

AIST's R&D Activities for Energy-Efficient and Green IT

What is Green IT?

Improvements in energy saving and efficiency in every aspect of society are required to reduce global warming gas emissions. Though IT equipment may be regarded as consuming less electricity than lighting, air conditioning, and electric trains, in fact it consumes 4 to 5% of the total electric power generated in Japan, that is about 1 trillion kWh annually. Also, power consumption in this field is increasing in synch with the ascending curve of Internet traffic, which continues to grow at an annual pace of 40%, through the widespread use of PCs (Fig. 1).

The energy supplied to vehicles and refrigerators produces physical effects such as the transportation of people and cooling of food. Although 100% of the electric power input into computers is converted to heat, it allows information to be delivered to people and other devices. By using the delivered information, the work of transporting people and cooling food can be reduced, thereby lowering the energy consumption. As it can be seen in videoconferencing and weather forecasting, for example, the communication and information processing have two aspects: consumption of energy, and reduction of the energy consumed by other activities. The Ministry of Economy, Trade and Industry (METI) has proposed the

energy savings in these two aspects named "Green-in-IT" and "Green-by-IT," which are together referred to as "Green IT". The Green IT Promotion Council estimates that CO₂ emissions can be reduced by as much as 130 million tons in 2020 by developing appropriate technologies, whereas Japan's total CO₂ emissions in 2007 were about 1.3 billion tons. Featured articles here describe Green IT-related research activities at AIST.

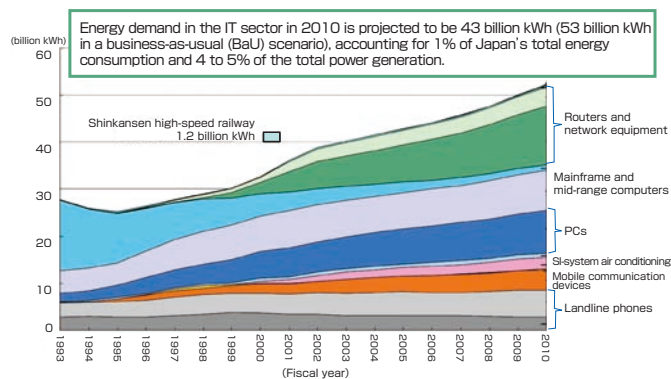
Targets of AIST's Green IT research

Most of the Green-IT research at AIST falls into the category of Green-in-IT, or improvement of the energy efficiency of IT equipment. Central processing units (CPUs, also referred to simply as processors) and memory devices play major roles in IT equipment. Power supplies and cooling devices are auxiliary devices to help the CPU perform tasks. If the power (= heat) consumed by the CPU and the memory is reduced, the power consumption of the power supply and the cooling device can be reduced accordingly. The CPU consists of more than 100 million transistors, while the memory (dynamic random access memory: DRAM) consists of

capacitors, which need refreshing every tenth of a milli-second. The primary targets of Green IT research are transistors operable at lower power consumption and non-volatile memories that do not require refreshing. As an example of non-volatile memory, the spin-RAM to replace the DRAM is highlighted in one of the articles. Also described in another article is our research on organic electroluminescence (EL) devices, which will lead to improvement in the energy efficiency of displays extensively used for IT and TV applications.

Fig. 2 shows the increasing trend of energy consumption by each type of IT equipment, as projected by the Green IT Promotion Council. Internet traffic of video images is rapidly increasing, replacing e-mails, texts and still images in html contents. In addition, the energy consumption of network and data centers is rising with the increasing speed and volume of traffic and the spread of ubiquitous services. We are proposing a fully optical communication system i.e. an optical path network, suitable for high-volume transmission of video that has consistent connections.

In the 1990s, it was predicted that information



(BaU case in a report by the Study Group on ICT Systems and Networks Contributing to Environmental Load Reduction)

Fig.1 Energy demand in the IT sector

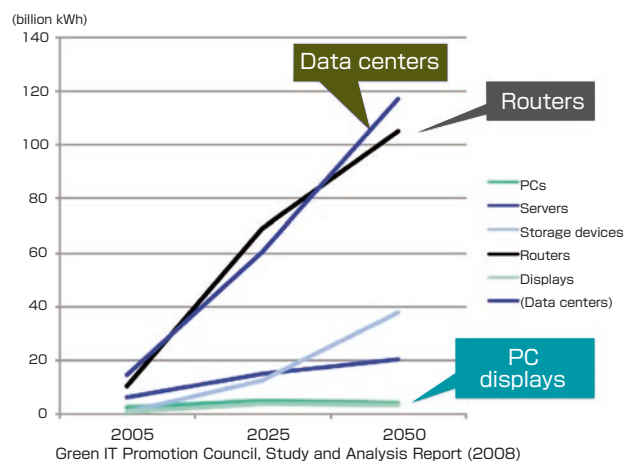


Fig.2 Projected energy consumption by IT equipment type

Scenario B: A projection for the case of no innovation in energy-efficiency technologies, with medium market penetration and medium growth rate of power consumption



processing would be distributed throughout the world via networks. While PCs are a necessity for offices and homes, with a household penetration rate of 85 % in Japan, data storage and processing functions are being centralized in data centers. This is analogous to the situation in which the development of a transportation network for regional revitalization ends up reaccelerating the concentration of resources in metropolises. The concentration of functions in data centers allows quick updates and advanced management of equipment, and is therefore

expected to save energy in a controlled manner. Some featured articles focus on improvement of the energy efficiency of power supplies and air conditioning in data centers, as well as technologies regarding cloud computing.

Toward green innovation

Green IT is a technology for energy saving of and by IT. The prices of goods and services include the cost of energy required to produce and deliver them. Saving this energy can help reduce prices and revitalize the economy. We

expect the development of Green IT as described in these articles to bring about innovations by serving as a core for promoting the widespread use of new networks, creating computers with new usages, reorganizing systems, and fostering human resources.

Research Coordinator
Toshihiro Matsui

Power Consumption Visualization Technologies

Metrology Institute of Japan
Toshiyuki Takatsuji

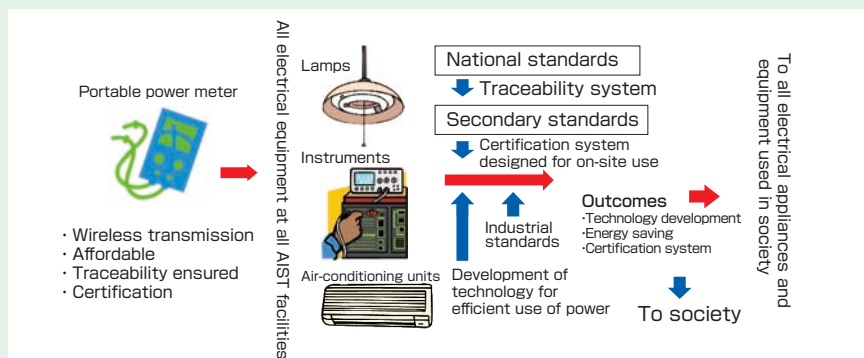
Plug-in power meters that indicate power consumption from hour to hour are available on the market. Some of them can also show power consumption in terms of electricity bills and CO₂ emissions. Last summer, new models of air conditioners with built-in power meters were released. The visualization of power consumption is expected to increase energy-saving awareness among consumers, leading to reductions in energy consumption.

The use of such visualization technologies in manufacturing plants makes it possible to individually measure and control the power being used by each plant and to systematically take energy-saving measures.

To implement visualization of power consumption on a large scale, reductions in the size and price of power measurement devices are needed. Technologies such as methods for transmitting

measurement data, processing the large amounts of data received, and ensuring the reliability of the measurements must be developed. It is also necessary to build systems (measurement traceability, type approval, and inspection rules) to allow the widespread use of such visualization technologies by the public.

A series of these technology and system development activities are made possible through cooperation among multiple research units at AIST, where research and related tasks are conducted in a wide variety of areas. The development of visualization technologies has been under way since FY2009 as one of our interdisciplinary projects. A prototype system will be installed at AIST to achieve the visualization of power consumption and investigate its effectiveness.



Overview of project for power consumption visualization technology and measures to promote its widespread use

Optical Network-based Technology to Reduce Power Consumption

Network issues

Today, we rely on communication networks to such an extent that we cannot live and work without a network. The amount of information transmitted via networks continues to increase at an annual rate of 40 % (Fig. 1). This is due to the increase in video information transmitted through sites such as YouTube and Google Videos. Video images contain more information than e-mails and web pages. The amount of information contained in video images will continue to rise as their resolution becomes higher. The power consumption of network routers was 8 billion kWh in 2006 and is expected to increase in proportion to the expansion of network traffic. If it continues to rise at the current rate, the use of the network will be limited by restrictions on power consumption. Because of this, it is essential to develop technology to significantly reduce power consumption by changing the way networks are built.

Ultralow power consumption by the use of an optical path network

In the current Internet, small information packets called Internet Protocol (IP) packets are electronically processed by a router to determine their destination. This is the most power-consuming process of the router and is said to account for one-third of its power consumption. Our concept is to achieve ultralow power consumption by processing large amounts of information such as video information using an optical path network. In an optical path network, circuit (path) switching for information is performed by optical switches, instead of electronically determining the destination of packets. Users are connected to each other through the optical path. It would be possible to develop low power-consumption optical switches. Eventually, the consumption per unit of information is expected to decrease by 3 to 4 orders of magnitude compared with existing routers. We believe that in 10 years from

now, a combination of two types of networks will be used: the existing IP packet network convenient for e-mailing and web browsing but with lower power consumption, and the optical path network for handling high-resolution images (Fig. 2).

Research and development projects and the future

We are developing optical switches using a silicon micro-optical waveguide, as well as technologies to maintain the quality of transmission through the optical path, to control routing, and to manage network resources, in cooperation with companies in a project named "Vertically Integrated Center for Technologies of Optical Routing toward Ideal Energy Savings" funded by the Special Coordination Funds for Promoting Science and Technology. We are also evaluating the possibility of reducing the energy consumption of networks combining various routing protocols such as the packet and path protocols in the Green IT Project of the New Energy and Industrial Technology Development Organization (NEDO). In addition, we are engaged in the research and development of an ultra high-speed LAN that supports a super high-definition TV system being developed by the Japan Broadcasting Corporation (NHK) with 16 times the number of pixels of existing high-definition TV systems in NEDO's Next-Generation High-Efficiency Network Device Project.

In these research and development projects, our objective is to develop technologies that improve the utility of the network, make it possible to receive new services with ultra

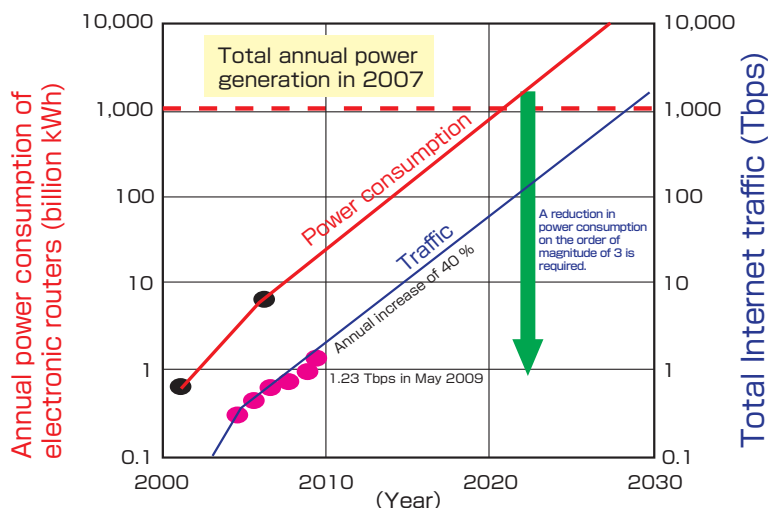


Fig.1 Amount of Internet traffic and power consumption of electronic routers in Japan



low power consumption such as highly realistic videoconferencing and distance medical services using high-definition video communication systems, and lead to a reduction in energy consumption from use of the network.

Network Photonics Research Center

Hiroshi Ishikawa
Shu Namiki

Information Technology Research Institute

Tomohiro Kudo

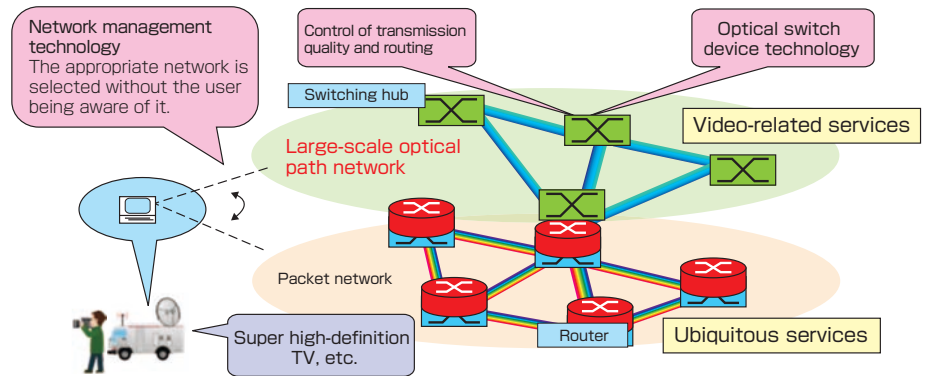


Fig.2 Image of the network of the future

The packet network is used for small volumes of information and the optical path network is used for large volumes.

Optical Interconnection

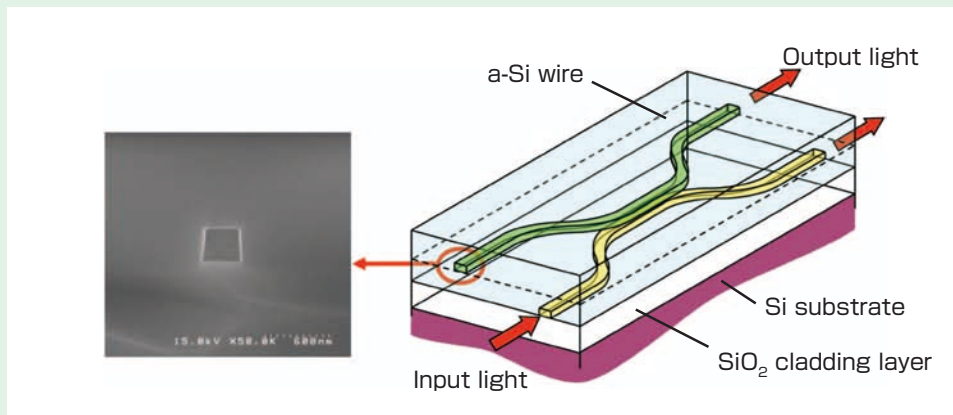
Photonics Research Institute

Masahiko Mori

With the never-ending growth in the volume of information to be processed today, the energy consumption of information processing equipment (e.g. high-performance computers and servers, which are the main equipment of data centers) is also increasing as well as that of networks, causing serious problems. Optical interconnection technology is a focus of expectations as a solution to these problems. Specifically, the bottleneck inside the equipment lies in the connections between the large-scale integrated circuit (LSI) chip packages and the printed circuit boards. Optical interconnection between the chips is therefore the first issue to be considered. It is also necessary to start the development of intra-chip connection technology, which

requires long-term efforts.

In recent years, silicon photonics technology based on Si-CMOS process technology has been attracting attention as a means of photonics-electronics integration for optical interconnection. We have been developing a technology to integrate a laser source and a silicon optical waveguide, and an amorphous-silicon (a-Si) optical waveguide technology for three-dimensional optical interconnection. We will continue our research and development to achieve higher performance devices and modules and system demonstrations, for solving the above problems in collaboration with industrial circles and academic institutions.



Schematic illustration of a vertically coupled optical branch (a directional coupler) and cross-sectional view of an amorphous-silicon optical waveguide

Improvement in Energy Efficiency of Computers – Non-volatile Memories –

○ Spintronics and normally-off computers

Two reasons of improving the energy efficiency of computers

Computers have become indispensable in our daily lives, and will be used in various forms from now on including large numbers of microelectronic devices embedded in home appliances, walls, and roads. Improvement of their energy efficiency has two aspects. One aspect is the total energy consumption. In addition to the massive power consumption of data centers, the power consumption of electronic devices smaller than PCs is not negligible due to their huge number. The other aspect is the convenience of electronic devices for prolonged use. Laptop PC batteries currently last only a few hours per charge. If they last a week, a few months, or a few years, new uses for PCs will emerge.

The advantage of spintronics: information storage in non-volatile memory

Spintronics is a new electronics technology using nanometer-scale magnets that is expected to play a significant role in improving the energy efficiency of computers. The greatest advantage of electronic devices employing magnets is their ability to store information without using energy (non-volatile memory). Up to now, however, it has been necessary to use conventional electromagnetic coils to make the connection between magnetism and electricity. This has been the principal cause of the difficulty in improving performance. Spintronics, a new technology that has rapidly advanced over the past 10 years, provides a

fundamental solution to this problem. This technology allows magnetism and electricity to be connected at the quantum mechanics level. A typical example of its successful application is the CoFeB/MgO/CoFeB tunnel magnetic resistance (TMR) device jointly developed by AIST and Canon in 2004.^{[1][2]} This has made it possible to develop small hard disk drives (HDDs) having considerably increased memory density and idle power reduced to about one-fifth. Currently, our technology is being used for HDDs worldwide and contributing to a reduction in their power consumption, which accounts for about one-third of the heat generated by information technology equipment in data centers.

Non-volatile memory and PCs with ultralow power consumption

The next target of spintronics technology is to develop a non-volatile computer memory. As

current CPUs are very powerful, they are often not fully used. It is said that only a few percent of the CPU's power is utilized by networks, for example. For the most advanced CPUs, it is becoming common to use technology to power on and off the arithmetic-logic unit at short intervals of less than one-thousandth of a second when the CPU has no task to perform. However, the power of the computer itself cannot be turned off. This is mainly because power must be continuously supplied to retain the information in the dynamic RAM (DRAM) and static RAM (SRAM) used as the memory. As the density of the DRAM and the SRAM becomes higher, their standby power further increases. It is an important issue to reduce the power consumption of the memory.

If the memory is made non-volatile, the power of the computer can be completely turned off at short intervals without the user even being aware of it. Such a computer would not need

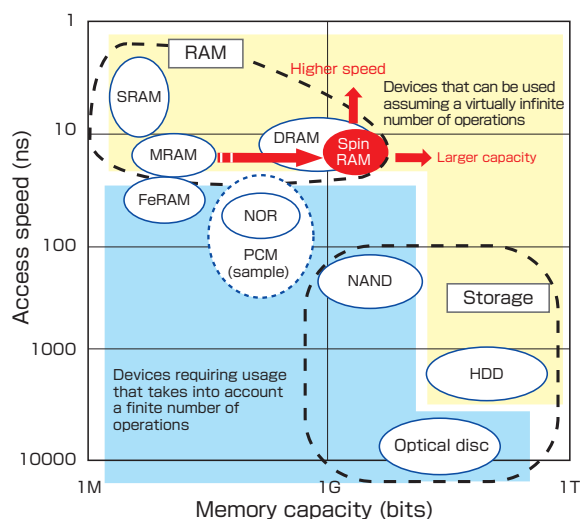


Fig.1 Status of various commercial memory storage devices (sample in the case of PCM)^[3] and the goal of developing a spin-RAM



a power switch. We are working to realize such a computer, referred to as a normally-off computer.

However, computers need high-performance memories. The DRAM is required to have an operating speed of as fast as 30 ns and endure more than 10^{15} read and write operations. Also, a capacity exceeding 1 Gbit is needed. This is a very high hurdle to overcome, considering the performance of flash memories that are typical large-capacity non-volatile memories. They have the operating speed of the order of a microsecond and endure write operations of the order of 10^5 . At the moment, no non-volatile memories are available to replace the DRAM and the SRAM.^[3]

Spin-RAM

Magnet-based memories store information by changing the direction of the electron spin, and therefore do not involve the movement of atoms, making it possible in principle to perform an infinite number of write operations. The direction of the spin can be changed in less than 1 ns. The magnetic core memory used in early computers disappeared from the market because the magnetic coil used to read and write information prevented high integration of the memory. The situation has dramatically changed with the advent of spintronics technology. Magnetic RAMs (MRAMs) with comparable speed to the DRAM are already available on the market. However, their storage

capacity is only 16 Mb and their theoretical maximum capacity is 256 Mb, making it impossible for them to replace the DRAM. This limitation is due to the fact that a TMR device is used to read information but a magnetic coil is used for write operations. However, when spintronics technology is used for writing, the capacity of the MRAM can be increased to more than 1 Gbit. The key to achieving this is the spin injection magnetization reversal process using quantum torque produced by the spin, which is a vector. The next-generation MRAM is called spin-RAM. We are jointly engaged in a NEDO project with Toshiba, Osaka University, Tohoku University, and the University of Electro-Communications to develop a large-capacity spin-RAM. It was initially taken for granted that the CoFeB/MgO/CoFeB TMR device developed by AIST would be used as the core of the spin-RAM. However, this TMR device was developed for HDD heads, and is not, in reality, suitable for the spin-RAM. This is because CoFeB loses magnetism if it is smaller than 65 nm, which corresponds to 1 Gbit. We recognized this problem early on and took on the challenge of developing a new TMR device using a material called a perpendicular magnetized film, which has strong magnetic properties. As a result, we succeeded in developing the world's first spin-RAM technology which enables more than 1 Gbit RAM.^[4] This success has shown the possibility of realizing a high-speed spin-RAM

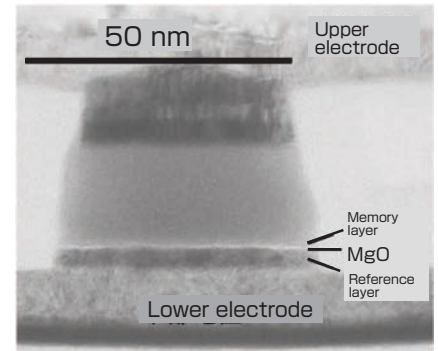


Fig.2 Electron microscope image of a 50 nm perpendicular magnetized TMR device (developed jointly with Toshiba, etc.)^[4]

to replace the SRAM and a very large-capacity spin-RAM for storage. We have, in fact, succeeded in demonstrating sub-nanosecond spin injection magnetization reversal.

Toward the realization of normally-off computers

A high-performance non-volatile memory is required to realize normally-off computers. Also required is collaboration among a wide variety of technologies such as displays, power supplies, memory architecture, and operating systems. We are working to achieve a reduction in the power consumption of computers with the resulting improvement in convenience, using spintronics technology as the core.

Nanoelectronics Research Institute
Koji Ando

References

- [1] S. Yuasa, T. Nagahama, A. Fukushima, Y. Suzuki, and K. Ando: *Nature Materials*, 3, 868 (2004).
- [2] D. D. Djayaprawira, K. Tsunekawa, M. Nagai, H. Maehara, S. Yamagata, N. Watanabe, S. Yuasa, and K. Ando: *Appl. Phys. Lett.*, 86, 092502 (2005).
- [3] NEDO electronics · Information technology load map 2009: http://www.nedo.go.jp/denshi/roadmap/2009/kaisetsu_memori.pdf
- [4] T. Kishi, H. Yoda, T. Kai, T. Nagase, E. Kitagawa, M. Yoshikawa, K. Nishiyama, T. Daibou, M. Nagamine, M. Amano, S. Takahashi, M. Nakayama, N. Shimomura, H. Aikawa, S. Ikegawa, S. Yuasa, K. Yakushiji, H. Kubota, A. Fukushima, M. Oogane, T. Miyazaki, and K. Ando: *IEDM Tech. Dig.*, 309 (2008).

Improvement in Energy Efficiency of IT Equipment

○ Low-power transistors

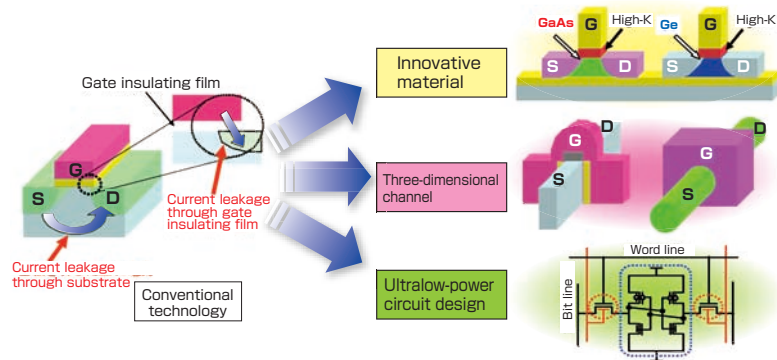
Background

It is no exaggeration to say that the evolution of the IT society and the tremendous reduction in the power consumption of IT equipment is the outcome of reductions in the size of transistors. Further reductions in transistor size, however, are becoming increasingly difficult. As a result, power consumption is increasing instead of decreasing. We are working to develop innovative materials and new three-dimensional structures and to propose and verify new circuit configurations that make it possible to achieve ultralow power consumption, with the aim of obtaining solutions to the problems that prevent reductions in transistor size and achieving further significant reductions in power consumption.

Materials technology to achieve significant reductions in leakage current and significant performance improvements

With decreasing transistor size, power consumption increases due to the leakage of current through the gate insulating film. This is a major concern. We are developing a new gate insulating film with a high dielectric constant that can greatly reduce leakage current without increasing the film thickness. We are also developing channel materials that make it possible to improve performance without relying on reductions in transistor size. Specifically, we are developing transistors that outperform silicon-based transistors, using materials such as germanium and gallium arsenide.

A three-dimensional multi-gate transistor to achieve a further reduction in transistor size



Research activities at AIST to further reduce the size and power consumption of transistors and improve their performance

We are working to achieve high performance and ultralow power consumption using innovative technologies in the areas of materials, structures, and circuits.

In order to structurally reduce the large leakage current between the drain and the source due to reductions in transistor size, we have proposed a transistor (a three-dimensional multi-gate transistor) that has a three-dimensional channel structure instead of the conventional planar channel, and multiple gates over the channel. We confirmed that this structure provides ideal properties at gate lengths of even less than 20 nm without an increase in leakage current. We are also developing a transistor having a nanometer-order wire-shaped channel that makes it possible to further reduce the transistor size.

New circuit configurations and new-principle devices to achieve ultralow power consumption

The properties of a device after fabrication can be freely controlled if multiple gates can be controlled individually. We have proposed a new circuit to make effective use of the ability to control properties at will on the transistor level. For example, we have succeeded in reducing the static leakage current of the entire

circuit to 1/100 by setting transistor properties not contributing to the functioning of the circuit to the standby state. We are conducting research and development to further reduce the voltage of the power supply by means of a device based on a new principle using the quantum tunnel effect.

Advances are being made in the reduction of transistor size using the innovative technologies described above in the areas of materials, structures, and circuits. This has opened up the possibility of reducing the power consumption of LSI circuits to less than 1/100. We are working on the development of basic technologies for high-performance, low-power, VLSI employing these technologies in order to contribute to the IT society and the semiconductor industry in Japan.

Nanoelectronics Research Institute
Meishoku Masahara

Nanodevice Innovation Research Center
Hiroyuki Ota



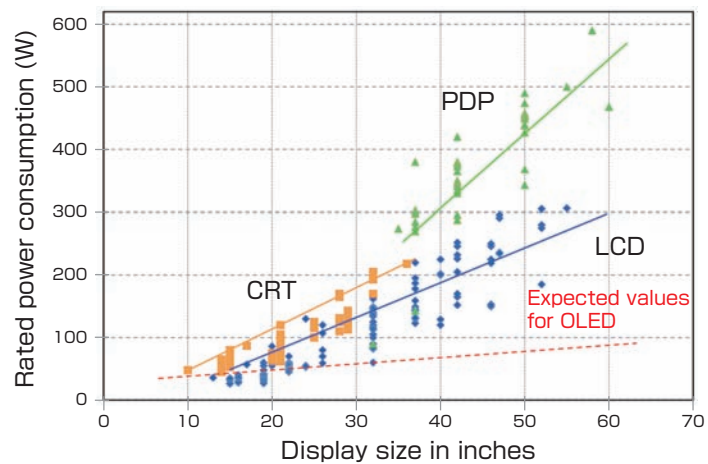
○ Organic LED displays

Trends in display development

Displays such as those used in TV sets are the most important devices by which people today receive electronic information in their daily lives. Against the backdrop of very strong demands for convenience and ease of use, improvements have been made such as increases in screen size, resolution, and operating speed. However, these functional improvements have been accompanied by increased power consumption. The total annual power consumption of TVs has increased at an annual rate of 5 to 7 % due to upgrading to higher performance sets. Today, TV sets account for about 2 % of Japan's total power consumption and are projected to consume three to four times as much power as at present 20 years from now unless their energy efficiency is improved.

Organic LED technology for ultralow-power displays

Today, extensive research is being conducted to develop low-power displays such as liquid crystal displays (LCD) and plasma displays. However, to achieve improvements in both function and power consumption, fundamental innovation of the display principle is required. Organic light-emitting diode (OLED) technology has been attracting attention in recent years, particularly as a means of achieving low power consumption. OLEDs for display as well as lighting applications are being extensively developed, and global competition in the development has become increasingly fierce. The OLED is a self-light-emitting device and, when used in a display, it reduces the number of parts, such as filters, that reduce the efficiency of utilization of the light. Almost 100 % efficiency of the light emission itself



Relationship between size and power consumption of different types of displays

CRT: cathode ray tube, PDP: plasma display panel, LCD: liquid crystal display, OLED: organic light-emitting diode display

can be achieved in terms of internal quantum efficiency. For these reasons, OLEDs make it possible to develop ultralow-power displays capable of displaying high-quality images. They are all-solid-state, requiring no vacuum or liquid parts, allowing ultrathin, lightweight displays to be realized. There are rising expectations that large but space-saving and lightweight displays will be able to be developed thanks to this technology.

Development of technology for manufacturing large devices

The major technical issue in introducing OLED displays on the market is the development of technology to manufacture large devices with high productivity. Wide-ranging manufacturing technology is required to produce meter-order large-area thin-film devices with micrometer-order precision.

Unlike the case of LCDs, the manufacturing technology for small OLEDs cannot be applied

readily to large-area OLED displays. Our aim is to realize displays with high performance and low power consumption by developing a technology for manufacturing large-area, solid-state thin-film devices that offers high speed, precision, homogeneity, and a low defect rate. The manufacturing technology for large thin-film devices is a basic technology applicable not only to displays but also to other large-area devices such as for lighting and solar cells. Its development requires the collaboration of industry, academic, and public sectors.

Photonics Research Institute
Toshihide Kamata

Improvement of Energy Efficiency of Power Supplies and Air Conditioning in Data Centers

○ SiC power devices

Present situation of power supplies in data centers

In usual data centers, AC power is supplied to the server racks via uninterruptible power supplies (UPSs). The supplied AC power is converted to DC (for example, 48 V) by the power supplies on the rack and further to lower voltages (such as 3.3 V) by the power supplies on the boards, and is then consumed by the memory, CPU, and other devices. The conversion efficiency of individual power supplies is high, at about 95 %, but the voltage conversion ratio cannot be increased. It is therefore necessary to perform the conversion in multiple stages. As a result, the total power supply efficiency between the receiving end and the load end is not necessarily high (Fig. (a)). This means that it is important to further increase the efficiency of each power supply and reduce the number of conversion stages.

Effect of introducing SiC power devices

Silicon carbide (SiC) power devices have the characteristics of lower loss, higher switching

speed, and superior thermal durability compared with current mainstream silicon (Si) power devices, and represent a promising technology that can contribute to improved efficiency of power supplies and a reduction in the number of conversion stages. For example, the use of SiC converters makes it possible to improve the total efficiency by (1) reducing the conversion loss to about 65 % that of existing Si converters, (2) supplying high-voltage DC power (400 V class), and (3) reducing the number of conversion stages from 7 to 3. As a result, the total power supply efficiency between the receiving end and the load end can be dramatically increased from 72 % to 91 % (Fig. (b)). With its experience in the development of low-loss/high-speed power devices and a high power-density power converter using these devices^[1], the Advanced Power Electronics Research Center has been given responsibility for the research and development of power devices and power converters with higher operating temperatures^[2].

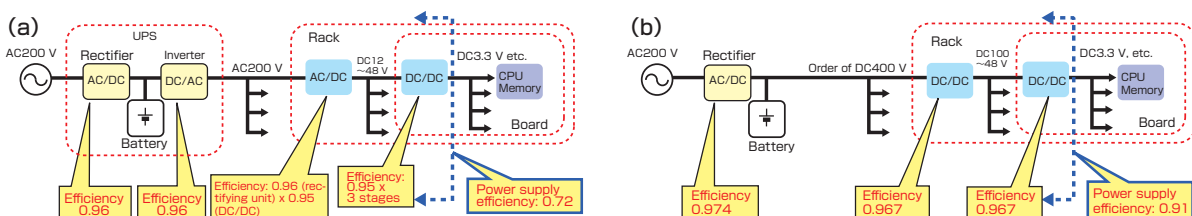
and communication equipment is ensured by redundancy*. Operation with redundancy always requires an excessive power supply capacity in comparison with the load capacity and is therefore disadvantageous in terms of power supply efficiency. We are investigating power supplies taking operational aspects into account, such as the application of adaptive management of the capacity of power supplies to prevent reduced efficiency during partial-load operation and to respond to load changes.

(*)An operation method in which auxiliary power units are always operating and the required capacity of the power supply is ensured by several power units. For example, a capacity of 100 is supplied by three power units each having a capacity of 50. The reliability of the power supply is enhanced because its required capacity is dependably supplied even when one of the units is out of service.

Power supply management technology

The reliability of power supplies for information

Advanced Power Electronics Research Center
Hiroshi Yamaguchi



Efficiency of power supply in a data center

(a) Example of power supply system based on conventional method (b) Example of power supply system using SiC power devices

The conversion loss is reduced to 65 % by using SiC power devices. In addition, the use of SiC power devices makes it possible to supply high-voltage DC power (400 V class) and reduce the number of conversion stages.

References

- [1] AIST Advanced Power Electronics Research Center web page : <http://unit.aist.go.jp/adperc/index.html>
- [2] NEDO web page : <http://www.nedo.go.jp/activities/portal/p09004.html>



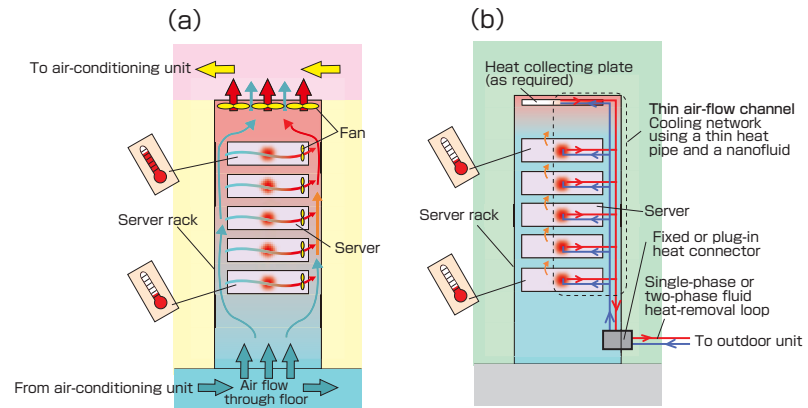
○Advanced cooling-network system

Introduction

The shares of power consumption in a data center vary with its size and site conditions. Air conditioning accounts for 30 to 40 % of the power consumption and servers account for nearly the same percentage. CPUs account for about 70 % of the power consumption of the servers. Most of the power consumed by the CPUs is lost as heat. The heat generated by the CPUs in a server (each CPU consumes more than 100 W) is removed by the air conditioners and the fan for each CPU. It can therefore be said that the cooling of the CPUs in the servers accounts for most of the huge power consumption of the air-conditioning units in data centers.

Methods of cooling servers

The figure shows a comparison of the concepts of a conventional air-cooling system for a server rack and the advanced cooling-network system^[1] being developed by AIST. In an air-cooling system, cold air is supplied through the floor and circulated through the rack to cool the servers. Due to the significant amount of heat generated in the servers, however, the air temperature downstream of the air-conditioning unit increases significantly. As a result, the air-conditioning temperature is excessively lowered to cool the CPUs and other devices to the desired temperatures and the air-flow rate is increased, or the power to the fans is increased. The primary purpose of air conditioning is to cool the CPUs and other heat-generating devices only. In reality,



Comparison of two server-cooling systems

(a) Conventional cooling system (b) Advanced cooling-network system

however, air conditioning is wasted as a result of cooling the entire server room and the entire building more than necessary. In the advanced cooling-network system, first the CPUs are directly liquid cooled (by a single-phase fluid involving no phase change or a boiling two-phase fluid involving a gas-to-liquid phase change) or indirectly liquid cooled by a high-performance heat pipe to recover most of the heat generated by the CPUs as the sensible heat of the liquid or the latent heat of vaporization, thereby minimizing the heat released into the server room. Heat removal from one server rack is shown in the figure for illustration purposes. In this system, sets of server racks in the server room are interconnected by heat-transfer cables as if they were networked by LAN cables, and are systematically cooled for heat removal by the cooling network of

cables.

Energy-saving effect

After cooling the servers, the warm coolant is cooled by an outdoor chiller. The power consumed by air conditioning of the server room can be reduced to 35 to 45 % of the current level even when the efficiency of heat removal is underestimated and the power consumption of the chiller is taken into consideration. We aim to achieve a reduction of more than 60 % by increasing the efficiency of heat removal.

Energy Technology Research Institute
Yoshiyuki Abe

Reference

- [1] Y. Abe *et al.* : *Advanced integrated cooling systems for thermal management in data centers*, Proc. IPACK2009, IPACK2009-89009 (2009).

Improvement of Energy Efficiency in Cloud Computing

○ Storage system for cloud computing

'Cloud computing' is one of the promising approaches to reduce power consumption of IT equipment. In cloud computing, IT services and the equipment to provide the services are available on the network, instead of being owned by individual users or companies. For example, you could call web mail services, such as Gmail, cloud services. These services are centrally controlled and hosted by huge data centers. The overall power consumption of IT equipment is reduced through shared use by a large number of users as well as through improved efficiency by centralization.

In achieving cloud computing, data storage devices such as disks are of particular importance. Unprecedented volumes of data

must be stored and provided to enormous number of users in cloud computing. Needless to say, reliability is absolutely essential. These requirements are met by placing multiple storage devices in parallel and automatically replicating data among them.

We believe that performance guarantees are also important for the advancement of cloud computing. Guaranteeing performance is not general practice in the Internet world. However, for applications such as video streaming, which is expected to become richer and richer in the coming years, it is necessary to guarantee the performance of data storage systems, as well as networks for data transfer to the end users.

Another important topic is the

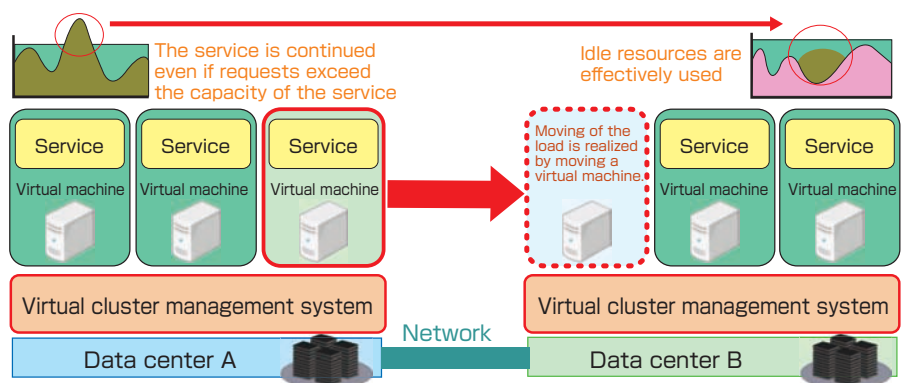
semiconductor storage devices, which are rapidly becoming commodities. Semiconductor storage devices provide faster access speeds and consume less power than HDDs. However, if HDDs are replaced by semiconductor storage devices and the network speed remains the same, the network speed will become a bottleneck, preventing full use of the high speed of semiconductor storage devices. We are conducting research on technology to take full advantage of semiconductor storage devices by minimizing data transfer.

Information Technology Research Institute
Hidemoto Nakada

○ Greening by virtualization

With the increasing number of information systems being operated in data centers in recent years, power consumption and heat generation at data centers have become a major concern. In particular, the server density per unit area is increasing, resulting in increased power consumption. There are, however, seasonal, weekly, and daily changes in the operation of most servers used for business applications. Their capacity is not fully utilized, with an average utilization rate of only about 30%. From the perspective of energy saving, it is more efficient to turn off the power of servers not in use and increase the utilization of those that are turned on as much as possible.

With the advent and dissemination of



Live migration of virtual machines makes it possible to balance the load on the data center through the network to maintain its utilization.

Software as a Service (SaaS) and cloud computing, users can enjoy a variety of services without being aware of the physical servers. In data centers providing these services, physical servers can be logically divided into several virtual servers to increase

their utilization, employing virtualization technology. In this way, the number of physical servers used to provide the same service can be reduced, contributing to reductions in energy consumption. In reality, however, there is a limit to the improvement

Global Trends in Green Information Technology, the Significance of Our Commitment, and Interdisciplinary and Domestic/International Collaboration

of energy efficiency using the current level of virtualization technology. The utilization of data centers generally varies with time, making it difficult to constantly maintain high utilization.

We are developing a cross-data-center virtualization technology as an advanced solution to improve energy efficiency. This technology allows data centers remotely located from each other to be managed in a unified manner through an interconnecting network as if they were a single data center. It

also allows a service being operated by a data center at one location to be moved to a data center at another location without interrupting the service.

Within a data center, a technology called live migration of virtual machines is used to change the operating location of services. However, it was believed to be difficult to use this technology between remotely located data centers due to performance degradation resulting from delays in the network. We have solved this problem by proposing a new data

transfer technology to overcome such delays. Performance degradation due to a delay in the network is prevented by transparently moving storage data on a virtual computer to a remote location. A service can be moved in less than one second by optimizing the method of moving memory data on the virtual computer.

Information Technology Research Institute

Takahiro Hirofuchi
Satoshi Itoh

Power Monitoring through kHz Band PLC

Information Technology Research Institute

Tetsuya Higuchi

The High-speed Power Line Communication Collaborative Research Team is conducting the research and development of kHz band power line communication (PLC) with The Tokyo Electric Power Company, Inc. (TEPCO). There are two types of PLC systems: one using a carrier wave in a MHz band to carry a signal and the other using a carrier wave in a kHz band. The MHz band PLC systems have high transfer rates and can only be used indoors in Japan. The kHz band PLC systems have low transfer rates, and yet they are allowed to be used both indoors and outdoors. Because of this regulation in Japan where power meters are placed outdoors, it is considered effective to incorporate a kHz band PLC device into the power meter, in order to read and monitor the power consumption of the home and to notify the users of their power consumption thus raising awareness of energy saving. The real-time power consumption of each home can be sent to the power company for optimal power distribution. The PLC main unit built into the power meter can also control the power consumption of household appliances by communicating with PLC sub-units built into the appliances. In this way, an in-home network can be created.

However, since the kHz band PLC systems use a carrier wave

of less than 450 kHz, it is very important to withstand the intense noise from household appliances concentrated in this frequency range. Conventional kHz band PLC systems have only been able to offer slow transfer rates due to this noise. The PLC system developed by AIST and TEPCO solves the noise problem. It is very robust against the noise and has achieved the world's fastest transfer rate of 200 kbps (March 2009 press release).

A power meter with a built-in communication function such as PLC is called a smart meter. This is one of the fundamental technologies for the next-generation power grid (smart grid), which has recently been attracting attention. In the United States, there is a movement to use ZigBee, a short-distance wireless technology, as well as PLC. In the case of wireless technology, however, there are problems in communication with equipment located on different floors such as a basement. It is therefore unrealistic to use only ZigBee as the communication infrastructure for all power meters. In the United States, the new smart meter-based, in-home communication infrastructure is regarded to be the second Internet and is expected to provide new business opportunities. Therefore, the entry of business ventures as well as large companies into this field are accelerated.