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Challenging Ultra-Low Power Consumption by Next-Generation Data Centers

Photonics–Electronics Convergence Is a Game-Changing Key Technology

– Interview with Dr. Shu Namiki, AIST –

Growing global demand for data centers is increasing total power consumption rapidly. To reduce power consumption by data centers, the Ministry of Economy, Trade and Industry (METI) launched the Development of next-generation green data center technology Project in FY 2021 as part of its Green Innovation Fund Project (GI Fund Project)[*1] in Japan.

Anritsu interviewed Dr. Shu Namiki, Chair of the Council on Devices and Systems for Next-Generation Green Data Centers (GDC Council)[*2] established to promote the activities of the GDC Council and photonics–electronics convergence technology as a key to reducing power consumption.

National Institute of Advanced Industrial Science and Technology (AIST)
Director of Platform Photonics Research Center

Dr. **Shu Namiki**

Section 1 Activities of GDC Council to Promote Reduced Power Consumption by Data Centers

Social Issue of Annually Increasing Power Consumption by Data Centers

Demand for data centers continues growing due to increasing Cloud and AI-based services, and data traffic, resulting in sharply increased power consumption. Data-center power consumption today is estimated at a few percent of world total power consumption. Using current technologies, this percentage is predicted to increase and will account for about 10% of total power consumption by 2030. How to reduce power consumption while meeting the demands of the digital society is an urgent issue for data centers..

— What are the current status and challenges of data centers?

Namiki: As demand for data centers continues to grow, Moore's Law, which was the driving force behind semiconductor performance improvements, is finally failing to describe future advances. When Moore's Law was still fully applicable, the paradigm was that faster processing semiconductor performance resulting from CMOS process miniaturization would not increase power consumption, chip size, and cost.

However, with the end of Moore's Law in sight, we need to change the fundamentals of computer architecture. For example, configuration of virtual servers using multiple physical servers and distribution of AI processing to dedicated accelerators is already common.

— Conventional systems were configured using a single high-performance server, but Cloud-based systems are configured using virtually aggregated distributed server resources.

Namiki: That is right. As a result, transferring large amounts of data requires communications between servers or racks because data processing speed is inadequate using a single server. In fact, several reports show that data traffic within data centers is larger than outside data centers.

By the way, what is the most efficient data transmission method? Photonics technology has the overwhelming advantage in terms of bandwidth, transmission distance, latency, security, and power consumption. Although electronics technology is adequate up to a certain bandwidth, the transmission distance is relatively shorter due to signal attenuation and other factors. In addition, power consumption by network switches increases. We are beginning to see a real situation where we must use photonics technology to get by.

— Building the Development of Next-Generation Green Data Center Technology Project and GDC Council —

The GDC Council was established to facilitate the Development of Next-Generation Green Data Center Technology Project, a GI Fund project, as well as to share information and exchange opinions for social implementation.

— What is the purpose of the GDC Council?

Namiki: Our lives and society depend on various Internet services and the rapid increase in power consumption by data centers has become a social issue (Figure 1). To address this issue, METI is promoting the Development of Next-Generation Green Data Center Technology Project (Figure 2).

To both save power and improve performance of information infrastructure, especially data centers, the GDC Council was established to share information, exchange opinions, propose joint research, and conduct standardization activities among companies and institutes that comprise the value chain. Although the GDC Council do not develop directly, the GDC Council focus on organizing and discussing symposiums and study groups.

— What kind of structure do you operate under?

Namiki: The GDC Council consists of three committees:

- Social Implementation Promotion Committee
- System Architecture Study Committee
- Co-packaging Technology Study Committee.

The purpose of the Social Implementation Promotion Committee is to investigate, share, and discuss technological and market trends to make new technologies viable as a business.

The System Architecture Study Committee manages the policy of the Development of Next-Generation Green Data Center Technology Project, focusing on innovative technologies required for data centers in 2030. Two subcommittees are active:

Disaggregation Subcommittee, which appropriately arranges components such as processors and accelerators to achieve higher performance as a system and higher efficiency in resource utilization.

Photonics Smart NIC (Network Interface Card) Subcommittee, which realizes higher bandwidth and energy-saving at communications between components and between servers.

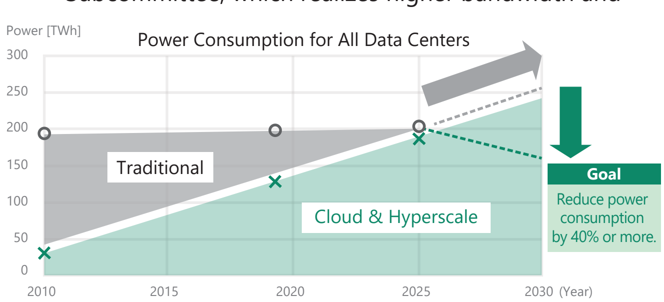
The Co-Packaging Technology Study Committee focuses mainly on integration of photonic circuits, such as optical transceivers and electronic circuits, into a single chip, as well as a technology for forming optical waveguides on circuit boards, gathering a wide range of members.

— AIST established the Platform Photonics Research Center*3 in 2020, under the leadership of Dr. Namiki as Director. What is the role here?

Namiki: The Platform Photonics Research Center at AIST is an organization that researches fundamental photonic technologies. Although the center was established in 2020, AIST has been conducting R&D for more than 10 years, proving that photonic technologies are important for next-generation digital infrastructure.

The center researches various topics, including photonics–electronics convergence integration using polymer waveguides, fabrication of large-scale integrated circuits based on silicon photonics in a super-clean room, ultra-low latency and ultra-low power photonic networks using all-optical paths, and photonic device technology.

AIST manages the GCD Council as a provider of photonics and photonics–electronics convergence technologies required for next-generation data centers to member companies to create synergies and assist in their practical application.



The figure is based on the data of "IEA Global data centre energy demand by data centre type, 2010-2022" and was created by METI.

Figure 1 Conventionally, although reducing the number of small-scale data centers slightly increases power consumption for all data centers, the aim is to cut power consumption by at least 40% because a future rapid increase in power consumption is anticipated due to an increase in the number of large-scale data centers.

Source: Outline of the Research, Development, and Social Implementation Plan (Draft) for the Establishment of Next- Generation Digital Infrastructure Project, Commerce and Information Policy Bureau, Ministry of Economy, Trade and Industry, July 2021.

[From p. 30 of https://www.meti.go.jp/shingikai/sankoshin/green_innovation/industrial_restructuring/pdf/003_04_00.pdf (Japanese)]

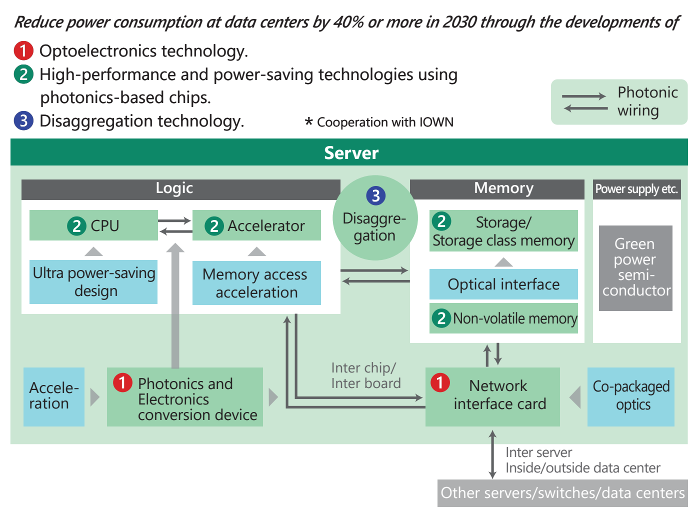


Figure 2 Summary of Next-Generation Green Data Center Technology Development Project Promoted as GI Fund Project.
The goal is to reduce power consumption at data centers by 40% or more in FY2030 compared to current increase rate.

Source: Outline of Research, Development, and Social Implementation Plan (Draft) for Establishment of Next-Generation Digital Infrastructure Project, Commerce and Information Policy Bureau, Ministry of Economy, Trade and Industry, July 2021.

[From P. 36 of https://www.meti.go.jp/shingikai/sankoshin/green_innovation/industrial_restructuring/pdf/003_04_00.pdf (Japanese)]

Section 2 What is Photonics–Electronics Convergence for Power Saving in Network Systems?

R&D Creating Photonics–Electronics Convergence Chip Generations

Photonics–electronics convergence technology is listed as a game-changing technology in the Development of Next-Generation Green Data Center Technology Project. The project aims to increase network capacity, reduce latency, and significantly reduce power consumption of the entire network system by integrating photonic and electronic devices and replacing electrical wiring with photonic wiring.

— What kind of technology is photonics–electronics convergence?

Namiki: The convergence of photonic circuits and electronic circuits is called photonics–electronics convergence. The first goal is to integrate an optical transceiver consisting of a semiconductor laser and a photodetector on a silicon substrate together with a processor and other logic circuits. That is called co-packaged optics technology.

Although the size of modules*4 widely used as optical transceivers are large, they are acceptable for transmissions between server enclosures. Unfortunately, the large module size is not appropriate for communications between boards within an enclosure or between chips on a board. Therefore, we must utilize co-packaged optics and downsize modules.

— Are both electronic and optical circuits integrated on a single chip?

Namiki: That is the final goal. However, since the Group IV element, silicon (Si), cannot be used as a laser, Group III–V compounds must be formed on silicon substrate. This complicates the manufacturing process and makes mass-production challenging. Also, since semiconductor lasers are heat-sensitive, packaging lasers close to hot processors and accelerators can degrade laser performance.

Therefore, rather than jumping to the final goal immediately, R&D is being performed generation-by-generation. The first generation is the optical module type with miniaturized optical transceivers mounted near the logic chip to form a module (Figure 3, center).

The next generation is the high-performance semiconductor package type using chiplets*5 (Figure 3 right).

— How to achieve input/output and transmission of optical signals for co-packaged optics?

Namiki: The Platform Photonics Research Center researches a technology to form and integrate optical waveguides using polymer on the surface of printed circuit boards (Figure 4). This technology emits an optical beam from the end face of a co-packaged chip, adjusts the beam spot size using a gold-plated micro-concave mirror or the like, and couples the beam to a polymer waveguide. Once achieved, a single board can transmit both electrical and optical signals.

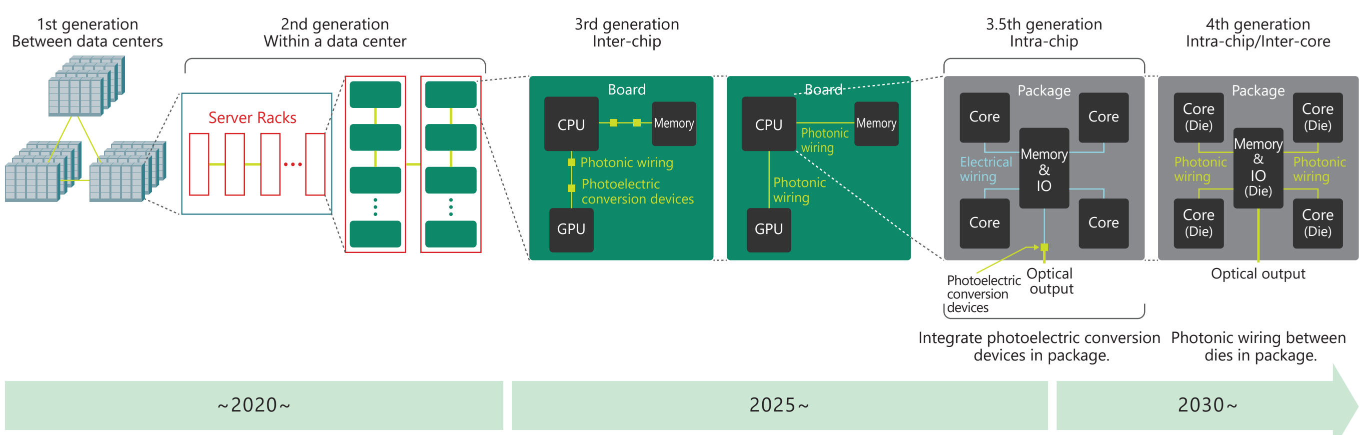
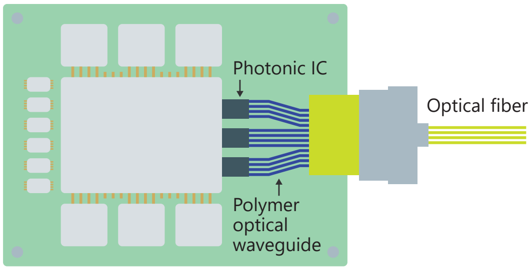


Figure 3 Co-packaged Optics Roadmap.
R&D aims to evolve a fourth-generation chiplet type after the third generation, where miniaturized module-type optical transceivers are packaged close to the chip, and the 3.5 generation, where they are placed adjacent to the chip to form multi-chip modules.
Source: Strategy for Semiconductors and the Digital Industry, METI, Nov. 2021.
[From p. 61 of https://www.meti.go.jp/policy/mono_info_service/joho/conference/semicon_digital/0004/04.pdf (Japanese)]



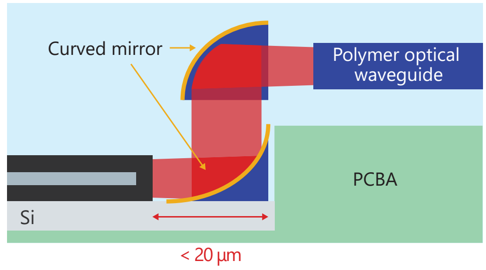


Figure 4 Coupling to Polymer Optical Waveguide on Substrate using Micro-concave Mirror.

Since it is difficult for AIST itself to develop mass-production technologies while controlling costs and yields, AIST hopes to expand the circle of photonics–electronics convergence by attracting various companies to the Co-Packaging Technology Study Committee in the GDC Council.

Note that the Development of Next-Generation Green Data Center Technology Project uses third-generation technology with optical fiber cables connected via small connectors to optical transceivers mounted on boards, rather than the technology described above. Photonics–electronics convergence is achieved by attaching a processor or other device to a socket on a circuit board and plugging an optical transceiver into a nearby socket.

Hopes that Japan's Photonics–Electronics Convergence Technology will Lead World

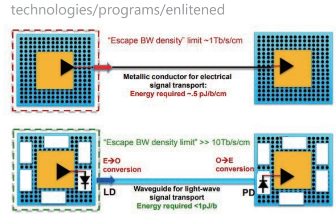
Many technical barriers still stand in the way of achieving photonics–electronics convergence. However, considering future visions for data centers, use of optical networks to increase communications capacity and save power is inevitable. Finally, we asked Dr. Namiki about prospects for data centers and photonics–electronics convergence.

— What is the goal of Development of Next-Generation Green Data Center Technology that is the GDC Council's Target?

Namiki: The GI Fund project has disclosed our business strategy vision under and aim to commercialize the project around 2029. The goal is to achieve energy savings of 40% or more by 2030 compared to power consumption by data centers if they continue to increase at the current rate by combining the three fundamental technologies mentioned above — development of optoelectronics technology, enhancement of performance and energy saving of chips and other components compatible with optics, and development of disaggregation technology.

	Institute/Project	Description	Amount	2014	2018	2022	2026	2030
United States	DOE, ARPA-e ENLITENED	Photonic integration technology converts a signal from electricity to light, improving the energy efficiency of data centers.	$ 25M					
United States	DOD, DARPA PIPES	Significantly improved chip-to-chip connection performance using photonic technologies (100 Tbps, 1pJ/bit).	$ 45M					
United States	DOD, DARPA LUMOS	Integrate lasers using heterogeneous material integration and apply to optical neuromorphic computing, etc.	$ 70M					
United States	HPE The Machine	Memory-driven computing + optical interconnection.	—					
Europe	Microsoft Optics for the Cloud	Application of photonic technology to Cloud computing and development of new applications.	—					
Japan	NEDO Optical electronics implementation project	Fundamental technology development of photonic wiring technology for data communication between chips, etc. and its integration technology.	$ 168M					
Japan	NTT IOWN	Network and information processing infrastructure with innovative technologies centered on photonics.	—					

https://arpa-e.energy.gov/technologies/programs/enlitened



Japan was the first to establish the project and started R&D. One of the leading countries for its technology development.
(Implemented by the Technical Research Association)

Figure 5 National Roadmaps for Photonics–Electronics Convergence Game-Changing Technology.
Source: Outline of Draft R&D and Social Implementation Plan for Establishment of Next-Generation Digital Infrastructure Project, Commerce and Information Policy Bureau, Ministry of Economy, Trade and Industry, July 2021.
[From page 32 of https://www.meti.go.jp/shingikai/sankoshin/green_innovation/industrial_restructuring/pdf/003_04_00.pdf (Japanese)]

— What are challenges in realizing photonics–electronics convergence technology in AIST?

Namiki: For co-packaged optics, it is necessary to establish new technologies at the mass-production level, such as packaging optical transceiver chip made by silicon photonics and forming optical waveguides on printed circuit boards. Since many of these packaging processes still do not exist, companies in charge of packaging and circuit board fabrication have voiced concerns. However, there is a chance we can lead the world in this field. The Co-packaging Technology Study Committee is also advancing discussions on these new value chains.

Previously, optical-communication experts did not know much about computing, while computing experts did not know much about optical communications. In fact, it is not uncommon for engineers to not understand each other's terms or jargon. As a result, when it is not easy to decide where the boundary of responsibility for products, that photonics–electronics convergence technology is applied to, should be set and how quality assurance should be handled.

In this regard, I expect vendors of test and measurement equipment, who have the technology to evaluate both photonic and electronic performance, to serve as pioneering guides in photonics–electronics convergence.

— US companies hold most of the technology and know-how for processors, AI accelerators, network-switch LSIs, the server hardware that integrates them, and ecosystems that configure large-scale data centers.

Namiki: Japan is ahead of other countries in the development of photonics–electronics convergence technology (Figure 5). NTT, an advisory member of the GDC Council, is promoting the IOWN (Innovative Optical and Wireless Network) concept to achieve high-speed, large-capacity communications infrastructure through innovative technologies centering on photonics-electronic convergence. The concept is expected to be established and implemented in society.

Nevertheless, it is true that the US leads the data-center ecosystem, and many new standards originate in the US. Development of photonics–electronics convergence technology for data centers has been dynamic in North America, in part due to requests from large-scale Cloud providers and major social network service providers. Several ventures have been able to produce prototypes in just 2 years or so. Collaboration with some data centers has begun and the investment is astonishingly huge. This may accelerate the roadmap for photonics–electronics convergence.

— Finally, please tell us about the future.

Namiki: With the applicability of Moore's Law coming to an end, photonics–electronics convergence is essential for development of data centers, both in terms of performance and power consumption. The time may come when optical interfaces will be directly mounted on processors, and these will be combined by software like block toys to form systems.

While it may be difficult for Japan to create a photonics–electronics convergence ecosystem, it is quite possible for Japan to participate in a new ecosystem using its superior technology, improve it, and create competitive technology. It is expected that Japan builds good relationships with major overseas players and communities, integrates the semiconductor and silicon photonics industries, and makes use of young talent and new ideas for sustainable development. We, too, would like to contribute through the activities of the GDC Council and the AIST Platform Photonics Research Center.

— Thank you very much for your time today.

*1 Ministry of Economy, Trade and Industry Plan Formulated for "Development of next-generation green data center technology" Projects https://www.meti.go.jp/english/press/2021/1019_001.html
*2 GDC Council https://unit.aist.go.jp/pprc/gdc/english/index.html
*3 Platform Photonics Research Center, AIST https://unit.aist.go.jp/pprc/en/index.html
*4 45.0 mm × 13.7 mm × 8.6 mm for SFP/SFP+/SFP28 module
*5 Chiplet: A small bare chip (die) manufactured for a specific function using optimal process. Multiple chiplets are arranged like blocks on a substrate to form a system LSI.

The opinions in this article are Dr. Namiki's and do not necessarily represent the views of the AIST Platform Photonics Research Center or the GDC Council.