Corporate Research and Development

CELL REGZA™ User Interface Technologies and Super-Resolution Technology for Internet Video

Example of "Roaming Navi" display

The CELL REGZA 55X1 digital high-definition (HD) liquid crystal display (LCD) TV offers an intuitive user interface as well as super-resolution display of Internet video contents, making full use of the powerful capabilities of its Cell processor.

The main features of the newly developed technologies are as follows:

• Metadata processing technology
Toshiba has developed an intuitive user interface called "Roaming Navi™" that helps users to find appropriate contents from among a large volume of recorded, on-the-air, and to-be-aired programs based on their relevance. Highly accurate relevance evaluation is performed using a metadata processing platform, which can store various types of metadata and provide search functionality. The platform is integrated with knowledge-processing modules to enrich the metadata and improve the accuracy of the relevance evaluation and search results.

• Stroke recognition technology
Our newly developed stroke recognition technology processes strokes made by the trajectories of the user's finger on a touchpad incorporated in the CELL REGZA's remote controller, allowing the user to input handwritten text and gestures directly on the touchpad. This technology makes it possible to input keywords for content search, move the focus in the electronic program guide (EPG), and control the mouse pointer on Web pages much more easily and intuitively.

• Super-resolution technology for Internet video
Up to now, users have not been fully satisfied with Internet video contents displayed on large-screen TV

Japanese/Chinese/English Six-Directional Speech-to-Speech Translator for dynapocket™

Speech-to-speech translator running on dynapocket translating Chinese speech into English

Toshiba has developed a speech-to-speech translation application that runs on its dynapocket smartphone. This application can translate users' speech input in all six directions among Japanese, Chinese, and English.

Many of our state-of-the-art technologies have been utilized and downsized for this system, including (1) scalable, noise-tolerant, large-vocabulary continuous speech recognition; (2) forest-driven spoken language translation capable of handling ambiguities in spoken language; (3) highly accurate statistical machine translation; and (4) plural unit selection and fusion model-based speech synthesis.

This application can serve as a reliable partner for overseas travelers who cannot speak foreign languages. It was selected by U.S. independent writers as a finalist for the Innovation Award at CEATEC JAPAN 2009.

sets due to the occurrence of compression noise and lack of resolution. Our super-resolution technology improves the resolution of Internet video by reducing its compression noise, and reproduces a sharper, finer image in real time.

1.2 kV SiC Vertical Power MOSFET

Silicon carbide (SiC) vertical power metal-oxide-semiconductor field-effect-transistors (MOSFETs) have attracted considerable attention as next-generation switching devices to replace conventional Si power devices because they can operate with lower loss, at higher frequencies, and at higher temperatures. On the other hand, low channel mobility due to the interface states of gate oxides of SiC MOSFETs has been a critical issue for the commercialization of SiC power devices.

Toshiba has demonstrated a drastic reduction of the interface states by an optimized MOS gate fabrication technique on a so-called carbon surface. We have also optimized the structure of the MOSFET by miniaturization of the cell pitch and other measures. As a result, we have realized a device with a low specific on-resistance of 5.0 mΩcm^2 and a high blocking voltage of 1 360 V.

Although SiC power devices are expected to be used under high-temperature conditions, the threshold voltage reduction due to release of electrons from the interface states was an issue of concern because the MOSFET cannot hold normally-off characteristics at high temperatures. We also demonstrated that the fabricated MOSFET held normally-off characteristics at a high temperature of 250°C.
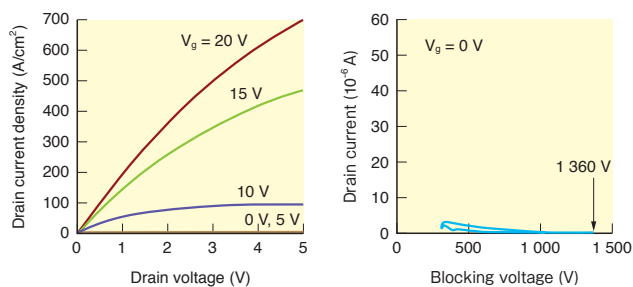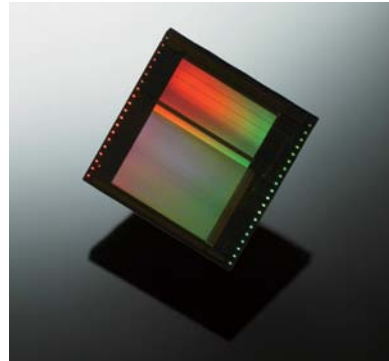
V_g: gate voltage

Forward conduction characteristics and blocking characteristics of fabricated SiC MOSFET

Uncooled Infrared Radiation Image Sensor

Uncooled infrared radiation image sensor chip

Toshiba has developed a 32 μm pitch and 160 × 120 pixel uncooled infrared radiation focal plane array (IRFPA).

For infrared detection, we use silicon single-crystal p-n junctions, which can realize high uniformity of the temperature coefficient and low voltage drift of the signal. Since the IRFPA is fabricated on a Si-on-insulator (SOI) substrate using 0.35 μm complementary MOS (CMOS) and microelectromechanical systems (MEMS) technology, high reliability and mass productivity are simultaneously attained.

We have also developed a low-noise CMOS readout circuit on the same SOI that can compensate for substrate temperature variations in each frame period by comparing two types of pixels: an infrared detection pixel and an unresponsive pixel. This means that the IRFPA requires no thermoelectric cooler and can be mounted on a low-cost standard ceramic package, leading to miniaturization of the sensor module.

Thanks to these breakthrough technologies, our IRFPA is expected to be used in various applications including the consumer products and security fields.

Corporate Research and Development

Design Technology to Realize Pleasant Product Sounds

Quie™ VC-3000X

Quie™ VC-PS300X

Vacuum cleaners incorporating sound quality design

Sounds from electric appliances such as vacuum cleaners cannot be disregarded in the development of quality products. It is not easy to obtain pleasant mechanical sounds, however, when electric appliances are designed according to the conventional trial-and-error method.

Toshiba has developed a design methodology to obtain pleasant mechanical sounds and applied it to products.

This methodology incorporates four steps as shown in the figure (below). The first step is to extract the voice of customer (VoC) data considering diverse customer's Kansei(∗) needs. The second step is to define the metrics for product sound by mapping the psychological metrics and physical metrics. The third step is to set the target sound in terms of the metrics by considering the tendency of the current product development process. The final step is to realize the target sound by applying mechanical design technologies.

The figure (top) shows two types of vacuum cleaners developed based on design for product sound quality. In order to realize the target sound, a newly developed supporting system and brush mechanism were applied in these products.

(∗) Kansei is a Japanese word that refers to the human sensitivity of a sensory organ at which sensations or perceptions take place in response to stimuli (e.g. a product) from the external world. Kansei includes evoked senses, feelings, emotions and impressions.
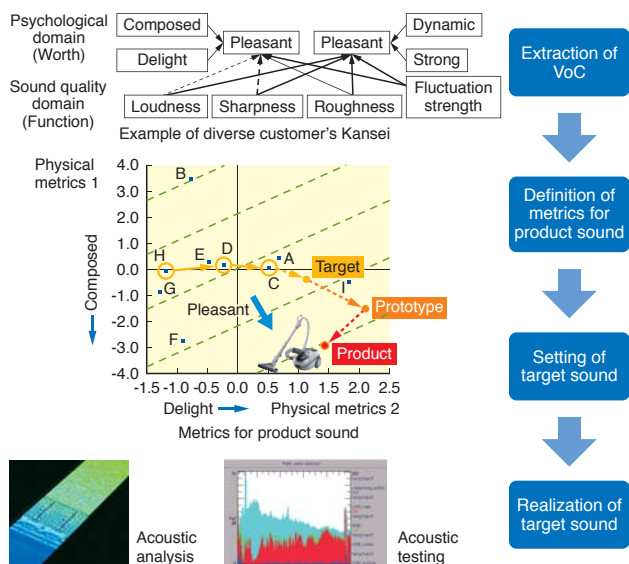
Procedure for realizing pleasant product sounds

Behavior-Aware Energy Management System for Smart Homes

Toshiba has developed a smart home system for energy-saving, called BeHomeS (Behavior-based Home Monitoring and Energy-saving System), with the National Institute of Advanced Industrial Science and Technology (AIST) and other companies.

This system can reduce energy wastage by not only turning off lights or air conditioners in empty rooms, but also controlling the running modes of home appliances depending on the living situations of the inhabitants.

A family of four has lived in the smart home for half a year, and energy savings of 8%, 2%, and 16% were achieved in summer, autumn, and winter, respectively.

This research was carried out as part of the "Research and development of energy-saving system responding to living behavior" theme under the Strategic Development of Energy Conservation Technology Project/Leading research phase of the NEDO of Japan.


Architecture of BeHomeS

Software Implementation of Forward Error Correction for IPTV Terminal Devices

Internet Protocol (IP) TV delivers scheduled TV programs and video on demand over IP networks, allowing such services to be provided at low cost. On the other hand, packet losses and delays are inevitable in IP networks, degrading audio and video quality.

To solve this issue, Toshiba has developed a practical technology for implementation of forward error correction (FEC) software for mid-range and low-end TV sets and PCs. Our algorithm and its implementation are platform-independent and adjustable for each product, without the need for any additional hardware.

This algorithm reduces processing time by 40% and memory usage by half, which is achieved by integrated processing of delay compensation, reordering, and loss recovery.
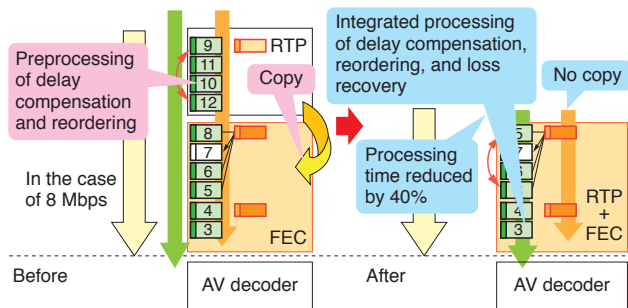
RTP: Real-time Transport Protocol
AV: audiovisual

FEC for low-end-model TV sets

Digital Predistorter for Power Amplifiers

Toshiba has successfully developed a digital predistorter (DPD) that improves the efficiency of a power amplifier in order to reduce the power consumption of a wireless system.

The power amplifier accounts for most of the power consumption of a wireless system. However, it has been difficult to directly reduce the power consumption of power amplifiers because the output signal is distorted by nonlinear behavior. This results not only in a conspicuous degradation of the communication quality of the system itself, but also increased leakage to the adjacent channels, which interferes with other telecommunication systems.

The principle of operation of the DPD is as follows. The distortion of the power amplifier operated with the power consumption decreased in a nonlinear region is measured, then distortion opposite to that of the amplifier is applied to the transmission signal from the signal source. This procedure is performed using highly accurate digital signal processing. When the processed signal is passed through the power amplifier, a high-quality transmission signal without distortion is obtained.

We have succeeded in attaining a 30% reduction in power consumption of a power amplifier compared with the distortion compensation technique using a conventional analog circuit.
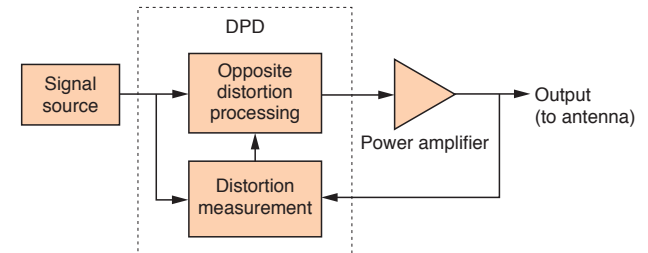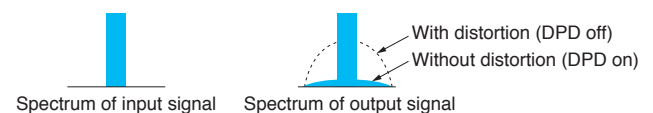

DPD for radio-frequency power amplifiers

## Spin MOSFET Based on Si-CMOS Technology for Reconfigurable Logic/Memory LSIs

The spin MOSFET is an emerging FET consisting of a MOS structure and magnetic source/drain electrodes. This device utilizes spin-dependent transport from the magnetic electrodes through a Si channel. The operating principle provides promising features such as nonvolatile memorizing, fast operation, stability, reliability, and compatibility with Si-CMOS technology in order to realize future universal large-scale integration (LSI) circuits.

Toshiba has proposed an original structure for a spin MOSFET that has magnetic tunnel junctions (MTJs) for its electrodes so that the magnetization direction can be changed by spin-transfer torque switching. We have successfully demonstrated read operation of spin transport and write operation by spin-transfer torque switching in a fabricated back-gate type spin MOSFET. We have also confirmed good read/write endurance originating from the MTJs. These results have opened the way for the use of reconfigurable logic/memory LSIs with low power consumption due to dramatic reduction of the circuit area.
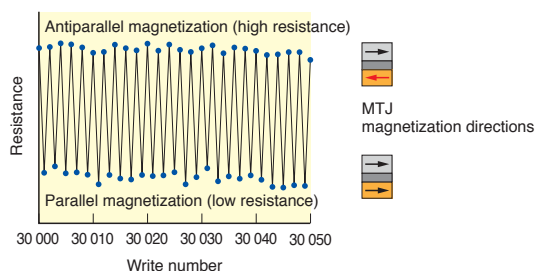
This work was partially supported by the NEDO of Japan.
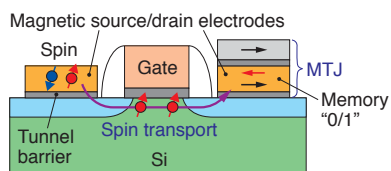
Toshiba original spin MOSFET (front-gate type)
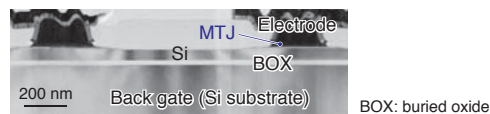
Transmission electron microscope (TEM) image of fabricated spin MOSFET on Si-on-insulator (SOI) substrate (back-gate type)


Read/write endurance test by spin-transfer torque switching

Novel Lifetime Prediction Method for Negative Bias Temperature Instability under Device Operating Condition

Reliability has become an essential issue with the advances made in LSI technology, since the electric field applied over gate insulators is increasing as they become thinner. Accordingly, negative bias temperature instability (NBTI), which refers to the degradation of device performance under high-temperature operation, has become an issue of greater concern. Although NBTI is normally evaluated under direct current negative bias temperature (DC-NBT) stress, the degraded device performance recovers after the stress bias is removed. Therefore, such recovery should be taken into account in predicting the device lifetime.

Toshiba has developed a simple but accurate lifetime prediction method. This method predicts the NBTI lifetime with extrapolation of a recovery envelope defined under low-frequency alternating current negative bias temperature (AC-NBT) stress. Using our method, the NBTI lifetime under the device operating condition can be predicted more accurately than with the conventional method using DC-NBT stress.
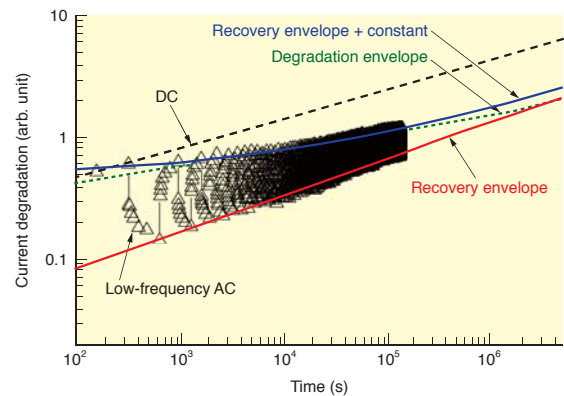
Time evolution of degradation in device current under low-frequency AC-NBT stress

Low-Cost and Reliable Package for RF-MEMS Tunable Capacitor

The use of a MEMS variable capacitor makes it possible to reduce the electrical parts and system size of radio-frequency applications such as a multimode mobile system.

Toshiba has developed a package for an electrostatically actuated MEMS variable capacitor. Since the MEMS capacitor is required to be operated at atmospheric pressure in a dry atmosphere, we developed a wafer-level package (WLP) encapsulation structure with four thin-film layers fabricated by conventional back-end-of-line (BEOL) technologies.

Furthermore, since the MEMS chip is actuated by a control IC chip that provides high voltage, we developed a stacked multichip package (MCP) to integrate the MEMS chip and the control IC chip. The process of the stacked MCP had to be optimized to handle the fragile WLP encapsulation. The newly developed stacked MCP is 4.5 mm × 4.5 mm in size and 0.8 mm in thickness.

The stacked MCP has sufficient reliability, and we confirmed that the MEMS variable capacitor operates normally even in a humid atmosphere.
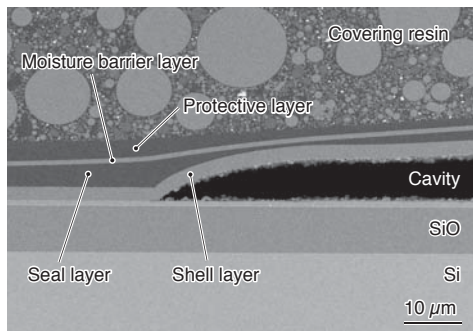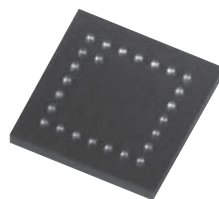
SiO: silicon oxide

Cross-sectional view of WLP encapsulation
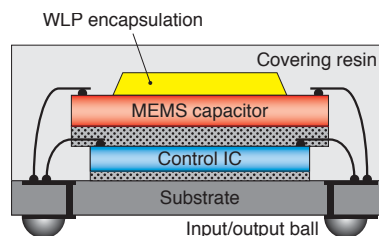
Schematic view of stacked MCP

Ball-side view of finished MCP

## Sr-Sialon Phosphor for White LEDs with High Efficiency and High Color Rendering

White light-emitting diodes (LEDs) are promising devices for solid-state lighting and LCD backlights. Demand for high color rendering and high efficiency is expected to increase in the future.

Toshiba has developed two new types of phosphor based on strontium (Sr)-containing sialon for white LEDs with high efficiency and high color rendering. One is a green-emitting phosphor, $Sr_3Si_{13}Al_3O_2N_{21}:Eu^{2+}$, whose external quantum efficiency is 67%, and the other is a red-emitting phosphor, $Sr_2Si_7Al_3ON_{13}:Eu^{2+}$, with an external quantum efficiency of 61% for blue LED excitation. Since these phosphors also have the advantage of exhibiting relatively small thermal quenching, they maintain high efficiency under high-power driving when the device temperature drastically rises. White LEDs were fabricated using these newly developed phosphors combined with a blue high-power LED. The luminous efficacy and color rendering index Ra of the LED for typical white (4 500 K) at currents of 20 mA and 350 mA were 72 lm/W (Ra 85) and 50 lm/W (Ra 85), respectively.

The LEDs show small reduction of the luminous efficacy and high color rendering under high-power driving.

Al: aluminum
O: oxygen
N: nitrogen
Eu: europium
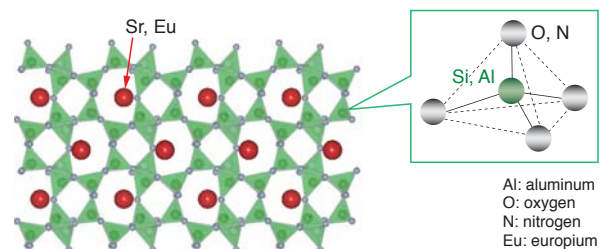
Crystal structure of new green sialon phosphor
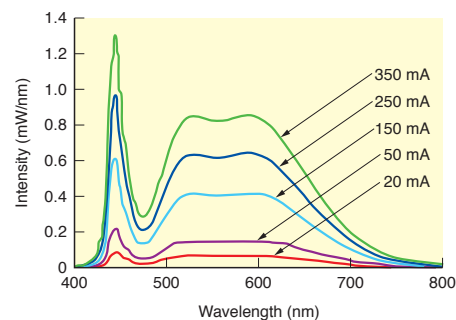
Emission spectra of fabricated high-color-rendering white LED with new green and red sialon phosphors driven at various currents

Accurate Resistivity Calculation in Nanoelectronic Metallic Interconnects Utilizing Monte Carlo Simulation

The effect of size on increased resistivity in copper (Cu) interconnects has recently become pronounced in the dimension where the line width and film thickness approach the electron mean free path. It is essential to understand the physical mechanisms and make accurate predictions of the effect of size on resistivity.

To contribute to fulfillment of these requirements, Toshiba has developed an effective Monte Carlo method to permit more precise resistivity calculation. At any given line width and film thickness, we simulated electron dynamics and calculated the average electron drift velocity along the current direction. The interconnect resistivity was reproduced from the drift velocity using Ohm's law.

The upper figure shows the dependence of resistivity on line width at room temperature. The Monte Carlo results exhibit better agreement with the experimental data than the conventional analytical results. In particular, the Monte Carlo model successfully describes the resistivity increase in narrow and thin Cu interconnects.

The lower figure shows the electron drift velocity distributions in a cross-sectional view of an interconnect and the electron scattering trajectories per picosecond. Scattering was concentrated at the corners of the interconnects and electrons underwent multiple scattering. This decreases both the electron drift velocity and the effective electron mean free path, leading to a further increase in resistivity.

Our Monte Carlo model can incorporate the geometric interaction of electron scattering, permitting more accurate predictions of the effect of size on resistivity than can be achieved by the conventional analytical model.

Comparison of resistivity between Monte Carlo model and conventional analytical model

Electron drift velocity distributions and scattering trajectories in cross-sectional view of interconnect
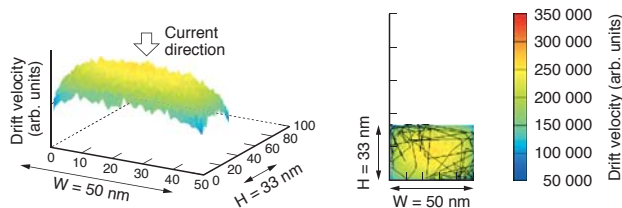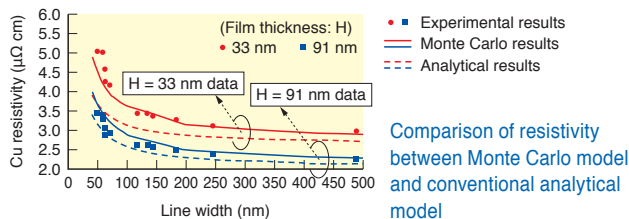
Improving Efficiency of Security Module for Networked Gas Meters

Toshiba has developed an embedded security module to meet the requirements for networked gas meters.

The resource-constrained nature of gas meters makes it difficult to obtain satisfactory performance while processing security protocols. Many of the low-end embedded processors adopted in most gas meters have a variety of constraints such as small memory size, low processing capability, and low power consumption, to ensure prolonged gas meter operation without the need for battery replacement.

In order to establish secure connectivity between utilities and gas meters over a wide-area network (WAN), our security module provides the capabilities to encrypt, decrypt, and authenticate messages according to cryptographic standards, and also incorporates key exchange methods and a method of preventing message replay attacks.

We implemented the security module on an actual networked gas meter in a cost-effective manner and verified these cryptography functions. The security module offered good performance, but we optimized it further to improve the efficiency of security protocol processing. By selecting configurable options specific to the target embedded processor and applying several source code optimization techniques to the security module, we achieved a 30% improvement in memory usage and an increase in speed of almost 30%.
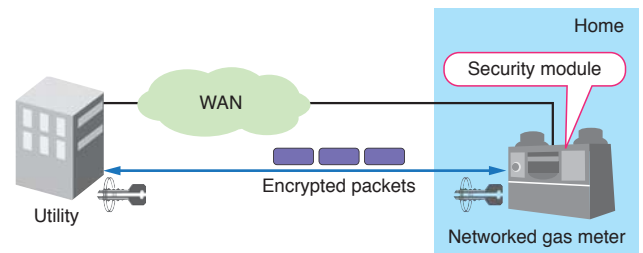
Next-generation network security for gas meters

Illumination-Adaptive LCD Control Technology

The use of mobile devices equipped with a LCD has recently become more common under various illumination conditions. Conventional LCDs, however, suffer from the problem of poor image quality because they appear too bright in a dark room and less brilliant in a bright outdoor location.

To overcome this problem, Toshiba has developed an illumination-adaptive LCD control technology that improves image visibility.

This technology provides backlight luminance control and contrast compensation based on a prediction of the optimal intensity of the image under the illumination condition. The control mechanism employs a human vision model, which is derived from rod and cone cells that mainly work in dark and bright conditions, respectively.

As a result, the visibility of the LCD is significantly improved over a wide range of illumination conditions, from bright outdoor locations (3 700 lx) to dark rooms (100 lx).

This technology has already been applied to our mobile phones and will be applied to future models of other mobile devices such as notebook PCs, car navigation systems, and music and video players.

Flow of illumination-adaptive LCD control under bright illumination condition
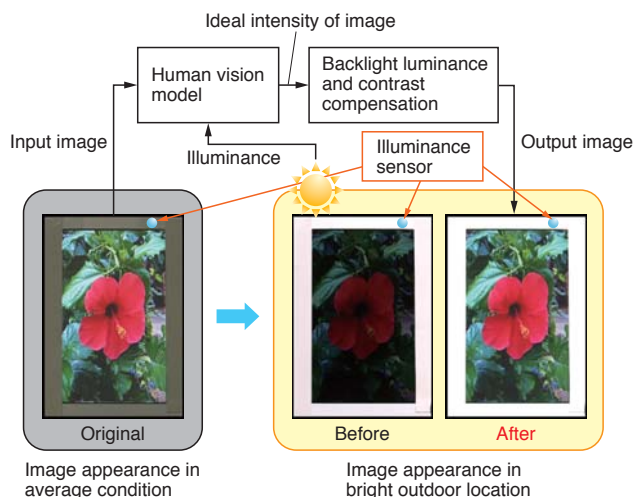
Variable Magnetic Force Motor

ACTIVE S-DD motor and washer-dryer equipped with it

A washer-dryer incorporates a mechanism in which the rotor of a motor and a drum (containing clothing) are directly linked and driven. Since the rotation speed and torque differ greatly in each of the two basic load conditions (washing and spinning), it is difficult to drive both efficiently.

Toshiba has developed a variable magnetic force motor in which the magnetic force of the magnet is changed for each running state, with the aim of comprehensively saving energy (reduced by 22% compared with the previous year's products).

In the process of this development, a magnet layout suitable for a multipolar thin-scale structure was newly proposed in order to conform with the depth limitations of a home laundry. Furthermore, in view of the appropriate electricity consumption for a household electrical appliance, the motor was equipped with a samarium-cobalt magnet that is capable of changing magnetic force by means of a completely new method.

Mass production of the motor began in September 2009, and a washer-dryer equipped with it has been designated No. 1 in energy-saving in the industry[*].
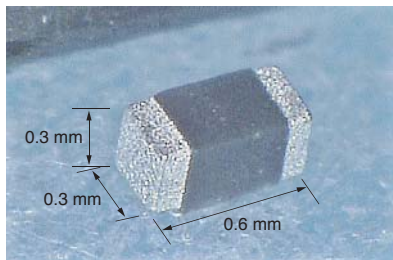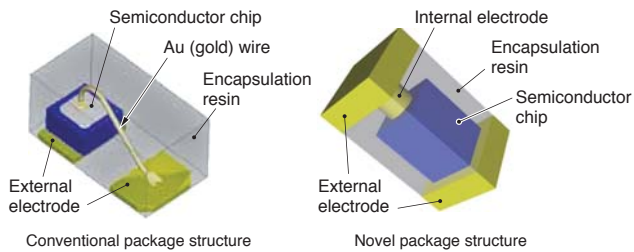
(∗) As of December 2009 (as researched by Toshiba)

Corporate Research and Development

Development of Wafer-Level Packaging Technology for Small Diode Packages

Toshiba has developed a novel wafer-level packaging technology in order to reduce the assembly cost of 0603-size small diode packages installed in mobile devices.

This technology greatly improves the productivity of small diode package fabrication by applying the batch assembly of wafers including the Cu plating process and wafer molding technology in place of the die-mount and wire-bonding process.

To realize this technology, we developed a new encapsulation resin for wafer molding that decreases the amount of wafer warpage while maintaining high bending strength.

Semiconductor chip
Au (gold) wire
Encapsulation resin
External electrode

Internal electrode
Encapsulation resin
Semiconductor chip
External electrode

Conventional package structure   Novel package structure

0.3 mm
0.3 mm
0.6 mm

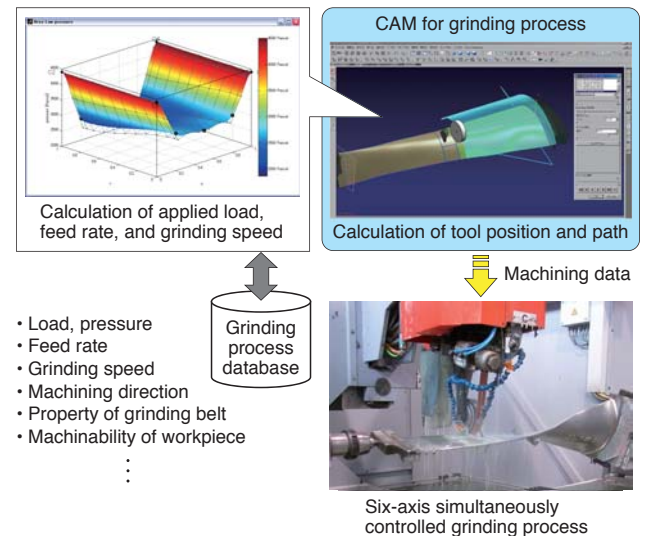Diode package assembled by wafer-level process

Automatic Grinding Process for Last-Stage Buckets of Steam Turbines

Toshiba has developed an automatic grinding system for the last-stage buckets of steam turbines for mass production.

In the grinding process, it is necessary to optimize grinding conditions such as the grinding speed, the applied load, and the feed rate in order to control the quality and productivity of machined parts.

We accomplished numerical optimization of the grinding process conditions by conducting experimental investigations into the relationship between the material removal rate in the grinding process and the grinding conditions, using a computer-aided manufacturing (CAM) system and a six-axis controlled grinding machine tool.

We succeeded in performing the grinding process automatically in mass production.

CAM for grinding process

Calculation of applied load, feed rate, and grinding speed

Calculation of tool position and path

Machining data

· Load, pressure
· Feed rate
· Grinding speed
· Machining direction
· Property of grinding belt
· Machinability of workpiece

Grinding process database

Six-axis simultaneously controlled grinding process

Numerically controlled grinding system for last-stage buckets

Multidimensional Indexing Technique

Toshiba has developed a multidimensional indexing function for database systems, and successfully performed high-speed searches of data such as thumbnail images in digital devices.

Thorough searches of multidimensional data can be achieved using a sphere/rectangle tree (SR-tree). However, as the number of dimensions increases, distinguishing the distances between pairs of data becomes increasingly difficult, thereby prolonging the search time. The approximate nearest neighbor (ANN) technique, on the other hand, implements a pruning method for a quick but unrefined search of multidimensional trees.

We have developed a technique combining ANN's time-efficient pruning search on an SR-tree by evaluating the data distributions of data clusters. In drilling down on more focused regions, we have achieved a desirable speed of search of multidimensional data without much sacrifice of the integrity and accuracy of the search results.
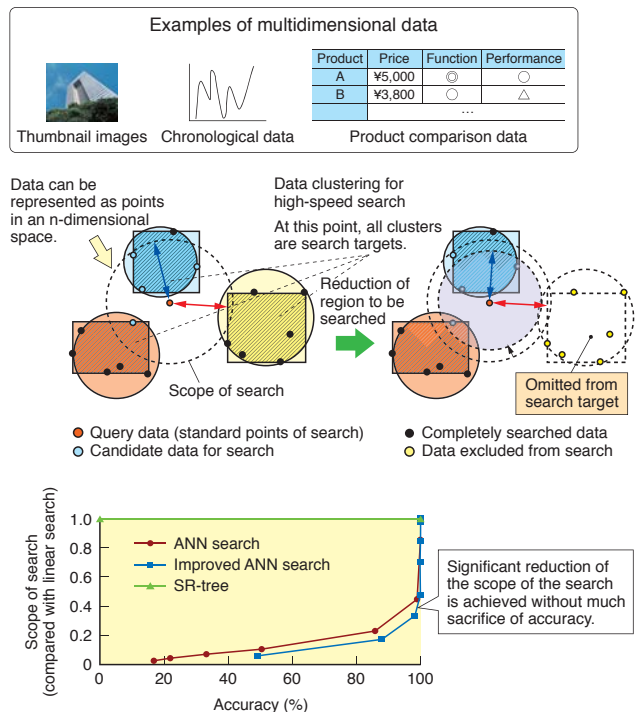
Expedited search using approximate nearest neighbor (ANN)

# Fast Adaptive Layout Method for Data Visualization

A fast adaptive layout method for data visualization is proposed. In this method, each item of data is represented by a rectangle. All rectangles are compactly packed into a two-dimensional display space. The user has a bird's-eye view while being conscious of the features of each item of data from the color, size, aspect, etc. of its rectangle. To pack rectangles into the two-dimensional display space, two tree structures are used: a slicing tree for recording the current layout, and a balanced tree for the unfilled spaces. The layout is incrementally created by finding an unfilled space for each rectangle from the balanced tree and then modifying the slicing tree. For n data, the computation complexity is O($n$log$n$). In our implementation, 20 000 data were laid out within 1 second using a PC equipped with an Intel® Pentium®4 3.2 GHz processor and 1 Gbyte memory.

We have applied this method to visualization of the quality of a software program. With the software metrics of static code analysis, each function is mapped into a rectangle. The software program is visualized in the display space. The quality of the software program is implied by showing the correlation among the metrics and the trends throughout the display space. As a general method for data visualization, this method can also be applied to or combined with other engineering tools.

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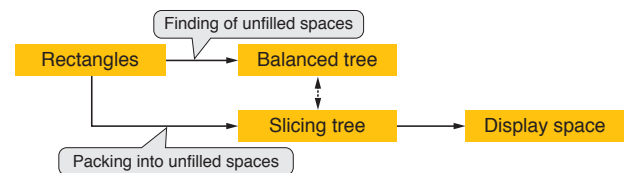
Flow of adaptive layout method
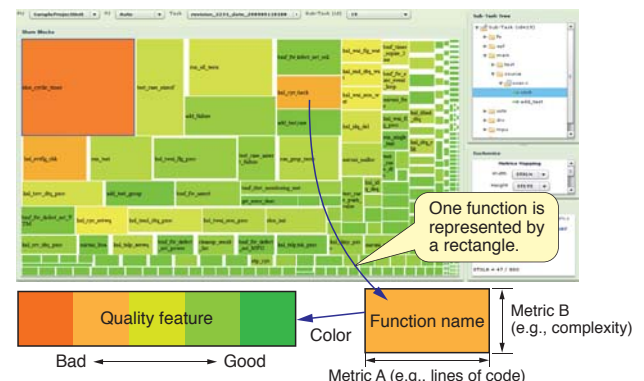
Visualization of source code metrics