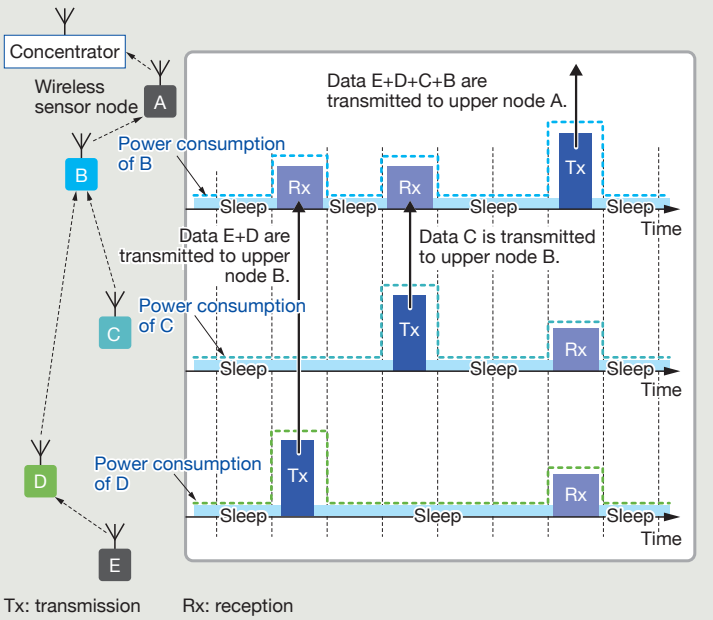
Low-Power Multihop Wireless Sensor Network Capable of More than 10 Years' Operation on Battery Power

Toshiba has developed a low-power multihop wireless sensor network technology that makes it possible to gather sensor data from a large geographical area with high reliability and at low cost.

Firstly, to substantially increase the communication distance, we adopted 920 MHz-band wireless links, which provide a line-of-sight communication range of more than 1 km, and employed multihop routing, which uses other devices as relays to transfer the received data. Secondly, to achieve a battery life of more than 10 years, we adopted a time-division communication protocol that places wireless devices in sleep mode during inter-communication intervals by controlling the transmission and reception times. Thirdly, to realize a high data acquisition rate, we developed a new retransmission method that selects a new communication partner with good communication status in the event of a communication failure. As a result of these innovations, we achieved a sensor data acquisition rate exceeding 99.999%.

Wireless sensor networks incorporating these technologies are easy to install because they are battery-powered and do not require communication or power lines. Currently, such wireless sensor networks are in field trials in various natural environments, buildings, and other structures.



Operation of time-division communication in low-power multihop wireless sensor network

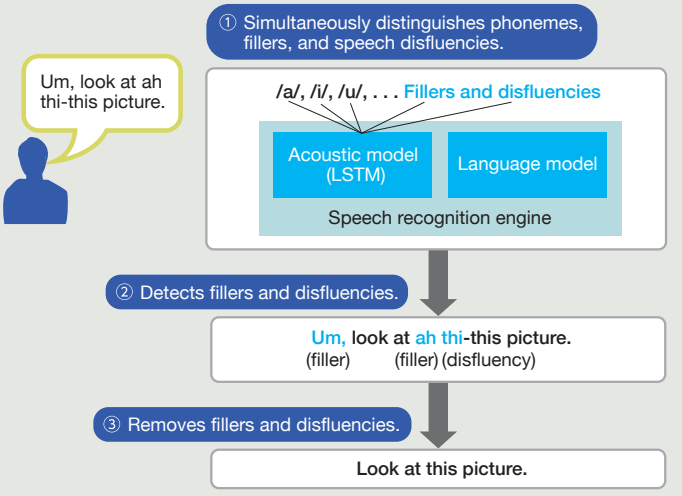
Speech Recognition That Detects and Removes Unnecessary Words for Spontaneous Speech Understanding

Toshiba has developed a speech recognition technique for understanding spontaneous speech.

Spontaneous speech often includes fillers such as *um* and *ah* and speech disfluencies such as "*thi-this*." These unnecessary words and sounds hinder understanding of the meaning of utterances. To remove their negative effects, we have created a speech recognition system that detects and removes filler and disfluency expressions using a deep-learning method called long short-term memory (LSTM) that takes time-series features into consideration.

LSTM can model phonemes consisting of short-term features and acoustic events consisting of long-term features in the same framework. This model can simultaneously recognize phonemes and detect filler and disfluency expressions.

In the future, this technique will be used for speech recognition at meetings and conferences to automatically create minutes of the proceedings.



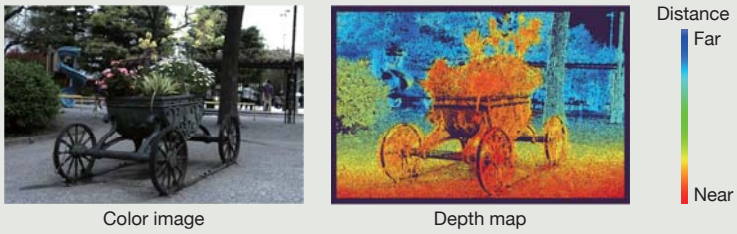
Acoustic event detection and removal technology for speech understanding

Simultaneous Color Image and Depth Map Acquisition Using Single Camera with Color-Filtered Aperture

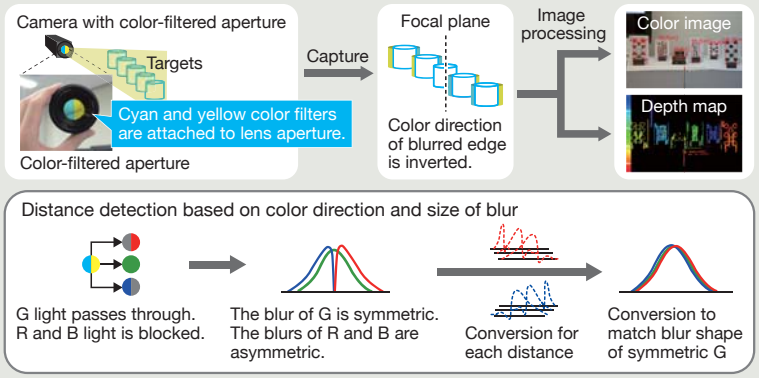
Toshiba has developed an imaging technology that allows a color image and a depth map to be simultaneously acquired by a single camera.

For example, in order to operate drones or robots autonomously, information on the distances to the surrounding objects is required. However, it is difficult to achieve both depth measurement precision and compact size with existing stereo cameras or laser rangefinders.

The newly developed technology attaches cyan and yellow color filters to the lens in order to generate asymmetric blurs in the red (R) and blue (B) images. The front-back relationship with the focal plane is determined based on the direction of the blur of each color. The distance from the focal plane is calculated by evaluating the differences between the asymmetric blurs in the R and B images and a symmetric blur in the green (G) image. Difference evaluation at the subpixel level makes it possible for a single camera to achieve distance measurement accuracy comparable to that achievable with stereo cameras.



Depth map obtained using color-filtered aperture



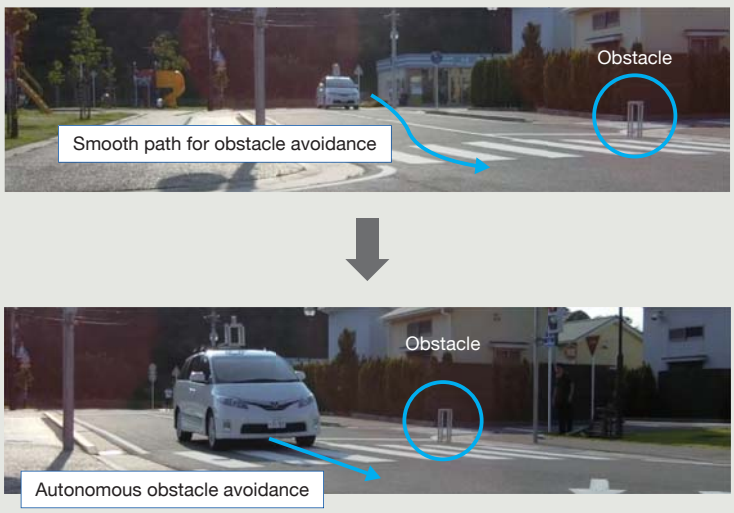
Overview of depth map acquisition technology using color-filtered aperture

Demonstration Experiments on Implementation of Future Autonomous Driving Technologies by Onboard Processor

Since autonomous driving requires a large amount of computation, it is difficult for an onboard processor to achieve real-time processing with low power consumption. For example, the measurement of three-dimensional (3D) points(*) from camera images is a computing-intensive task that is usually handled by a high-end PC.

Toshiba has realized real-time processing for autonomous driving using its Visconti™4 onboard image recognition processor. Newly developed technologies to create a map of obstacles around a vehicle and to determine a path for avoiding them are computationally feasible even for an onboard processor. In order to verify these obstacle avoidance algorithms, we implemented them on a Visconti™4-powered PC and demonstrated them using an autonomously driven car of Nagoya University. We have also successfully tested autonomous driving on public roads.

(*) Feature points on a two-dimensional (2D) image plus distance information from a camera



Demonstration experiments on technologies for autonomous driving

Comprehensive Big-Data-Based Monitoring System for Yield Analysis in Semiconductor Manufacturing

Product line	Failure type	Failure distribution map	Trend	No. of defective wafers	Candidates for causal machine
Product P	Type 1	Failure rate High Low	No. of defective wafers / Time	300	1 Process X: Machine X1 2 Process Y: Machine Y4 3 Process Z: Machine Z9
Product Q	Type 2	Failure rate High Low	No. of defective wafers / Time	200	1 Process A: Machine A5 2 Process B: Machine B2 3 Process C: Machine C4
Product R	Type 3	Failure rate High Low	No. of defective wafers / Time	100	1 Process D: Machine D4 2 Process E: Machine E2 3 Process F: Machine F7

Note: Names and values differ from those of actual cases.

Results obtained by comprehensive production yield monitoring system

Toshiba has developed a monitoring system for yield analysis in semiconductor manufacturing. This system provides a summary of failure occurrences and identifies the causes of failures from wafer failure distribution maps and manufacturing histories. By applying machine learning and data mining techniques to big data obtained from manufacturing processes, we realized a yield monitoring system capable of comprehensively inferring candidates for failure-causing machines, thereby reducing the time required by workers for analysis.

The major characteristics of the new yield monitoring system are as follows:

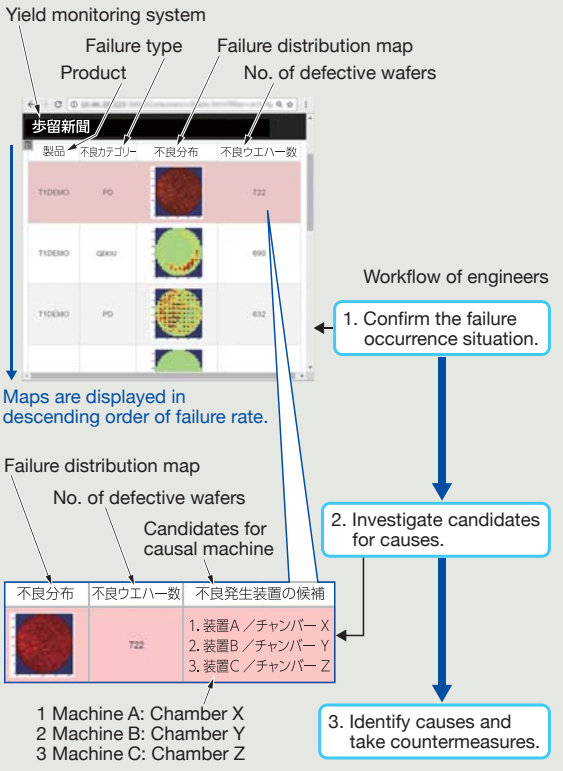
(1) Overview of failure occurrences

This system automatically classifies wafers with a similar failure distribution map into groups and displays their failure occurrence trends. We utilized a clustering method for classification. Due to the use of a distributed parallel clustering algorithm, the system completes clustering tasks 72 times faster than the previous system and can classify a large number of wafers from multiple product lines.

(2) Automated inference of causal machines

The system infers candidates for failure-causing machines from the failure distribution maps and manufacturing histories and shows a ranking list. For inference, we utilized a pattern mining method to efficiently find patterns of machines that frequently cause wafer failures.

The system shows a summary of failure distribution maps, failure occurrence trends, and candidates for failure-causing machines in a single view. If engineers discover a new failure distribution map on the screen, they can initiate an investigation from the candidates for causes and if the first candidate turns out to be an actual cause, they can rapidly take countermeasures. Our integrated comprehensive big-data-based monitoring system supports engineers' work and is expected to provide a significant increase in manufacturing yields. We will continue to improve the inference accuracy and enhance the functionality of the system to further support engineers' work and reduce the time required for a yield analysis.



Note: Names and values differ from those of actual cases.

Example of use of production yield monitoring system

Voltage-Control Spintronics Memory Architecture Offering Possibility of Ultralow Energy Consumption and High Density

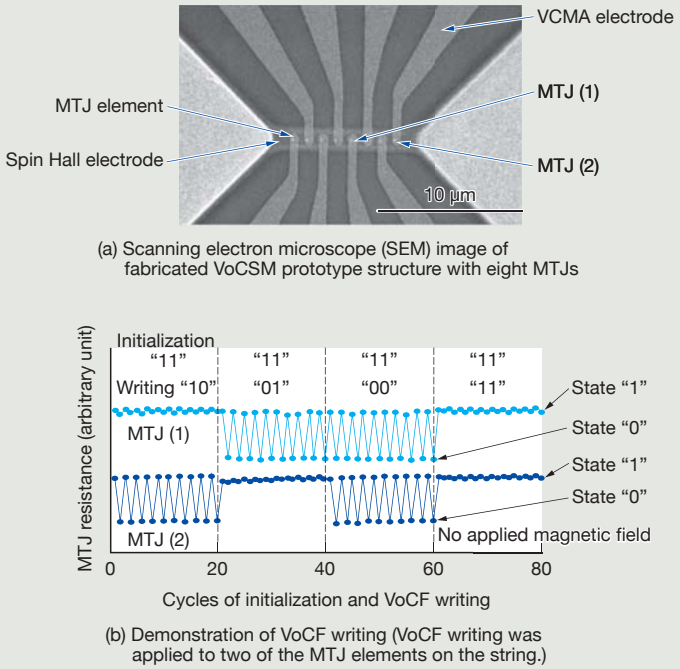
Toshiba has proposed a new spintronics-based memory architecture called voltage-control spintronics memory (VoCSM). The salient features of VoCSM are its utilization of the voltage-control magnetic anisotropy (VCMA) effect(*1) as the principle for bit selection and the spin Hall effect(*2) as the principle for writing.

We have fabricated a prototype unit cell and demonstrated the feasibility of the writing scheme implemented by this architecture. We have also shown that VoCSM has the potential to reduce the energy consumption of writing data per bit by an order of magnitude compared with conventional spin-transfer torque magnetoresistive random-access memory (STT-MRAM).

This work was partly supported by the ImPACT (Impulsing Paradigm Change through Disruptive Technologies) Program sponsored by the Cabinet Office of the Government of Japan. All of the team involved in this project, including researchers in industry, government, and academia, will continue to work cooperatively on improving the VCMA effect, which is the main issue with respect to practical application of this technology.

(*1) An effect in which magnetic anisotropy is controlled by the applied voltage

(*2) An effect in which spin-polarized electrons accumulate on the surface of heavy metals such as tantalum



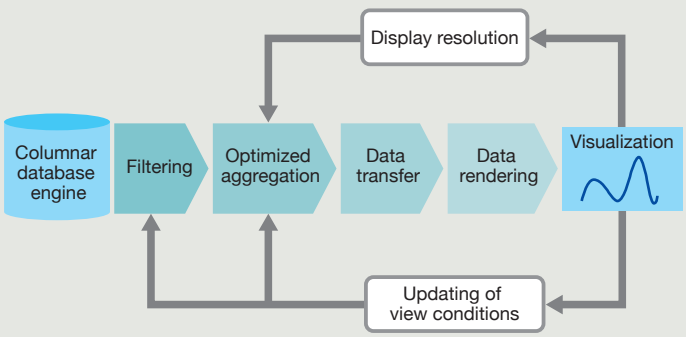
VoCF: voltage-control flash

Demonstration of VoCSM with prototype string of magnetic tunnel junction (MTJ) cells

Visualization Platform for Large Volumes of Data

To support the progress of the advanced information society, Toshiba has developed innovative services and products that provide new added value to big data applications, including data visualization and exploratory data analysis, and dramatically improve their efficiency. The development of the Polyspector™ big data visualization platform now makes it possible to visualize data from various perspectives and offers a new and effective way to quickly see and intuitively grasp trends and problems in collected data.

For big data visualization, the novel database engine of Polyspector™ optimally aggregates multiple data items mapped to the same screen location as a data object since the number of pixels in a screen is smaller than the number of data items. This allows a view of hundreds of millions of data points to be created in about one second with an ordinary PC. Polyspector™ dramatically reduces the time required to prepare and render data while maintaining the exact appearance of visualization results, irrespective of whether the visualization is an overview of an entire dataset or a detailed view of a selected subset.



Data processing flow of Polyspector™

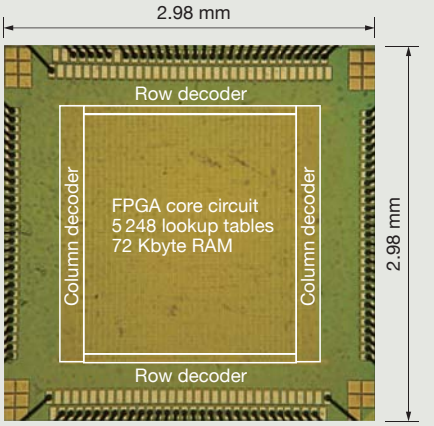
High-Density FPGA Circuit Using Pure-CMOS Antifuse-Based Nonvolatile Switches

Toshiba has developed a novel programmable switch technology for high-density field-programmable gate array (FPGA) circuits. The logic functionality of an FPGA circuit is configured after chip manufacturing. Demand for FPGA technology is increasing as the manufacturing of multiple custom large-scale integrations (LSIs) is becoming difficult due to their high development costs.

However, the logic density of a conventional FPGA is low due to the large circuit area. An FPGA has many wires and switch circuits to allow users to arbitrarily configure logic blocks. These wires and switch circuits increase the size of the FPGA circuit.

To address this problem, we developed a high-density switch array technology using antifuse-based nonvolatile one-time memory devices. Small nonvolatile FPGA circuits have been realized by replacing conventional switch circuits with this switch array. The new FPGA circuits can be fabricated using a standard complementary metal-oxide semiconductor (CMOS) process. Our FPGA technology reduces the size of a circuit necessary for logic configuration by approximately half. As a result, an FPGA test chip fabricated with a 65 nm standard CMOS process achieved the highest logic density among FPGAs implemented with the same process(*).

(*) As of June 2016, at the time of the 2016 Symposia on VLSI Technology and Circuits (as researched by Toshiba)



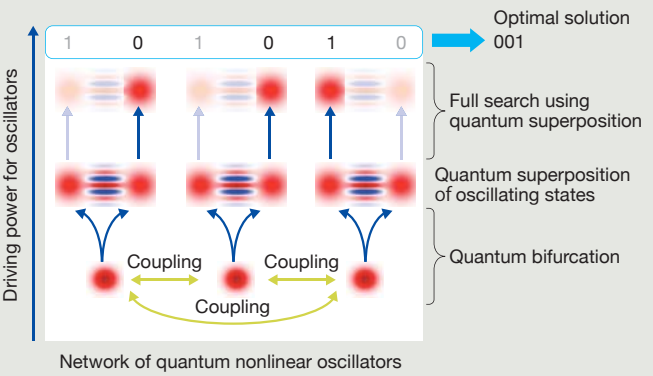
RAM: random-access memory

Prototype high-density nonvolatile FPGA chip fabricated using 65 nm CMOS process

"Quantum Bifurcation Machine" AI Device for Combinatorial Optimization

Combinatorial optimization problems that appear in various real-world situations are becoming more important, particularly in the fields of artificial intelligence (AI) and the Internet of Things (IoT). However, current computers cannot find optimal solutions among a huge number of combinatorial patterns.

As a solution to this issue, Toshiba has proposed a new type of AI device called the "quantum bifurcation machine." This machine searches for optimal solutions by harnessing the quantum-mechanical superposition of an exponentially large number of states. The new machine has a network of quantum nonlinear oscillators, each of which can generate quantum superposition of two oscillating states via quantum-mechanical bifurcation. We have confirmed through simulations that this quantum superposition method is effective in finding optimal solutions.



Mechanism of quantum bifurcation machine using nonlinear oscillator network

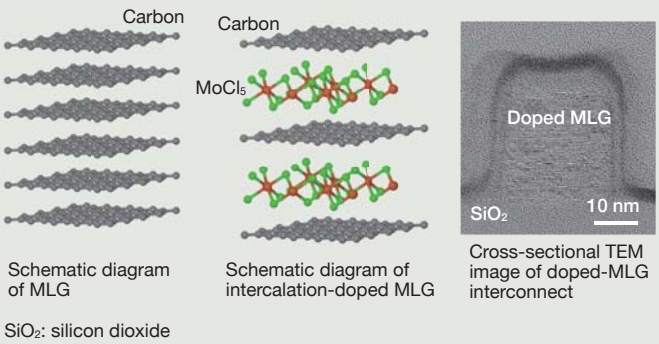
Intercalation Doping of Fine-Width MLG for Interconnect Applications

Multilayer graphene (MLG) is a focus of expectations as a candidate material for fine-width interconnects in future memories. Toshiba has developed an MLG doping process to reduce the resistivity of MLG interconnects even at widths of less than 30 nm.

As a consequence of the ongoing reduction in the width of MLG interconnects, conventional intercalation doping materials (dopants) are beginning to damage the MLG stack structures, leading to a loss of dopants from the MLG.

To address this problem, we have developed a new intercalation doping process using molybdenum chloride ($MoCl_5$) as a dopant that allows direct doping into fine-width (< 30 nm) MLG wires. As a result, the resistivity of fine MLG interconnects has been reduced by about 70%.

Part of this study was sponsored by the Ultra Low-Voltage Device Project for a Low-Carbon Society of the Ministry of Economy, Trade and Industry (METI) and the New Energy and Industrial Technology Development Organization (NEDO) of Japan.



Schematic diagrams of MLG and intercalation-doped MLG, and cross-sectional transmission electron microscope (TEM) image of doped-MLG interconnect

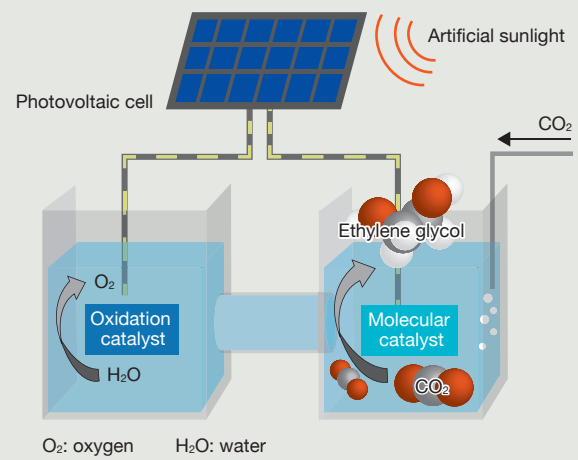
Photoelectrochemical System for Converting CO_2 into Ethylene Glycol

Toshiba has developed a photoelectrochemical system for converting carbon dioxide (CO_2) into ethylene glycol using sunlight. Ethylene glycol is a versatile industrial raw material that can be used in the manufacture of polyethylene terephthalate (PET) bottles, polyester fibers, and resins.

In this development work, an imidazolium salt derivative that acts as a molecular catalyst for the reduction of CO_2 was adsorbed to a metal surface at high density. Artificial sunlight powered a silicon-based photovoltaic cell, which in turn provided energy to the molecular catalyst. When CO_2 molecules interacted with the imidazolium salt derivative, direct multi-electron reduction took place that yielded ethylene glycol. Such a reaction has not been previously achieved. The energy conversion efficiency was 0.48%.

We reviewed the process of adsorption of the molecular catalyst to the metal to improve the CO_2 reduction performance. By controlling the photoelectrochemical system so as to realize efficient utilization of the catalyst, the production of ethylene glycol using light was made possible.

We will continue to improve this technology in order to commercialize a highly efficient system for producing industrial raw materials.



Photoelectrochemical system for converting CO_2 into ethylene glycol

High-Energy, Heat-Resistant Samarium-Cobalt Magnet

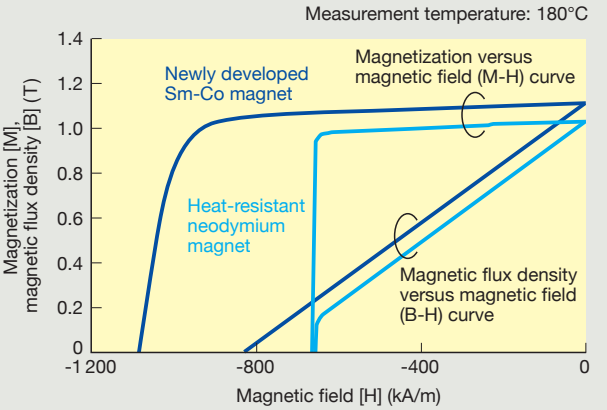
Traction motors for hybrid and electric vehicles and railway rolling stock as well as motors for industrial equipment and wind turbines all operate at relatively high temperatures, and heat-resistant neodymium magnets are generally used in these applications. However, these magnets contain heavy rare-earth elements that are in short supply and expensive.

Toshiba has developed a magnet that can maintain high magnetic force even in the operating temperature range of highly heat-resistant motors exceeding 140°C. This was realized by applying a unique heat treatment to a high-iron-concentration samarium-cobalt (Sm-Co) magnet free of heavy rare-earth elements developed in 2012. The new Sm-Co magnet exhibits a 30% increase in coercivity.

It was confirmed that this magnet has better performance than heat-resistant neodymium magnets and excellent demagnetization resistance even at 180°C.

The new Sm-Co magnet makes it possible to avoid the risks inherent in the supply of rare-earth elements. In addition, it either eliminates the need for or contributes to simplification of the motor cooling system.

We have also developed a basic mass-production technology for the new magnet in collaboration with Toshiba Materials Co., Ltd.



Comparison of demagnetization curves of newly developed Sm-Co magnet and conventional heat-resistant neodymium magnet

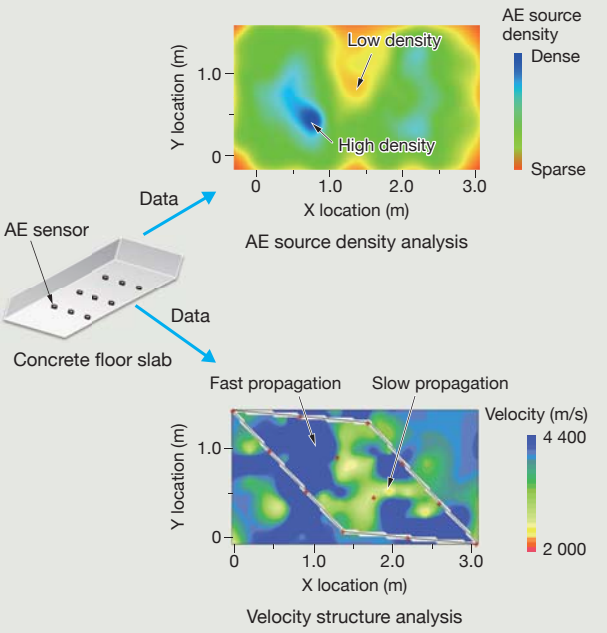
Nondestructive Sensing Technology for Concrete Structures

The aging of bridges and other infrastructures is posing a serious social problem in Japan. Most of these infrastructures were built during the country's postwar period of rapid economic growth. In addition, Japan's labor force is shrinking, which may lead to a shortage of infrastructure inspectors in the future. Preventive maintenance of social infrastructures is crucial under these circumstances. Nondestructive testing can provide a solution for fast and efficient inspection of latent defects.

In response to this situation, Toshiba, in cooperation with Kyoto University, has developed a new technology for analyzing data from sensors and visualizing internal defects in concrete structures such as bridge slabs. This technology uses highly sensitive sensors to detect acoustic emissions (AEs) generated as a result of concrete damage that is invisible from the external appearance of the structure, in order to estimate their locations. Data from the sensors make it possible to identify the locations of the AE sources. Moreover, to ensure accurate damage mapping, velocity distributions in the concrete can be determined by analyzing the propagation of the AE waves.

We have successfully verified this technology with an in-service bridge. The analysis results were directly compared with core samples taken from the concrete slabs to confirm that the estimated concrete conditions closely matched the actual conditions.

This work was partly supported by NEDO.



Setup of AE sensors on concrete floor slab and examples of analysis results

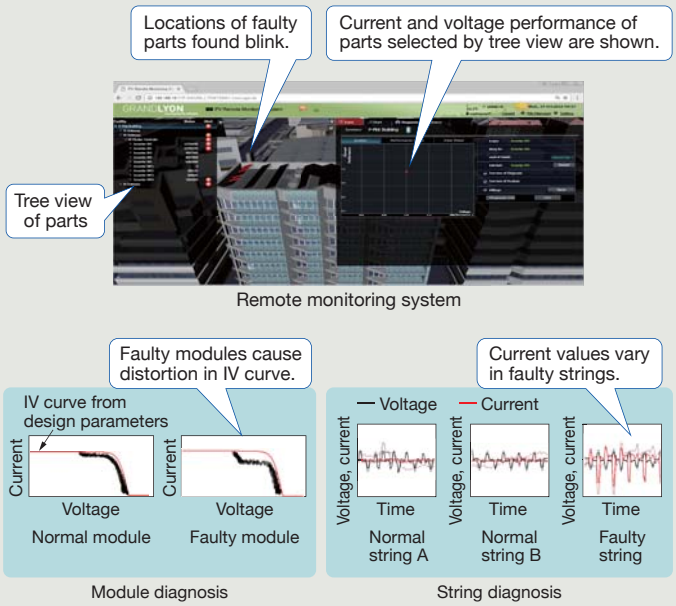
PV Fault Diagnosis System for Smart Community Project in Lyon, France

Many photovoltaic (PV) power plants have been constructed in recent years. Since the power generated by a PV system exhibits large fluctuations according to the weather conditions, it is difficult to find faults (i.e., abnormal decreases in performance) in a PV system based on raw sensor data. This poses a serious problem in the operation and maintenance of such systems.

Each PV system in the smart community demonstration project in Lyon, France, has three types of sensors, which measure the DC current and voltage in each PV module, each PV string (series-connected PV modules), and each PV array (parallel-connected PV strings), respectively.

Toshiba has developed a fault diagnosis system using data mining technology for the PV sensor data. This fault diagnosis system performs diagnosis using performance models derived from the sensor data in the absence of faults. We have demonstrated that, even under changing weather conditions, the fault diagnosis system can successfully detect a 10% decrease in PV performance if it lasts for several days.

This research was conducted as part of the Lyon Smart Community Project funded by NEDO.



Remote monitoring display and processed sensor data for fault diagnosis of PV system at Lyon Smart Community Project in Lyon, France

Home Energy-Saving Techniques in PEB Demonstration Experiment in Lyon, France

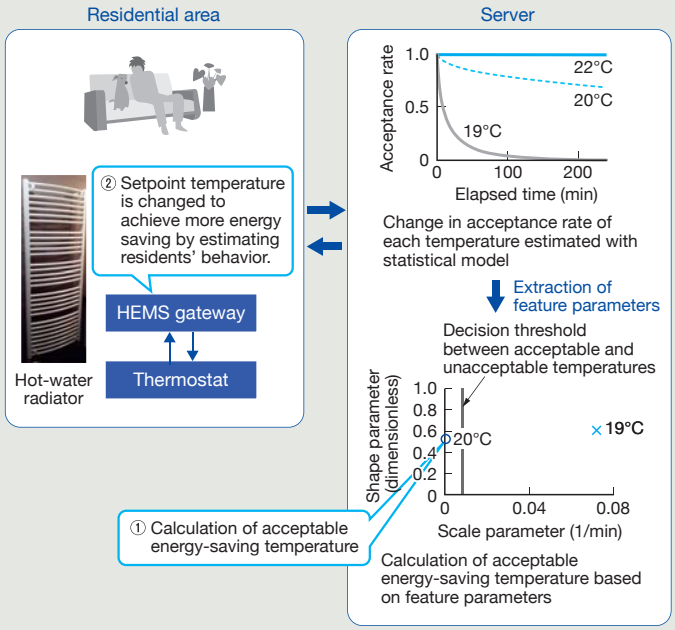
Toshiba has conducted a positive energy building (PEB) demonstration experiment in Lyon, France. We utilized our home energy management system (HEMS) called OMOTENASHI HEMS™ on the residential floors of a newly constructed demonstration building. (*Omotenashi* means "hospitality" in Japanese.) We developed a method for calculating an acceptable energy-saving temperature and an automatic space-heating control function based on the estimation of residents' behavior.

We performed experiments to evaluate these functions in December 2016 and January 2017, respectively.

Regarding the calculation of an acceptable energy-saving temperature, we obtained results for 23 out of 36 households, considering the residents' "at-home" percentage during the period of the experiment and their wish to participate in the experiment. The results showed a 23.6% energy-saving effect.

The automatic space-heating control function was enabled for 18 households and disabled for the others, except for manipulation of the thermostats and remote control via a Web system. The results showed an 18.6% energy-saving effect.

This research was conducted as part of the Lyon Smart Community Project funded by NEDO.



HEMS to calculate acceptable energy-saving temperature and automatically control space heating based on estimation of residents' behavior

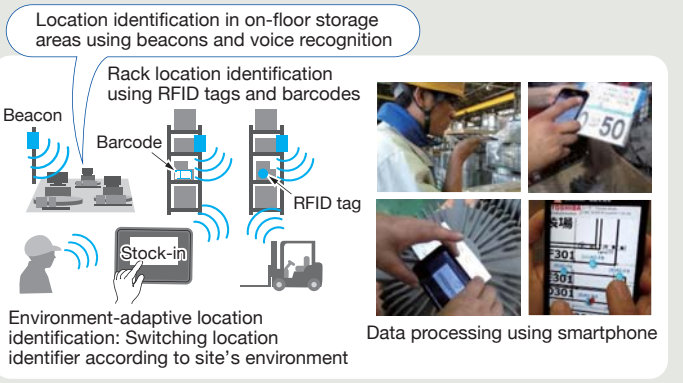
Hybrid Warehouse Management System Utilizing IoT Technology

To efficiently manage inventories of parts of different shapes and sizes that are stored and moved around factories in various ways, Toshiba has developed a smart warehouse management system using state-of-the-art IoT and sensing technologies such as Bluetooth®, radio-frequency identification (RFID), beacons, and QR Codes. The new warehouse management system helps users to visualize real-time data on the locations of parts, stock-in and stock-out events, and current inventory levels. Barcode deployment and accurate location management are particularly difficult at factories where parts are stored in a mixed manner, combining both on-floor and rack storage to allow a high degree of freedom in locations and methods of stacking.

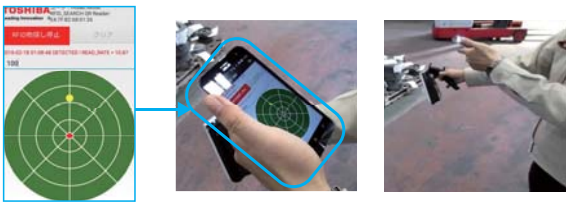
To address this issue, our hybrid warehouse management system combines beacons and voice recognition to provide users with greater flexibility in location input and realize accurate recording of location data. Furthermore, we have developed the system on a mobile platform so that users can implement all operations using only a smartphone. Our warehouse management system therefore offers high usability at a low deployment cost. Pilot trials at factories have verified the effectiveness of this system.

The Bluetooth® word mark and logo are registered trademarks owned by Bluetooth SIG, Inc.

QR Code is a registered trademark of DENSO WAVE Inc.



Smart stock-in/stock-out input



Checking readings of parts' RFID tags to locate items

Parts search using RFID detection

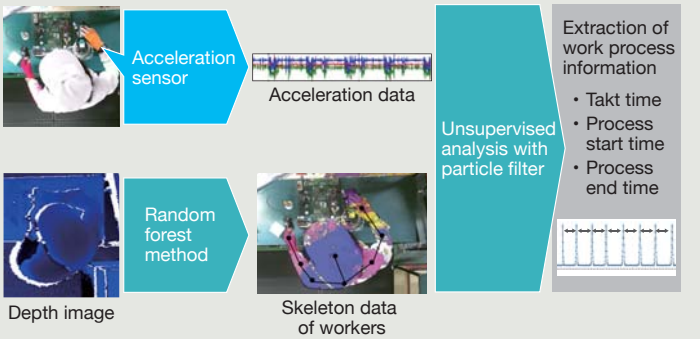
Features of hybrid warehouse management system for factories

Machine Learning Application to Extract Work Process Information at Manufacturing Sites

Toshiba has developed a machine learning-based application to automatically extract information on work processes at manufacturing sites in order to improve their efficiency.

This application uses a ceiling-mounted depth image camera and acceleration sensors to observe the work processes of workers hidden by equipment. Skeleton information is extracted from the depth images using a random forest method. To acquire acceleration data, acceleration sensors are attached to the wrists of workers. These data are used to automatically measure the takt times of repetitive work performed by factory workers. Sensor data are affected by the products to be manufactured, processes, work distributions, physical characteristics, and habits of workers. To address this issue, we applied a particle filter to keep track of work cycles.

In the future, we aim to achieve further improvement in work processes by incorporating additional information such as categorization of work processes, unsteady actions, and proficiency.



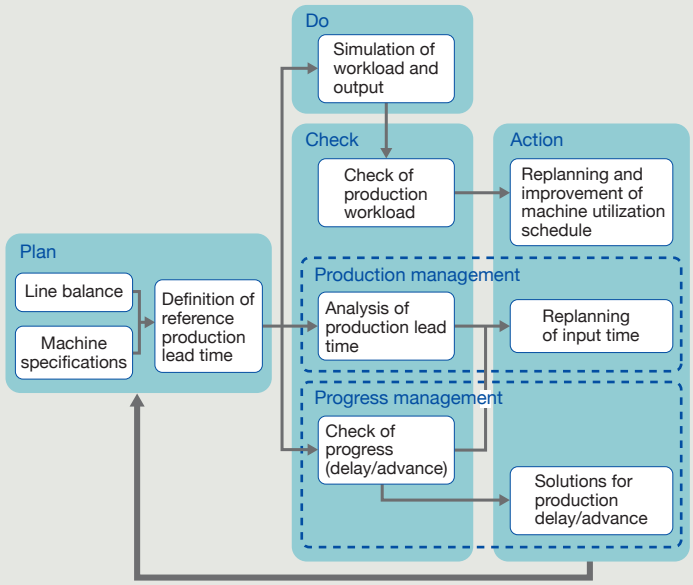
Flow of automatic extraction of information on manufacturing operation to improve work efficiency at site

Production and Progress Management System for High-Mix Low-Volume Semiconductor Manufacturing

In the front-end processes of high-mix low-volume semiconductor production, the required production capacities and production start dates continually fluctuate due to variations in product mixes and quantities. Failure to keep track of these variations therefore increases the risk of delayed deliveries and output shortages.

Toshiba has examined imbalances among production lines and machine specifications to define reference production lead times, and developed a production and progress management system.

We have confirmed that predictions of the items and quantities produced can be improved by simulating the workload of each process using the reference production lead times and adjusting machine utilization schedules accordingly.



Outline of production and progress management system for high-mix low-volume semiconductor manufacturing

Machine for Increasing Production of SCiB™ Lithium-Ion Rechargeable Batteries

In November 2016, Toshiba started mass production of high-input/output 10 Ah SCiB™ lithium-ion rechargeable battery cells, which are suitable for automotive start-stop systems as well as for railway and industrial systems using regenerative electric power.

For the injection of electrolyte into these 10 Ah SCiB™ battery cells, we have developed a new liquid injection and sealing machine that fills the electrolyte liquid using a hopper and seals the liquid inlet under reduced pressure.

This machine also supports the conventional 20 Ah battery cells, which are manufactured using a different process, and can therefore be used to increase the production of 20 Ah battery cells.

The footprint of the machine was reduced by 20% compared with the conventional machine by reducing the unit size and the amount of buffer through optimization of the manufacturing processes.

We also modified the internal structure of the machine covers in order to improve maintainability. Operators can access the mechanical parts of the machine through glove ports without opening the covers. This prevents ambient air from flowing into the machine.

Liquid injecting and sealing machine for 10 Ah/20 Ah SCiB™ battery cells

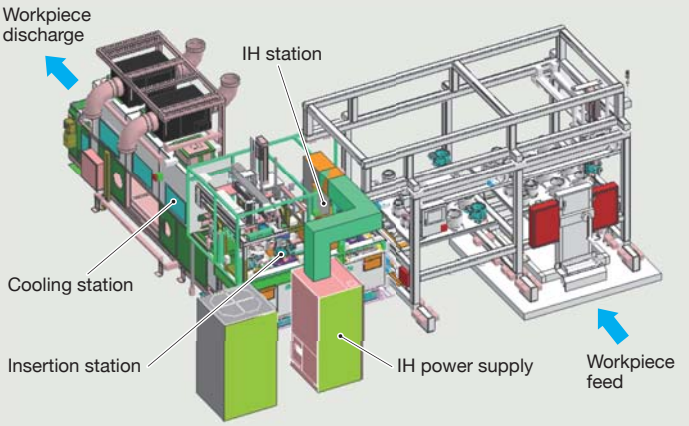
Application of Induction Heating to Shrink-Fit Process for HEV Generators

Toshiba Industrial Products and Systems Corporation has established a production line for a new generator for hybrid electric vehicles (HEVs), and commenced mass production in August 2016.

The shrink-fit process is an assembly process in which a housing is uniformly heated and expanded in order to insert a stator in it. In the conventional equipment, it was necessary to heat an oven to the prescribed temperature. Since heating took a long time, there were many in-process workpieces in the oven. Furthermore, the conventional equipment was large.

To address these issues, we developed shrink-fit equipment using an induction heating (IH) method. Since the generator housings have a complicated irregular shape and are composed of multiple materials, uniform heating to the specified temperature presented a challenge. We therefore conducted a coupled analysis of magnetic fields, heat, and structures to determine the optimal coil shape and heating conditions for the IH shrink-fit equipment.

The new shrink-fit equipment eliminates the need for preheating to the prescribed temperature. Since a housing can now be heated in several minutes, the heating station has no in-process workpieces. Moreover, the use of the IH shrink-fit equipment reduces both the cost of the heating equipment and power consumption.



Shrink-fit equipment using IH method

Compact AGV for Transportation of Small Lots

In order to reduce the load carried on production lines, Toshiba has developed a compact automatic guided vehicle (AGV) that is easy to introduce for the transportation of small lots.

The setting up of a conveying route for a conventional AGV required considerable time and effort, and any system change that involved a change in the route incurred a high cost. The use of a conventional AGV was therefore difficult.

The newly developed AGV can be easily installed simply by attaching commercially available tape and tags for motion commands. In addition, the operation of this AGV can be readily changed by transferring a comma-separated values (CSV) file.

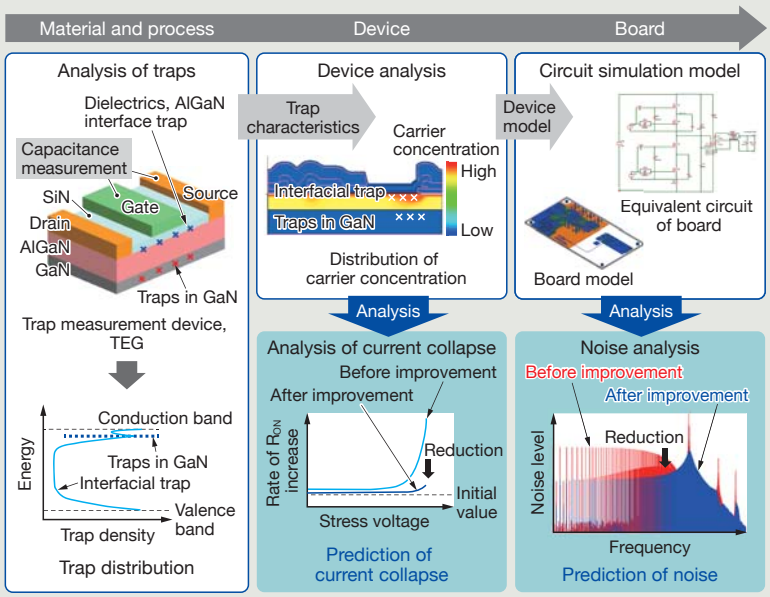
We are using the new AGV on our domestic and overseas production lines to reduce transportation costs, and will continue to further expand its use on various production lines.

Compact AGV allowing reduction of introduction cost

Accurate Modeling Technology for GaN Power Devices

For gallium nitride (GaN) power devices, it is essential to reduce the degradation of dynamic on-resistance (R_{ON}) due to current collapse as well as electromagnetic interference (EMI) noise due to ultrafast switching. High-density traps caused by GaN crystal defects lead to current collapse, whereas parasitic elements such as the capacitances and inductances of packages and boards are the main causes of EMI noise.

Toshiba has developed a novel simulation technology that considers not only the GaN device but also the influences of material properties, manufacturing processes, and boards. In order to accurately predict current collapse and EMI noise, the simulator considers trap characteristics obtained by a test element group (TEG) and parasitic elements extracted from an electromagnetic analysis. This technology will contribute to the development of GaN power devices and systems with optimal design and improved performance.



SiN: silicon nitride AlGaN: aluminum gallium nitride

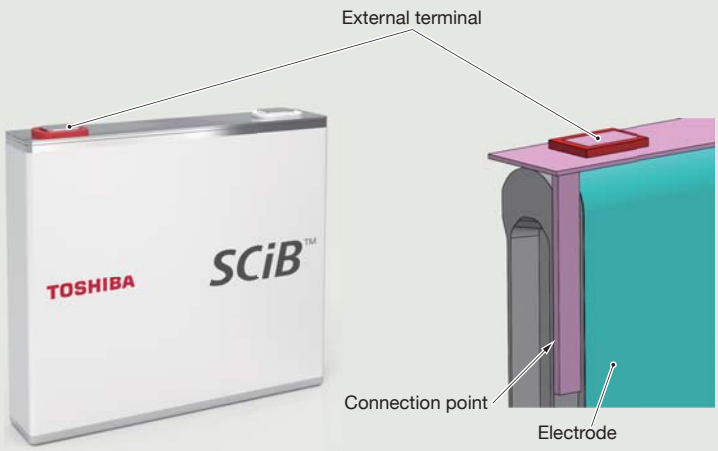
Integrated simulation technology to predict current collapse and EMI noise of GaN power devices

Technology for Connecting Electrode and External Terminal of 10 Ah SCiB™ Lithium-Ion Rechargeable Battery Cells

The 10 Ah SCiB™ lithium-ion rechargeable battery cell is well suited for applications requiring rapid energy input and output such as start-stop systems for passenger vehicles as well as regenerative power systems for railways and industrial equipment. For mass production of the 10 Ah cell, Toshiba has developed a technology for connecting the electrode with the external terminal.

The 10 Ah SCiB™ battery cell provides higher energy capacity and improved energy input and output performance than the current 2.9 Ah cell, and can therefore be used for a wider range of applications. In order to achieve high energy input and output performance, it is necessary to ensure low electrical resistance when connecting the electrode and external terminal. Long-term connection reliability is also required, particularly for automotive applications.

To reduce the connection resistance, we have developed a specialized tool for electrodes with a large cross-sectional area. We have also identified and optimized a significant parameter that affects the strength of the connection between the electrode and external terminal.



10 Ah SCiB™ battery cell and connection point of electrode and external terminal

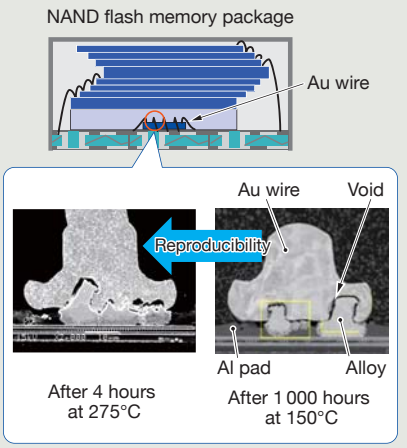
Method to Shorten Reliability Test Time for NAND Flash Memory Packages

In order to avoid iteration of time-consuming approval tests, Toshiba has developed a method for evaluating the high-temperature storage reliability of wire joints in a NAND flash memory package within a short time.

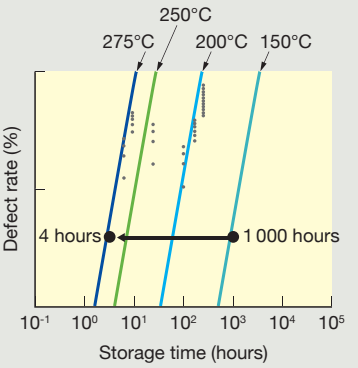
Reliability testing is facilitated by measuring the wire bonding strength of a specimen stored at 275°C for four hours instead of using the conventional test in which the package is stored at 150°C for 1 000 hours to check its electrical properties.

In developing the new method, we confirmed the existence of a correlation between the defect rate and the test temperature, as well as the reproducibility of the formation of alloy layers and voids at wire joints.

This method allows process engineers to select appropriate conditions so as to ensure reliability. In addition, even if wire bonding defects occur at a contractor's factory, it is possible to quickly ascertain whether the process conditions are appropriate.



Cross-sectional image of wire bonding junction after high-temperature storage



Lifetime at each storage temperature

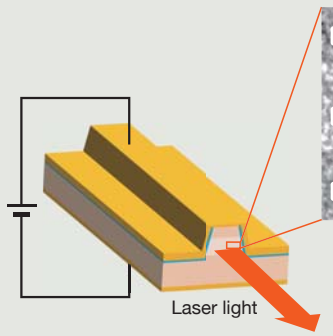
Au: gold Al: aluminum

Cross-sectional images of bonding wire after high-temperature storage and Weibull plots of bonding defects after short-term accelerated test

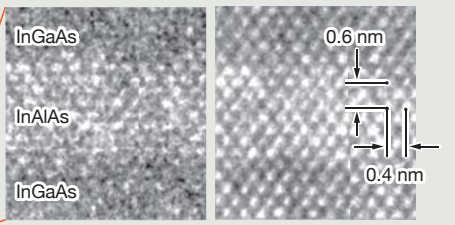
Quantum Cascade Lasers with Spectral Range from 4 to 6 µm

Quantum cascade lasers (QCLs) are semiconductor lasers that emit in the mid-infrared band. Toshiba has developed QCLs that oscillate at a wavelength of 4 to 6 µm in order to measure trace amounts of CO_2 and nitrogen oxides (NO_x). Laser absorption spectroscopy using QCLs can diagnose the presence of *Helicobacter pylori* and identify the source of environmental gases by quantifying the isotopic ratio of CO_2. QCLs can also be used to determine the place of origin of food by measuring the isotopic ratios of carbon and nitrogen.

High-precision techniques are necessary for the crystal growth of QCL device structures. Active layers composed of several hundred quantum wells are grown with a thickness accuracy of one atom without deviation of the crystal composition. A molecular beam epitaxial growth method was used to grow crystal films at this accuracy. We achieved regular crystal lattices by optimizing the crystal film growth conditions, and succeeded in lasing of the QCLs.



Schematic structure of QCL device



Crystal lattice images of quantum wells

InGaAs: indium gallium arsenide
InAlAs: indium aluminum arsenide

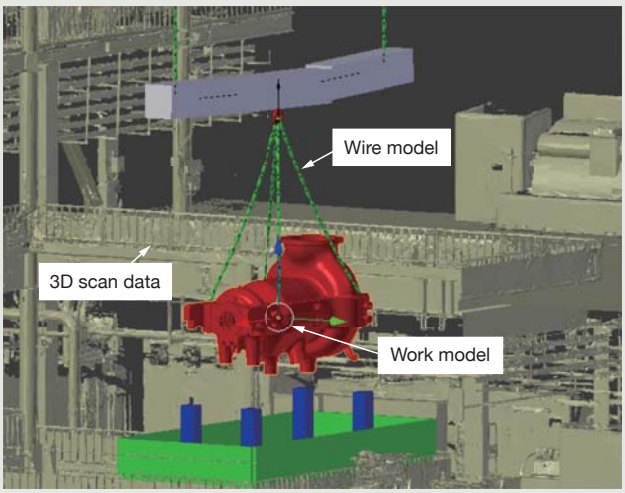
Schematic structure of QCL device and TEM images of semiconductor crystal lattices before and after optimization

Material Handling Simulation for Designing Large Products

Reducing the weight of large products contributes to the reduction of their cost and improvement of their performance. However, since weight reduction tends to make a product more susceptible to deformation, it is important to consider its manufacturing processes.

Toshiba has developed a technique for evaluating the handling of heavy products using cranes. Operators can create simple wire models merely by specifying the start and end points of wires with a simulator. They can then move the crane model using a graphical user interface (GUI) to interactively examine the swinging motion of an object and the resulting load force on it. The new technique can also combine the design data of a product with 3D scan data of a carry-in route or an installation site.

We have been using the new technique to simulate the installation of power generation equipment and explain its safety, quality, and processes to a customer.



Material handling simulation

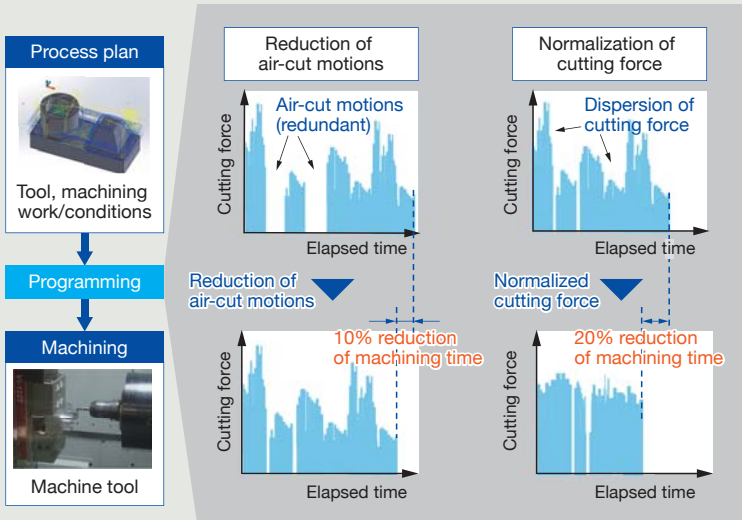
Improvement of Metal Cutting Efficiency Based on Cutting Force Analysis

Toshiba has improved the productivity of metal cutting processes in order to shorten lead times and reduce manufacturing costs.

For metalworking, numerical control (NC) programming defines the cutting tool paths based on a process plan. Poorly mapped-out tool paths that include redundant "air-cut" motions and dispersion of cutting force can slow down the entire production system. Since machine cutting is a complicated process performed at high speed, it has been difficult to identify these inefficiencies.

Computer simulation makes it possible to visualize changes in cutting force over time. Based on the results of such simulations, we have successfully removed air-cut motions and dispersion of cutting force, thereby improving productivity.

We have been using this technology at our sites for the manufacturing of social infrastructure products.



Visualization and optimization of cutting process

Optimization of cutting processes using machine tool based on cutting force analysis