Research & Development

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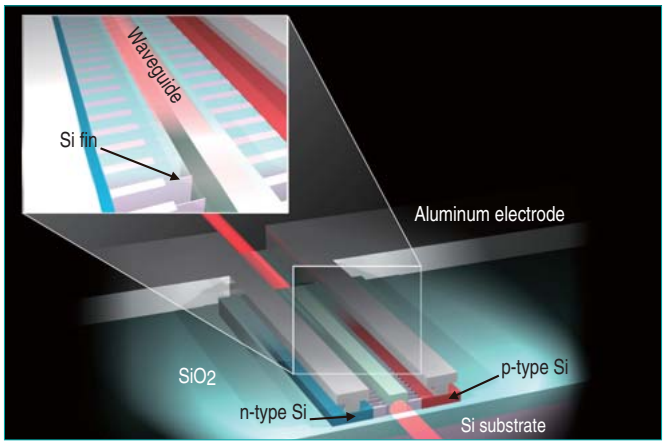
Observation of Light Amplification in Silicon-fin Light-emitting Diode—Breakthrough in Path to Silicon Lasers

Silicon lasers are recognized as a technology with the potential to achieve dramatically higher performance and lower power consumption in IT equipment by allowing optical transmission to be used to transmit data within and between semiconductor chips. To achieve this goal, Hitachi has produced a prototype LED with a fin structure made of 1,000 or more ultra-thin silicon films formed perpendicularly on a silicon substrate and confirmed that light amplification occurs. The presence of light amplification is one of the requirements for lasing to occur and represents a step forward along the path to creating a silicon laser.



Silicon-fin light-emitting diode

Path to Silicon Photonics

Silicon photonics seeks to use silicon to transmit data optically and is currently an active area of research and development around the world. If this technology were to enter practical use, it is anticipated that it would bring dramatic improvements in the performance of IT (information technology) equipment as the electrical wires currently used to transmit data within and between semiconductor chips could be replaced with optical links to increase speed and reduce power consumption.

While the development of optical waveguides, detectors, modulators, and other elements based on silicon is progressing well, the element proving most difficult to implement is a laser diode. Among the different types of semiconductor, silicon is particularly unsuited for light emission and, as a consequence, all conventional LEDs (light-emitting diodes), for example, are currently made from compound semiconductors. However, numerous benefits would accrue if LEDs could be made using the same silicon semiconductor that is already widely used as the basic material for IT equipment, including ease of integration with logic circuit elements and the ability to produce in large volumes and at low cost.

Observation of Light Amplification by Multi-quantum-well Structure

We have been working on research and development aimed at demonstrating lasing in a silicon LED, a requirement for optical transmission. Past results of this work include the observation in 2006 of light emission in an ultra-thin silicon element consisting of a single quantum well and the confirmation for the first time ever of light amplification in a thin-film silicon LED in 2008 which was achieved by embedding the single quantum well in an optical resonator. Light amplification is a requirement for lasing to occur.

Now we have succeeded in observing light amplification in a multi-quantum-well structure for the first time. Multi-quantum-well structures will be essential if practical levels of light emission are to be reached. The prototype LED has a fin structure made from 1,000 or more ultra-thin silicon films formed perpendicularly on a silicon substrate together with a waveguide made from a silicon-nitride layer formed on the fins to improve the light emission efficiency. The light produced when a current is injected can be observed traveling along the waveguide and being emitted from the end. Also, a detailed analysis of the emission spectrum indicates that light amplification has occurred.

Combining Suitability for Mass Production with Ease of Integration

Although the idea for the fin structure has been around since 2006, Hitachi struggled to perfect the etching process required to form the perpendicular fins using thin films with a thickness of only about 1 nm. The new fin-based prototype design of silicon LED is suitable for mass production because it allows a large number of fins to be formed per exposure. Hitachi has also developed a fin-based field effect transistor design which has the potential to be used in the next generation of transistors and the compatibility between the two types of device makes it easier to integrate them on the same substrate, making it likely they will be used to create hybrid optoelectronic chips.

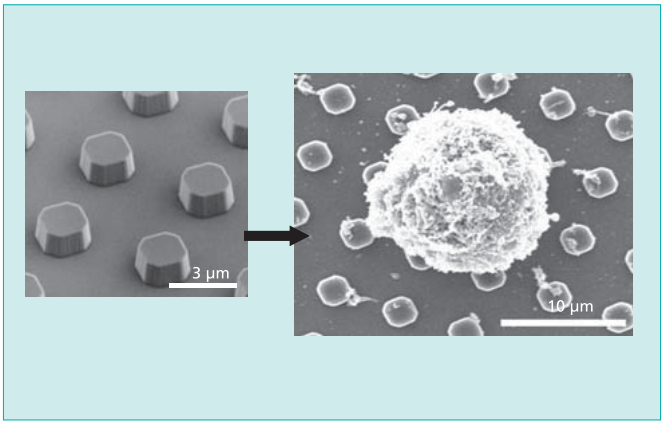
Work on this research has accelerated since 2010 due to its inclusion in the "Funding Program for World-Leading Innovative R&D on Science and Technology" (FIRST Program) with Professor Yasuhiko Arakawa of The University of Tokyo taking the role of core researcher.

The next step toward lasing is to achieve a higher level of light amplification and we are currently working toward this goal on a variety of fronts including materials, designs, and processes. We intend to continue working on research and development aimed at creating a silicon laser by drawing on knowledge from a wide range of fields, particularly the microfabrication technology built up by Hitachi's Central Research Laboratory.


Shinichi Saito (left), Senior Researcher; Toshiki Sugawara (right), Senior Researcher, Communication Electronics Research Department, Central Research Laboratory, Hitachi, Ltd.

Successful Culturing of Hepatocyte Spheroids Using Nanopillar Cell Culturing Sheets

In the development of new drugs by pharmaceutical manufacturers, shortening development times and reducing costs are major issues. Hitachi succeeded in culturing hepatocyte spheroids using a cell culturing sheet with microscopic pillars arranged in certain patterns. Because the cultured spheroids more closely resemble natural liver tissue than hepatocytes cultured in two dimensions, it is expected that this technology will be applied in the drug screening process and increase the efficiency of developing new drugs.



Hepatocyte spheroids (right) using a nanopillar cell culturing sheet (left)

Demand for Improved Efficiency in New Drug Development

In the development of new pharmaceutical drugs, first, screening is performed of a large number of candidate drugs to identify the compounds appropriate for the target medical condition. Next, non-clinical trials are performed using cell culturing and tests on animals to verify the efficiency of the candidate drugs and their effects on living organisms. This is followed by clinical trials on healthy people and patients. Making this process more efficient is a key issue for pharmaceutical manufacturers. In particular, there is growing demand for using cultured human cells that are close to living tissue from the non-clinical stage, in order to obtain more accurate data and narrow down the candidate drugs before entering clinical trials, which take time and money.

It has been confirmed that three-dimensionally cultured spheroids are more similar structurally and functionally to natural tissue than the conventional structure using the two-dimensional method. We took on the challenge of culturing spheroids that are close to living tissue, with the target of culturing hepatocyte spheroids, which are essential when researching the metabolism of drugs.

Controlling the Structural Shape with Microscopic Pillars

The material used for culturing is a nanopillar cell culturing sheet. This is a polystyrene sheet with microscopic pillars (nanopillars) arranged uniformly on it, and is manufactured with nanoprint technology where a microscopic pattern on a silicon mold is pressed and transferred to the material.

In this development, we tested several nanopillar types with diameters ranging from 180 nm to 5 μm and pitches between pillar centers of 360 nm to 10 μm. We found that spheroids were most effectively cultured closer to natural liver tissue when the diameter was 2 μm and the pitch between pillar centers was 4 μm. We confirmed that spheroids cultured on this sheet were closer to natural liver tissue than tissue cultured using the conventional two-dimensional method, that the expression of hepatic function related genes was higher, and that the activity of metabolizing enzymes was higher. An important feature of our method is that, compared to the common method of controlling the spheroid formation by using an application on chemical materials, we control by using nanopillar patterns only. This has the merit of preventing the inflow of unnecessary drugs into the new drug screening process.

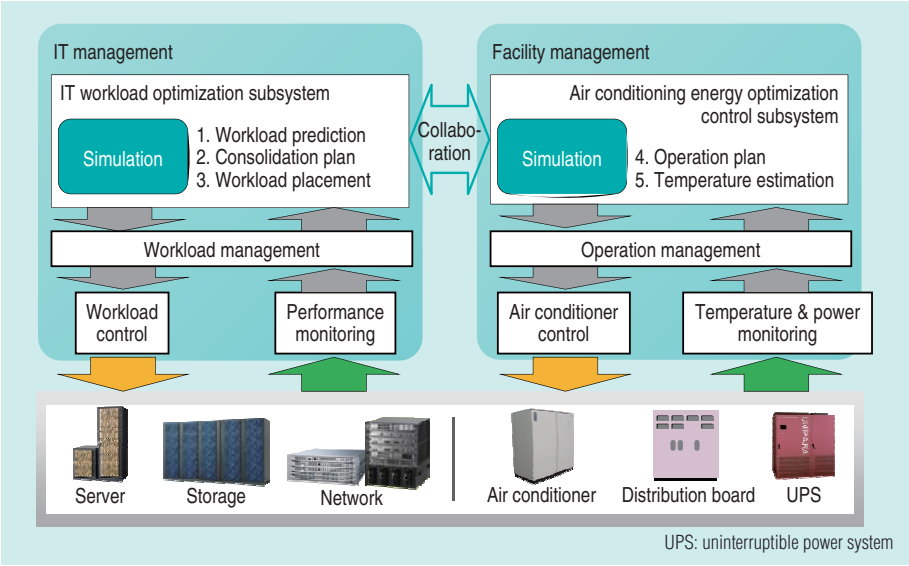
Faster Development through Teamwork

We achieved success in this project by fusing together core Hitachi technologies; namely, silicon molds that apply the semiconductor microfabrication technology of the Central Research Laboratory; the nanoprinting technology of the Hitachi Research Laboratory; and the cell culturing technology of the Advanced Research Laboratory (currently Central Research Laboratory). The research team cooperated with the Total Solutions Division. Further, we received a great deal of assistance from Professor Yasuhiko Tabata at the Institute for Frontier Medical Sciences, Kyoto University.

Our goal is to use the knowledge we have gained through these developments to make new drug development more efficient, enabling these drugs to help society as quickly as possible.

Akiko Hisada (left), Senior Researcher; Ryosuke Takahashi (right), Researcher, Advanced Research Department, Central Research Laboratory, Hitachi, Ltd.

Technology for Collaborative Control of IT and Facilities to Reduce Data Center Energy Consumption



Collaborative control of IT and facilities

Hitachi has developed technology for collaborative control of IT (information technology) and facilities to reduce data center energy consumption. The technology uses numerical analysis and simulation of the IT and facilities equipment in a data center to predict their workload and manage their operation in a way that improves energy efficiency.

The collaborative control system consists of an IT workload optimization subsystem and an air conditioning energy optimization control subsystem, while interoperation between these subsystems provides additional savings in IT and air conditioner power consumption.

The IT workload optimization subsystem consolidates IT workload onto fewer computers and switches off those that are not needed during periods of low resource utilization. To ensure that applications continue to run reliably on the smaller number of computers, the system continuously monitors the application workload and predicts their future usage of computing resources. It also coordinates with the air conditioning energy optimization control subsystem to consolidate the workload onto those computers where the air conditioning works most efficiently.

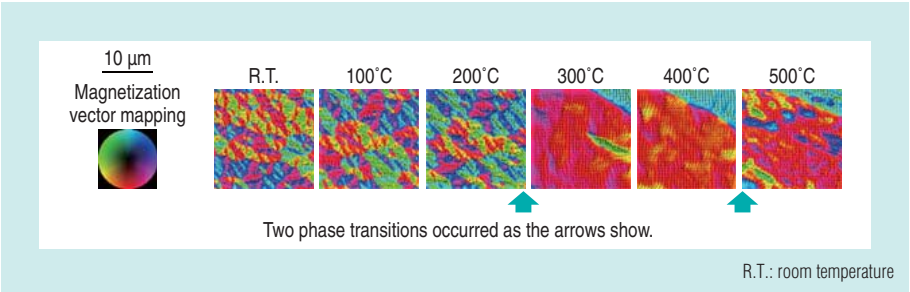
The air conditioning energy optimization control subsystem produces an optimal plan for air conditioner operation based on the amount and distribution of heat generated by the data center's IT equipment which it determines by using information about current and future IT workloads supplied by the IT workload optimization subsystem to estimate the temperature distribution.

Hitachi built a prototype of the control system and demonstrated that the system can reduce IT and air conditioner power consumption by more than 30% at data centers that host the typical enterprise business application systems used by many companies.

Sample Heating System up to 500°C for Spin-polarized Scanning Electron Microscopy

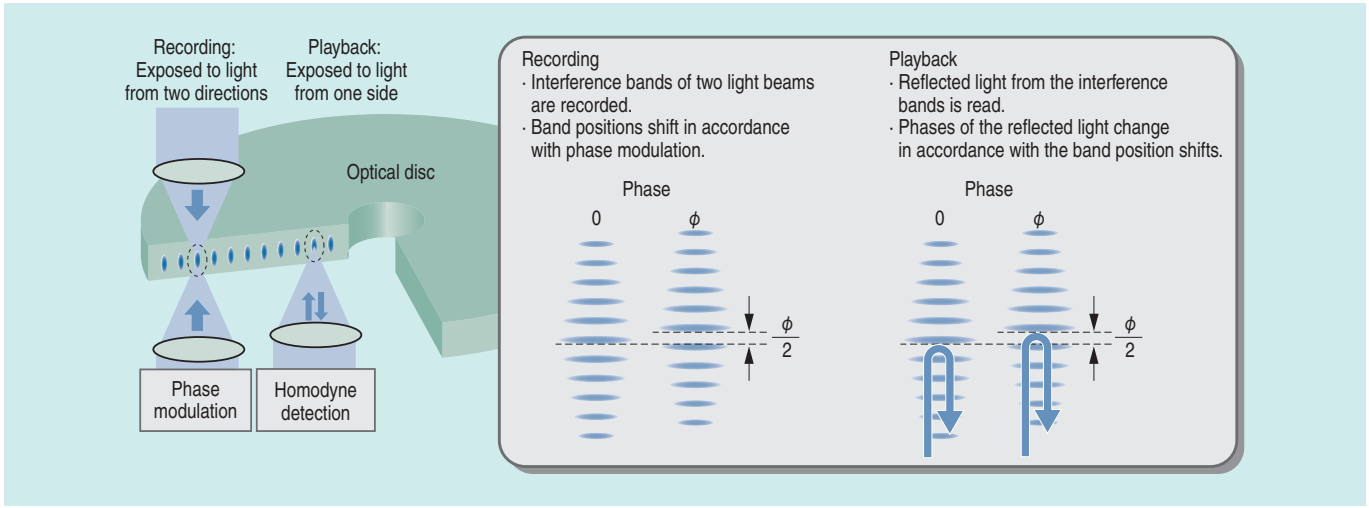
Hitachi has developed a sample heating system up to 500℃ for spin SEM (spin-polarized scanning electron microscopy). Spin SEM can image a surface magnetic structure independently of surface morphology in nanometer scale, and has been used to examine properties of permanent magnets such as NdFeB, HDD (hard disk drive) magnet devices, and other components. NdFeB magnets have been used in high-temperature conditions such as in the motor of HVs (hybrid vehicles), and there is demand for its coercivity to be improved in these conditions. Recorded bits in HDDs are becoming smaller as the recording density increases, while they are also required to keep enough thermal stability. Hitachi's sample heating system is very useful for investigating the magnetic properties of these devices in high-temperature conditions.

A compact ceramic heater maintains the UHV (ultra high vacuum) condition during the spin SEM measurement, and the analyzer has been modified to be operated in high-temperature conditions. The magnetic domain structures of Co single crystal were observed from room temperature up to 500℃ in order to demonstrate this new system. Two drastic changes in the magnetic domain structures at 220℃ and 400℃ were observed, and these are consistent with the related phase transitions formerly reported. It is expected that this new spin SEM system will contribute to improving the coercivity of the permanent magnets for HV automobile systems and increase the recording density in HDDs.



Magnetic domain images of Co (0001) at high temperatures

Phase Multi-value Recording and Playback for High-capacity, High-speed Optical Discs



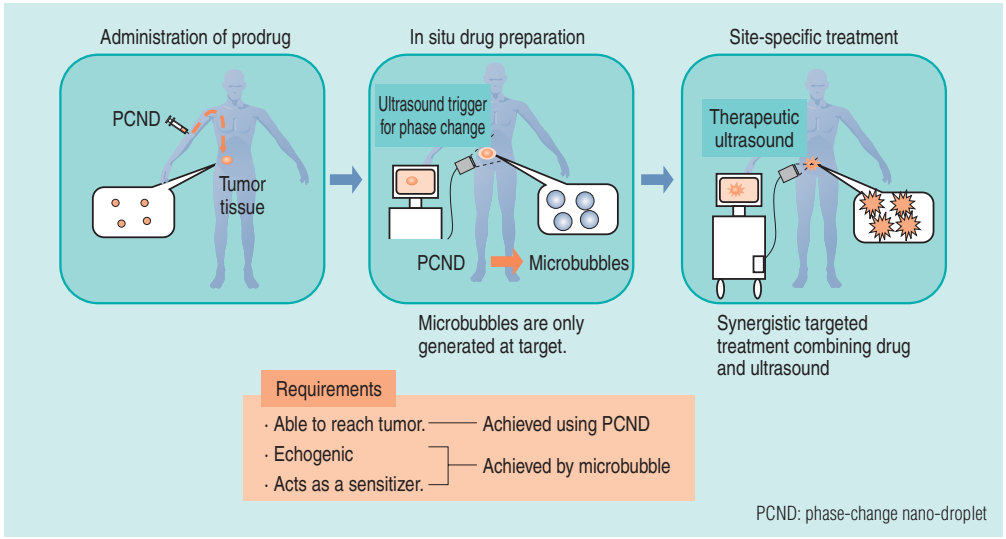
Principles of phase multi-value recording and playback

Hitachi has invented a phase multi-value recording and playback system for increasing the capacity and transfer speed of optical discs, and has succeeded in verification tests that prove the principles of the playback system.

The developed system is based on the microholographic technique of the 3D (three-dimensional) recording system that enables higher capacities while maintaining compatibility with current optical discs, and applies the homodyne detection technology that amplifies the detection signal using light interference, whose application on optical discs has been independently developed by Hitachi. The developed system enables more values, while at the same time increasing the capacity of optical discs and data transfer speeds. In the playback principle test, it was verified that phase 8-value signals could be played back.

In the future, by combining 3D playback with multi-values, optical discs will be made with a recording capacity and transfer speed performance more than 10 times higher than those of current discs.

Phase-change Nano-droplet for Efficient Tumor Therapy



Targeted tumor therapy using PCND

In 2006, Hitachi developed a novel tumor-specific ultrasound imaging modality which uses nanometer-sized droplets that turn into micrometer-sized bubbles when delivered into tumor tissue and exposed to a triggering ultrasound pulse.

Hitachi has now succeeded in prolonging the lifetime of these microbubbles. This technique provides a highly effective imaging-based ultrasound tumor therapy which can also be used to confirm whether the microbubbles are thoroughly dispersed through the tumor tissue. By enhancing the thermal effects of the therapeutic ultrasound, microbubbles provide an order of magnitude reduction in the ultrasonic energy required for tumor therapy.

This work was supported in part by the New Energy and Industrial Technology Development Organization (NEDO) of Japan.

Automatic Guided Vehicle with Autonomous Controller

Hitachi's spatial recognition technology for indoor autonomous travel that is applied to unmanned transportation vehicles for logistics within plants and warehouses has been commercialized and marketed by Hitachi Plant Technologies, Ltd. The map generation and self-positioning functions based on spatial recognition using range sensors enable travel without guides, such as magnetic wires or markers, which are required by conventional transportation vehicles. Because the installation and setup work for these guides are no longer required, introducing the system and changing the layout are very simple. Also, because the destinations and routes can be freely set, and routes can be changed to suit different conditions, transportation becomes much more flexible and efficient.

Product lineup examples [100-kg transportation weight type (left) and 500-kg type (right)]

In the future, Hitachi plans to enhance the functions to deal with a wider range of operation situations and environmental conditions, as well as expanding the technology to vehicles such as forklift trucks.

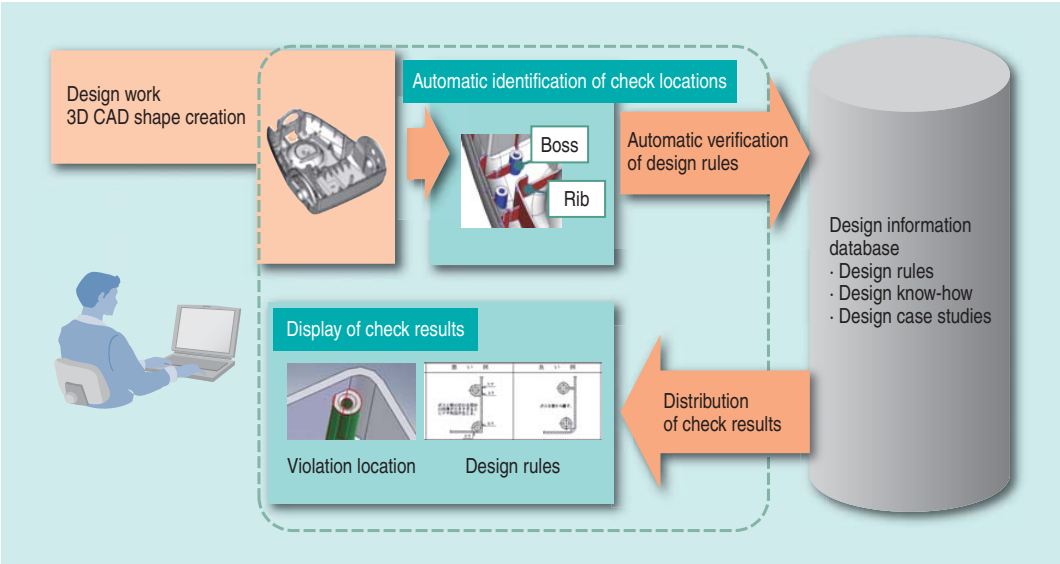
Design Rule Reminder Support Technology for 3D CAD Shapes

To improve the efficiency of product development, design must be performed while considering manufacturability (such as whether manufacture is possible). However, with the increase in the number of part types and the use of 3D (three-dimensional) drawings, it has become difficult to check everything with no omissions.

Hitachi has developed technology for automatically identifying the locations that should be checked in a complex product shape, using Hitachi's unique shape recognition technique. This enables the 3D CAD (computer-aided design) shape to be verified automatically against the design rules related to manufacturability, which reduces the time required for checking work.

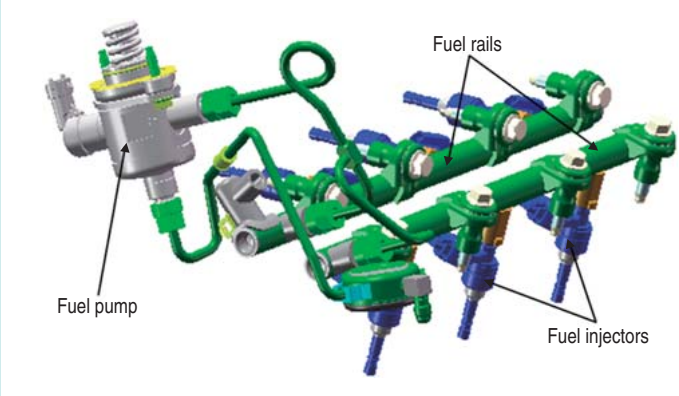
Also, the locations that do not comply with the design rules are displayed on the CAD system screen, and there is a reminder function for the points that the designer should consider. When automatic verification was performed during the design of a vacuum cleaner, more than 500 locations could be checked in less than five minutes.

In the future, Hitachi will contribute to improving the efficiency of product development by applying this technology in the design of products such as IT (information technology) devices and white appliances.



Overview of the design rule reminder support system

Development of Fuel Supply Subsystem for the Global Market

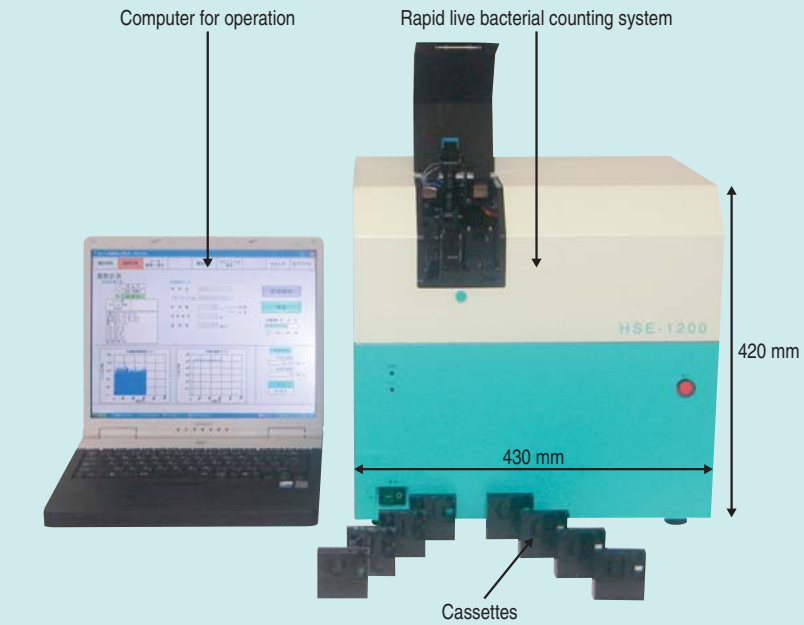


Fuel supply subsystem

Hitachi has developed an innovative fuel supply subsystem for SIDI (spark ignition direct injection) engines. This enhances conventional gasoline engines to have less fuel consumption with high maximum power, and yet lower noise and vibration. The key components and technologies are as follows.

(1) A fuel injector which can control a wide range of injection volumes. This enables engines to have low fuel consumption and high power according to the operating conditions. The key technology is the development of a compact magnetic circuit and a low hydraulic resistance design.
(2) A fuel pump which can control a high flow rate with lower noise and vibration. This enables engines to reduce the typical noise related to SIDI engines, which is made by the internal impacting of a solenoid valve. The key technology is the development of a solenoid valve with slow impact speed control.
(3) A fuel rail which isolates transmission of vibration between the engine head and fuel rail/injector. This reduces noise derived from injector vibration and pulsation, which is also typical of SIDI engines. The key technology is the development of an isolation mounting structure for the fuel rail.
These fuel supply subsystems and components are equipped on more than one million cars around the world through Hitachi's global customers in North America, Europe, and Japan, and they meet the latest environmental regulations in each region.

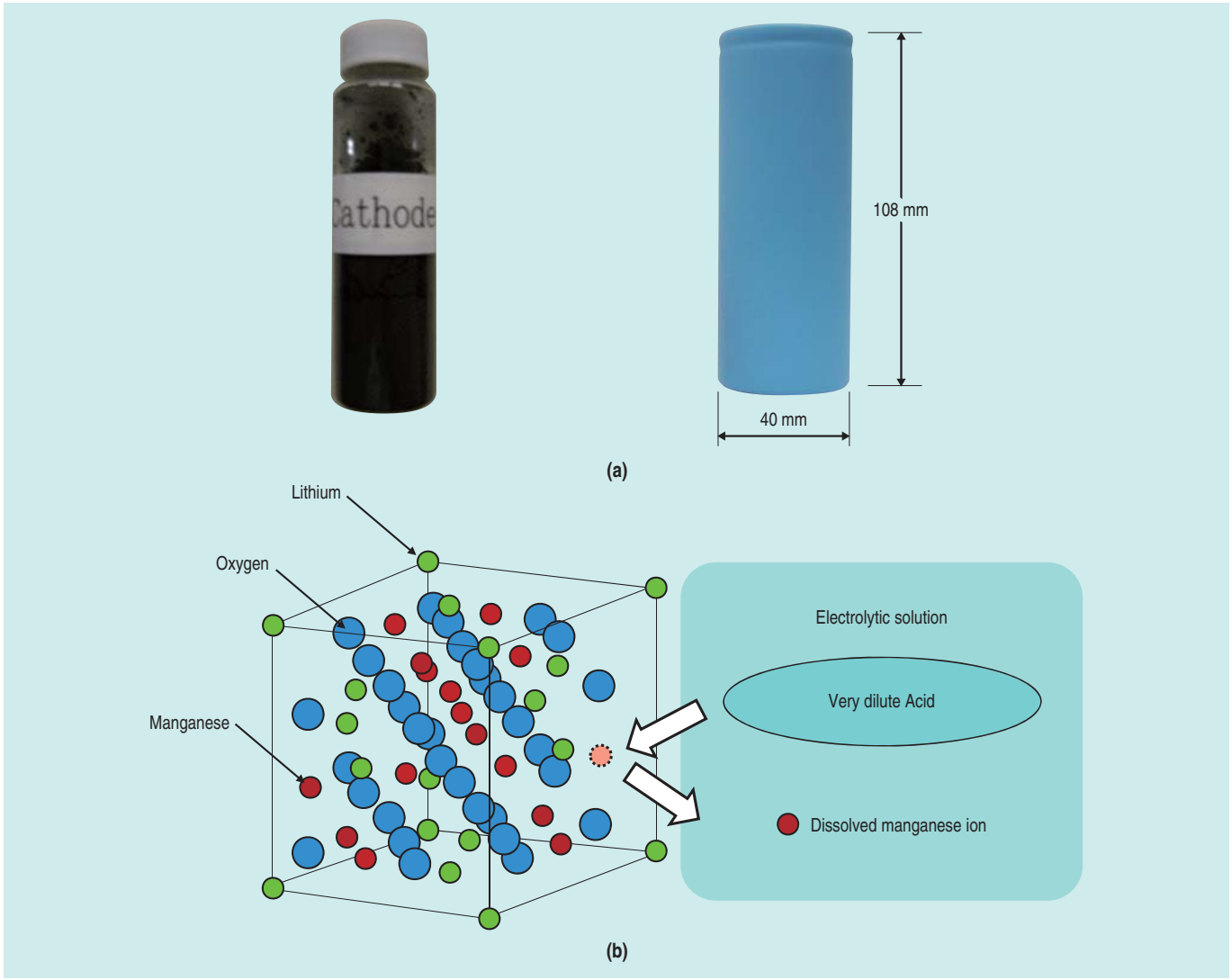
Rapid Live Bacterial Counting System



Rapid live bacterial counting system

Hitachi has achieved the full automation of the flow cytometry technique that counts the number of bacteria using fluorescent dyes, by mounting a counting unit with minute flow channels (minimum diameter: 40 μm) formed with MEMS (micro electromechanical systems) into a preprocessing integrated counting cassette.
For the fluorescent dyes inside the cassette, a triple dye technique using two types of fluorescent pigment for all bacteria and one type of fluorescent pigment for dead bacteria is utilized to discriminate between live bacteria and fluorescent pigment particles, reducing the detection lower limit from the previous 10^4 particles/ml to 10^2 particles/ml. This means that simply by inserting a cassette filled with the sample solution into the unit, counting the bacteria in a food specimen that would previously have taken one or two days can now be performed automatically within 90 minutes. Because the developed device is small and simple to handle, it can easily be used to provide environments where food hygiene inspections are conducted. Also, because the counting results are obtained in a short time, Hitachi plans to deploy this system to add value to a wide variety of usage techniques.
(Hitachi Engineering & Services Co., Ltd.)

Technology for Lengthening the Life of Industrial Lithium Ion Batteries



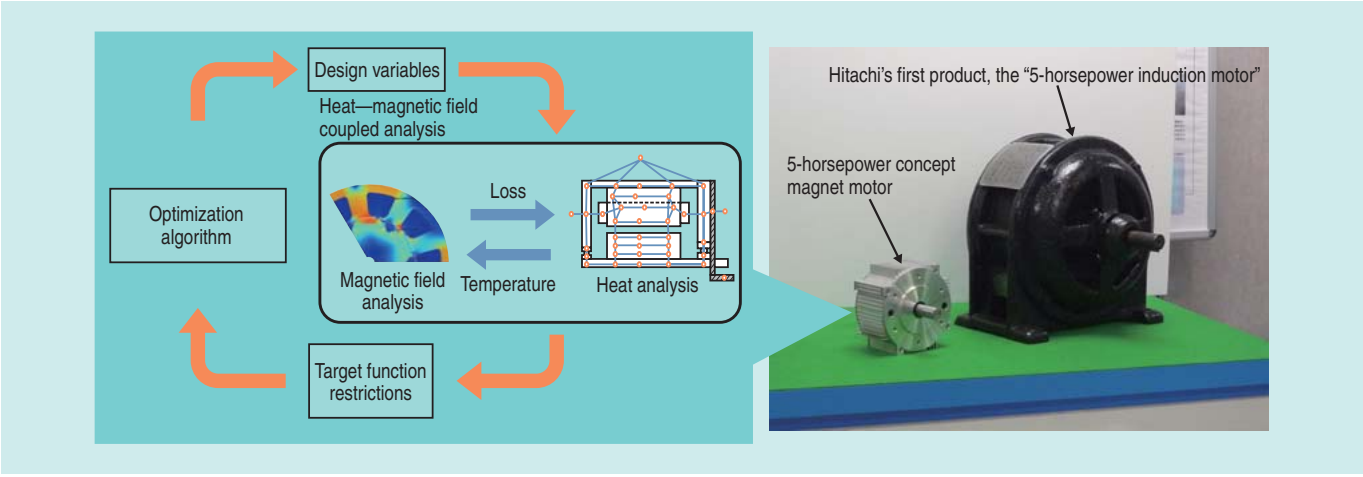
Manganese positive electrode material (left), and a cylindrical lithium ion battery in which it is used (right) (a) and speculated mechanism of manganese elution from a conventional manganese positive electrode (b)

Industrial lithium ion batteries have a higher energy density than other secondary batteries, such as lead storage batteries. For this reason, they have great potential for application in devices such as the power storage systems of wind or solar power, the power supply for electric construction machinery, and backup power supply systems. Manganese positive electrodes have gained attention as positive electrodes for industrial lithium ion batteries because manganese is an abundant natural resource. However, issues that remain are the changes in the area of the positive electrode crystals due to the repeated charging and discharging of the battery, and the decreased capacity caused by manganese elution from the tiny amounts of acid inside the battery.

In response to these issues, Hitachi dramatically improved the durability of the positive electrodes by minimizing the area changes in the crystals by replacing parts of the manganese with other elements, and by reducing the manganese elution by blending it with a stratified compound oxide that has excellent resistance to acidity. In a service life evaluation of lithium ion batteries that use the manganese positive electrode material developed by Hitachi, it was forecast that the service will be twice as long (10 years or more) as conventional lithium ion batteries.

This development was conducted jointly between Hitachi, Ltd. and Shin-Kobe Electric Machinery Co., Ltd. as a part of the "Development of Elemental Technologies for Power Storage Systems to Achieve Smooth Utility Interactions" project of New Energy and Industrial Technology Development Organization (NEDO) of Japan.

Design Optimization Technology for Motors Using Heat—Magnetic Field Coupled Analysis



Overview of design optimization technique, and an exterior comparison between the prototype motor and Hitachi's founding product

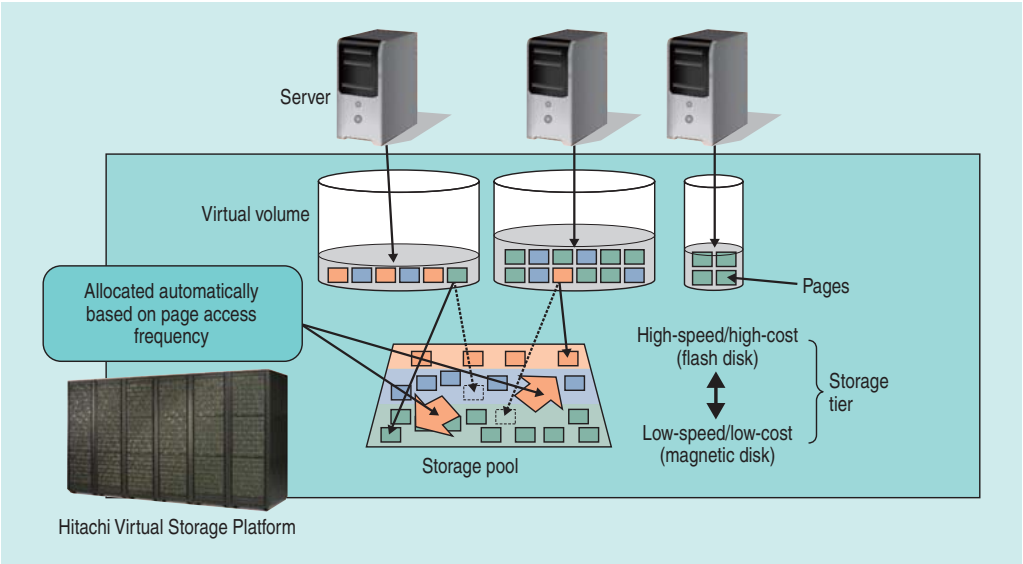
From the perspective of preventing global warming, motors need to be made smaller and more efficient.

To achieve both these objectives, energy loss occurring within the motor must be minimized, while the drop in the heat discharge performance that accompanies the smaller size must be mitigated. In this context, Hitachi developed coupled analysis technology that resolves the issues of heat and magnetic flux flow in the motor at the same time, and based on this analysis technology, also developed design optimization technology for the motor shape.

By fusing these technologies with the Hitachi's advanced motor materials (such as rare earth magnets and enameled wire), Hitachi made a prototype of a concept magnet motor of 5 horsepower (3.7 kW). Compared to the "5-horsepower induction motor," Hitachi's first product in 1910, its size is about one-fifteenth less and it achieves a high efficiency of about 94%.

In the future, Hitachi will apply this optimization technology to the development of a wide range of motors.

Tiered Storage Virtualization Technology



Tiered storage virtualization technology

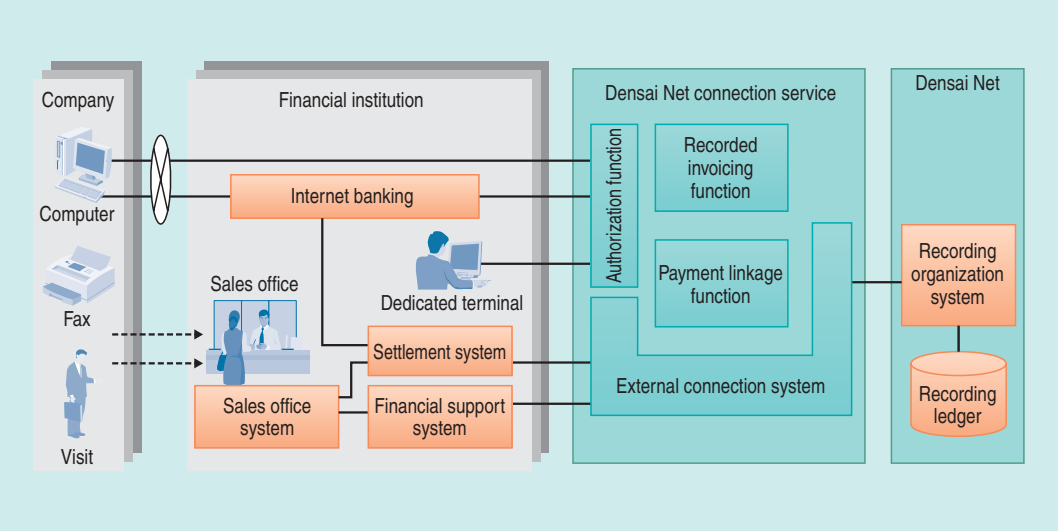
The rapid increase in data volumes in recent years has created a growing need to allocate data to the appropriate tier of the storage pool (flash disks, magnetic disks, and other media) based on the changing frequency of data access in order to reduce data storage costs.

In response, Hitachi has developed technology in which the storage system monitors the frequency of access to small-sized pages and automatically shifts pages to the appropriate tier of the pool based on changes in this access frequency. This improves performance for data with a high access frequency while reducing the storage cost for less frequently used data. The technology was released in Hitachi Virtual Storage Platform in September 2010.

Hitachi intends to continue developing storage virtualization technologies that further improve operational efficiency for system administrators.

Electronically Recorded Monetary Claims Solution

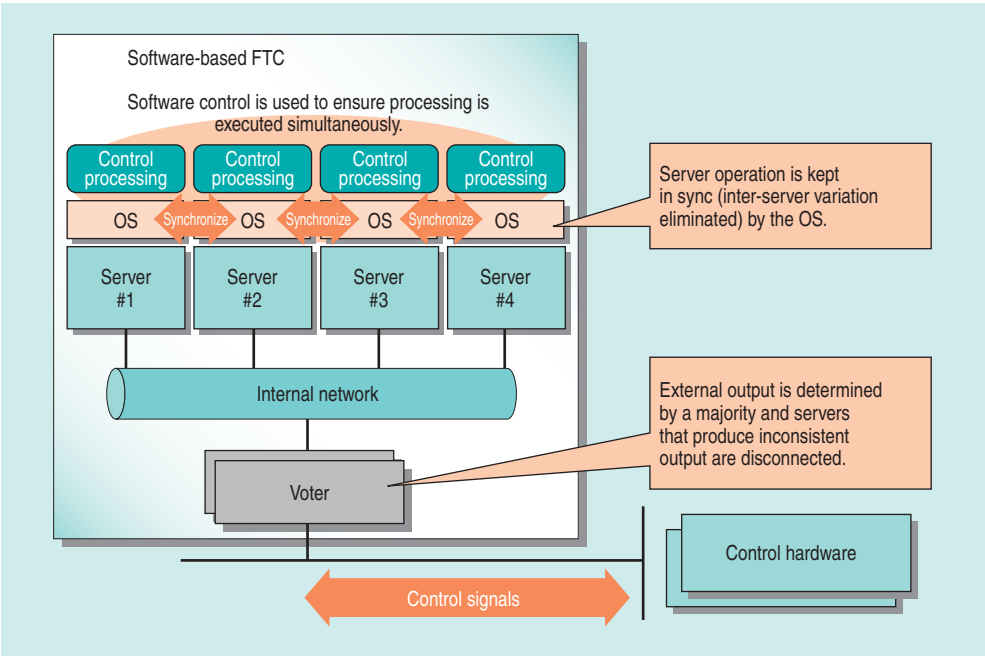
Based on its accumulated design know-how in system development for electronic bills and stock certificates, Hitachi has developed electronic rights management technology that makes the requirement extraction of systems managing "rights" more efficient. This technology is constructed from concept models and patterns of rights management. By using these as guides for system design, requirement omissions are reduced, making the creation of new concepts more efficient. Hitachi applied this technology to the "Densai Net connection service," an electronically recorded monetary claims solution that provides a corporate settlement service, which is used in the "Densai Net" electronic claims recording organization that was founded by the Japanese Bankers Association.



Densai Net connection service

Based on the results of this application, Hitachi will promote correct service operations and post-operation function expansions.

Software-based FTC Technology for Control System Applications



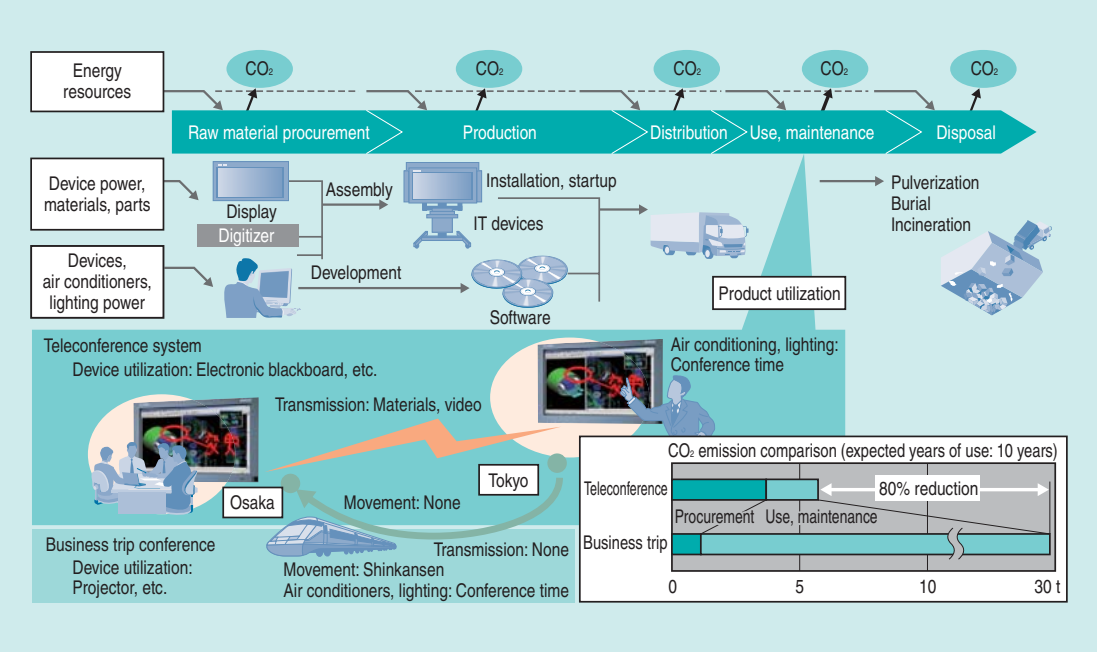
Configuration of software-based FTC system

Because of the major impact of even brief service outages, control systems used in social infrastructure such as electricity and transport require a high level of reliability and availability. For such applications, FTCs (fault-tolerant computers) are used in which the control computer components have a redundant configuration. Hitachi has developed a method for implementing FTCs using multiple conventional network-connected servers that are coordinated via software. A feature of the method is that it can implement an FTC using task synchronization technology that eliminates inter-server variation by keeping factors such as the process execution order and input in step at the OS (operating system) level without requiring explicit synchronization functions in the applications. This technology has been implemented in the CF-1000/FT FTC platform for control system applications.

It is anticipated that this technology will become increasingly important in the future as social infrastructure becomes more advanced.

Technology for Evaluation of Lifecycle CO_2 Emissions for IT Products

Hitachi has developed technology for evaluating CO_2 (carbon dioxide) emissions across the entire lifecycle of IT (information technology) products (devices, systems), with the objective of promoting the prevention of global warming through the utilization of IT products. Included in the evaluation are CO_2 emissions involved in the whole process for devices such as servers from the procurement of the raw materials to disposal; the power consumption of design devices and air conditioners during system development and construction work; and the energy and resource consumption during utilization by the customer. This enables the CO_2 emission reduction effects of introducing an IT product to be properly assessed.

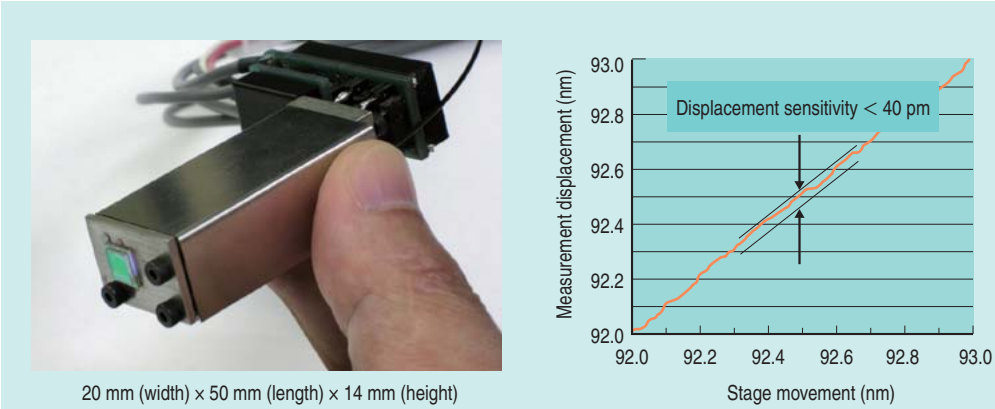


Lifecycle CO_2 emissions of a teleconference system

With this technology, Hitachi evaluated a teleconference system using the StarBoard electronic blackboard made by Hitachi Solutions, Ltd. In the future, Hitachi will expand this to areas such as cloud services.

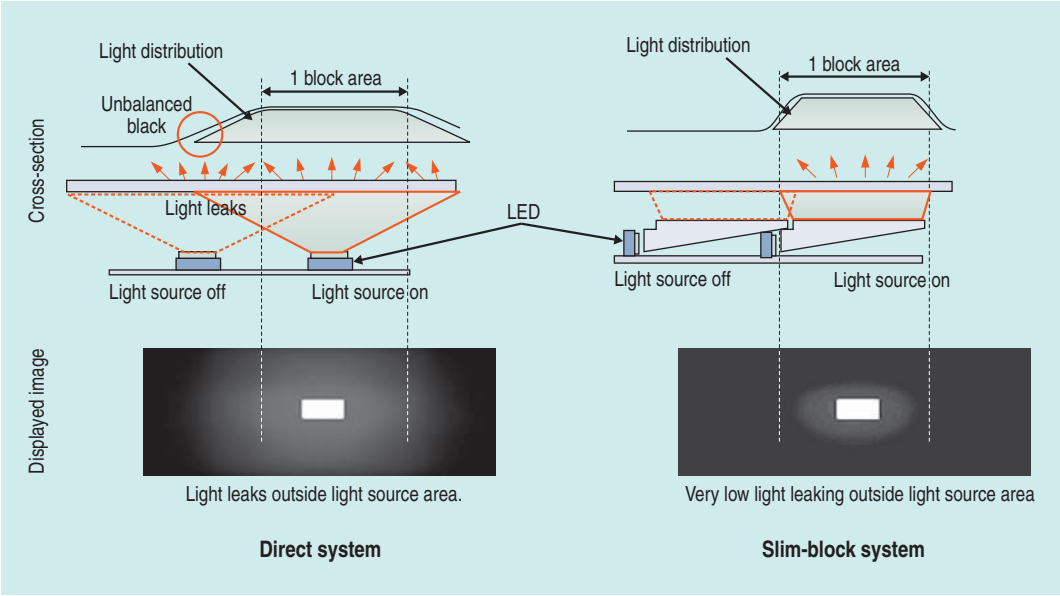
Ultracompact and Highly Sensitive Interferometric Displacement Sensor for Positioning with Picometer Accuracy

A deep-ultraviolet exposure system that achieves nanometer-scale lithography and a scanning probe microscope that measures atomic-scale surface profiles are widely used for the manufacturing and inspection of three-dimensional nanostructures such as LSI (large-scale integration) devices and magnetic head devices of HDDs (hard disk drives). With the ultraminiaturization of these nanoscale devices, a new high-resolution displacement sensor was required for aligning the samples with subnanometer accuracy or for scanning the probes at a resolution of tens of picometers. Hitachi has developed a new optical interferometry technology using photonic crystals, achieving the world's smallest size and highest sensitivity interferometric displacement sensor with a resolution of 40 pm or less. In the future, Hitachi plans to use this sensor in diverse fields as an essential core technology for ultra-precision processing and high-accuracy positioning of next-generation nanostructure devices. This sensor has been highly evaluated for its originality, practicality, and potential, and selected as one of the "2009 R&D 100 Awards" in the USA.



Ultracompact and highly sensitive interferometric displacement sensor and performance evaluation results

Slim-block LED Backlight System



Comparison between direct and slim-block backlighting

Hitachi has developed an LED (light emitting diode) backlight system for thin LCD (liquid crystal display) televisions that controls brightness by block, treating the optical block formed from a small number of LEDs and the light guide plate as a single unit, and lining up optical blocks as appropriate for the screen size.

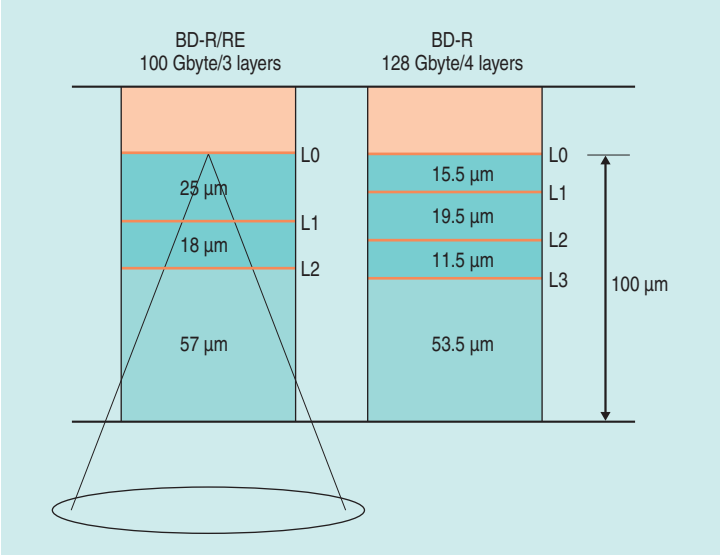
In this development, Hitachi minimized the light leaks and unbalanced black by using light guide plate technology that precisely controls the light distribution. In addition, a newly developed area control algorithm is used that performs optimum control of the light amount of the light guide plate block in accordance with the video signal, achieving the industry's best standards in terms of reducing power consumption during operation and increasing contrast. This backlight system technology is installed in slim-block LCD televisions.

In the future, Hitachi will improve the precision of this area control algorithm to achieve even greater power saving, and use large, high-precision molding technology for light guide plates to further reduce costs.

BD Multi-layer Storage Technology

The use of BD (Blu-ray* Disc*) has been increasing in recorders and computers in recent years. A new specification called BDXL* has been added to this technology (the specification was approved in June 2010 by the Blu-ray Disc Association). By increasing the density and number of layers in the recording layers, BDXL enables the production of optical discs with a recording capacity that can be more than two times higher than conventional BD, with 100 Gbyte in three layers, and 128 Gbyte in four layers. Three layers are available for rewritable discs (BD-RE), and three or four layers are available for discs that can only be written once (BD-R).

Hitachi jointly promoted the specification of BDXL with three other companies. Also, Hitachi developed in parallel optical pickups and signal processing LSI (large scale integration), which are key devices of optical drives, and the drive control technology, namely the recording and playback technology and servo technology, that drives these key devices. The BDXL compatible optical drives that use these key devices and drive control technology are expected to be installed in computers released by various companies from summer 2011.



BDXL disc structure

* See "Trademarks" on page 83.