An Essential Quality of a Researcher Is Persistence. Believe What You Are Doing Will Go Well

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Overview

The annual power consumption of datacenters in Japan accounted for 1% of Japan's total power consumption in 2015. As the speed and capacity of data processing and transmission increases, power consumption is steadily increasing, and reducing that consumption is becoming a serious issue. To address this issue, Dr. Shinji Matsuo, a senior distinguished researcher at NTT Device Technology Laboratories and NTT Basic Research Laboratories, is researching and developing innovative technologies for high-density integration of compound semiconductors on silicon substrates to enable photonics-electronics converged integrated circuits. We interviewed him about the progress of his research and his attitude as a researcher.

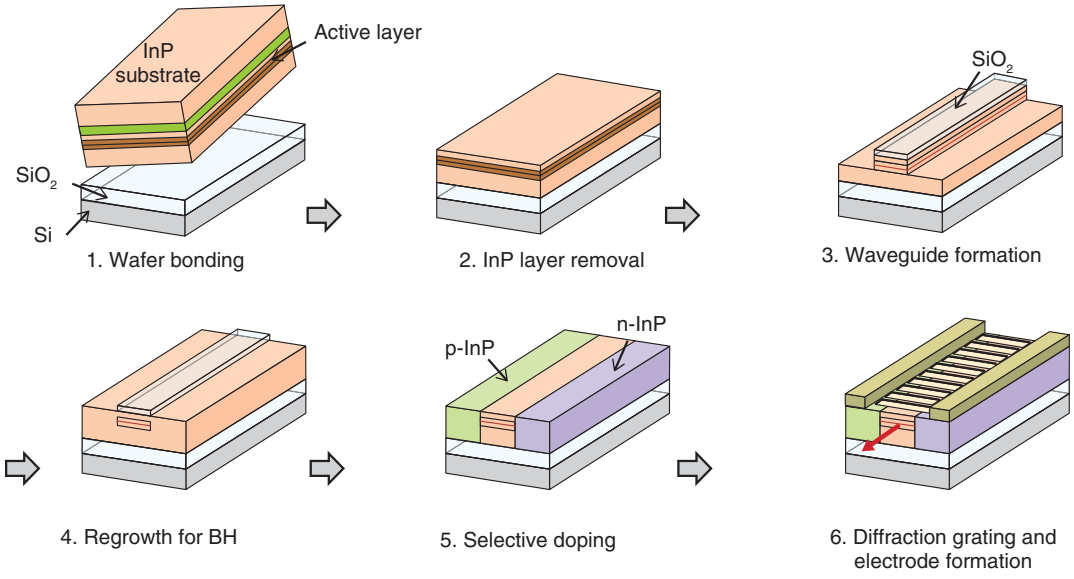
Keywords: photonics-electronics convergence, optical interconnection, directly modulated laser

One aim of the IOWN initiative is to achieve ultra-low power consumption

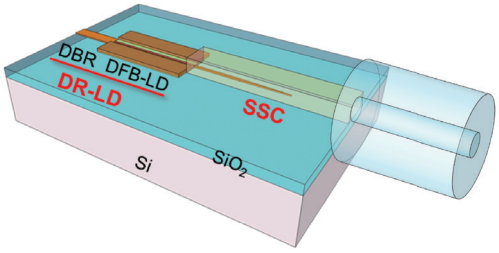
—Would you tell us about your current research?

In 2015, when I was last interviewed, we had just established the basic technology for fabricating semiconductor lasers on silicon (Si) substrates. Since then, our team's efforts have paid off, and we have moved from the research phase to the development phase. At that time, some people were skeptical about our technology because it was new, but now I feel that things are changing favorably. Research on this technology embodies the very characteristics of NTT Device Technology Laboratories, which is engaged in an integrated approach from basic research to applied research on semiconductor devices then to practical application and development of such devices.

We are currently investigating technology for making our devices more socially acceptable and usable, and working on two major themes. One is developing device technology for high-density, low-power, short-range optical interconnections [1]. The development of the Internet-of-Things and the expanded use of artificial intelligence will increase the speed and capacity of data processing and transmission, and power consumption is expected to increase. Therefore, reducing power consumption is a serious issue, and achieving ultra-low power consumption is one of



(a) Fabrication procedure for an LD on Si



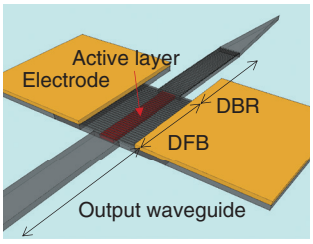
(b) Structure of an LD on Si

BH: buried heterostructures
DBR: distributed Bragg reflector
DFB: distributed feedback
DR: distributed reflection
InP: indium phosphide
SSC: spot size converter

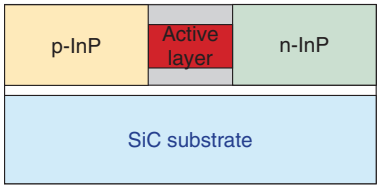
Fig. 1. Fabrication procedure and structure of an LD on Si.

key themes of the Innovative Optical and Wireless Network (IOWN) initiative that NTT has been promoting. To address this issue, we are conducting research and development on optical interconnection to increase the speed and reduce power consumption of electronic equipment used for data processing and transmission by applying optical technology to short-range communication on printed circuit boards of equipment installed in datacenters, etc., which have traditionally been connected by electrical wiring.

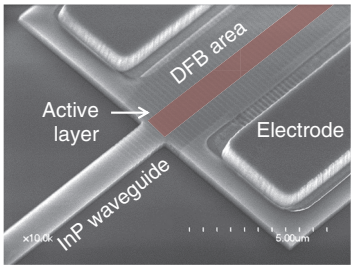
We are developing thin-film (membrane) directly modulated laser diodes (LDs) fabricated on Si substrates as a light source for intra-board optical interconnection (**Fig. 1**). By fabricating LDs on Si substrates, Si photonics technology can be applied to fabricate optical devices, such as wavelength-multiplexing circuits and photodetectors, with high density and at low cost. Forming LDs on a silicon-dioxide (SiO_2) layer having a low refractive index makes it possible to achieve smaller and lower-power-consumption LDs. To fabricate LDs with even lower energy consumption, we are currently developing LDs using photonic crystals. We want to contribute to the development of future information-processing infrastructure by increasing transmission capacity and enhancing high-density integration of LDs as well as integrating LDs with arithmetic processing circuits such as central processing units and graphics



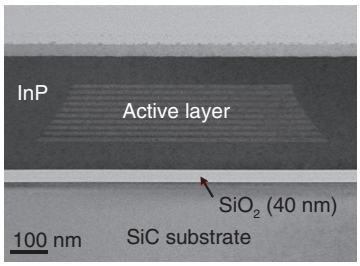
(a) Bird's-eye view



(b) Cross-sectional view near active layer



(c) Scanning-electron-microscope image



(d) Transmission-electron-microscope image of cross-sectional view near active layer

Fig. 2. Directly modulated laser on SiC substrate with bandwidth of over 100 GHz (world's fastest).

processing units.

The other theme is developing a directly modulated laser with the world's fastest bandwidth of over 100 GHz (**Fig. 2**). In collaboration with Tokyo Institute of Technology, we fabricated a membrane laser that uses an indium-phosphide (InP) compound semiconductor on a silicon carbide (SiC) substrate, which has a high thermal conductivity. This laser is the world's first directly modulated laser with a 3-dB bandwidth* exceeding 100 GHz and can transmit signals of 256 Gbit (256 billion bits) per second over 2 km. This achievement was published in the online breaking-news version of the British scientific journal Nature Photonics in 2020 [2, 3].

Although directly modulated lasers are now widely used in datacenters, their limited modulation speed has been an issue. We believe that our technology for fabricating such lasers makes it possible to cope with the expected increase in traffic at low cost and low power consumption, and if research and development of this technology further advances, it will contribute to enabling the high-capacity optical-transmission infrastructure for supporting IOWN. We aim to develop a high-speed, high-capacity communication infrastructure beyond the limits of conventional infrastructure by using innovative technologies centered on optical technology.

—What do you consider important when searching for research themes?

I think it is essential that researchers collect information. I actively participate in academic conferences and talk directly with researchers both inside and outside the company to carefully monitor the trends of NTT's technologies and the technologies that competitors are focusing on. When I was inexperienced, I was sometimes reluctant to attend conferences because I was worried that I would not understand what was being presented or be able to talk to senior or highly respected researchers. However, as I gained experience, those worries have eased. I am now closer to the generation of eminent researchers and speakers and have been invited to give lectures. When I think about the fact that I am now being approached by people to whom I once thought it would be difficult to even speak, I realized the importance of accumulating experience and only experience and effort

* 3-dB bandwidth: A frequency band in which the output power of the laser, which decreases with increasing frequency, attenuates to 70.7%.

make it possible to earn an appreciation from others.

When I was younger, I felt more comfortable studying through papers than interacting with researchers at conferences because I was not used to speaking English. However, I realized that it is difficult to receive new stimuli just by studying in the laboratory and recognized the usefulness of attending a venue such as an academic conference and intensively collecting information and making decisions.

It is also important for your research to be understood by others so that you can continue it. As my interactions with researchers around the world have increased, I have seen them express their ideas in a straightforward and appealing manner, and I have come to understand the importance of expressing ideas assertively. In consideration that research is about creating a brighter future, it is only natural that if you cannot convey to the people in front of you how your research envisions a brighter future, they will not understand it. Moreover, people have an image of researchers being steady and hardworking, and I think we take pride in that reputation; however, considering that we are corporate researchers, I think it is also important to pursue research by thinking about what we can do for our company and society. Therefore, it is necessary to take into account trends such as what our company is focusing on and what issues it is facing.

NTT's laboratories give us annual opportunities to review research plans, discuss them with our group, and promote our plans and learn about the requirements that are being placed on us. While it is important to promote your research to a large external audience, I also want to take advantage of such opportunities to get people close to me to understand the value of my research.

The role of a researcher varies with depth of experience

—Researchers are required to have various skills and roles other than those needed for research, right?

As well as collecting information and building human networks, identifying research themes is an important job for researchers. When identifying a research theme, I consider the personnel, equipment, and facilities and ask myself whether we can bear the responsibilities of using such assets. When it comes to purchasing equipment and other necessities, the financial cost is huge, so a research theme is carefully selected on the basis of whether the pursuit of the theme will benefit society.

On top of the financial costs, research results always come with responsibility. Regarding research on higher-performance semiconductor devices that we pursue, it is important to develop devices and demonstrate the correctness of our fabrication technology. In the development stage, how easily the device can be fabricated is important. However, we should not be bound by these guiding principles. While it is a prerequisite to be able to create something on our own, we also value our sense as researchers that something looks interesting or useful. It is also better to keep in mind that the prospect of "I can fabricate it" differs from person to person.

I believe that the concept of a researcher changes with one's depth of experience. For example, for the first 10 years or so, I thought that a researcher would be able to think of an idea for himself/herself and make that idea a reality on his/her own; however, I later learned the magnitude of the influence of those around me. I am currently a board member and committee member of academic societies and international conferences as well as a senior distinguished researcher at NTT laboratories. Through these experiences, I have come to believe that it is the role of a researcher to think about the research field and the community of researchers in ways like how to create a fruitful research environment for junior researchers and other researchers in the field.

—I heard that you are sometimes asked to give invited lectures at international conferences. Would you tell us about some episodes related to such lectures?

It is a great honor for a researcher to be asked to give an invited lecture. I feel that the invited lectures not only motivate me but also help me self-reflect, reaffirm my position in my research field, and look to the future. My first invited lecture was around 1993, which was five years after I joined NTT. I talked about how to fabricate an LD on a complementary metal-oxide-semiconductor, which is relevant to my current research. At that time, our fabrication technology was highly regarded as innovative, and I was invited to three or four conferences. After I was invited to these conferences, I was desperate not to do anything embarrassing. I had little experience in making presentations in English, and I was given twice as much time as usual to speak, so I practiced hard enough to memorize the presentation.

I have good memories of giving a tutorial-style lecture as a leading expert in the research field at a

conference held in Europe in 2015. I don't know if it was just a coincidence that the atmosphere was like that or if it was normal, but as soon as I took the stage, there was a round of applause. It was an indescribable feeling of elation. In tutorial lectures, experienced lecturers talk about the history of the field and the positioning and vision of their research at the beginning of their lectures. Therefore, I can organize my thoughts by telling my own version of the past, present, and future, and the fact that I can see where I am in the history of my research field and what I am responsible for motivates me to move forward. It is also quite instructive to read through past papers to improve the content of my lecture.

I'm also happy to give lectures to young people. In 2019, I was selected as one of the five lecturers for the Institute of Electrical and Electronics Engineers (IEEE) Photonics Society's Distinguished Lecturer Programs and traveled around and gave lectures in the United States and Canada. In addition to giving lectures on research to graduate students in departments of electronic engineering, I look forward to having the opportunity to interact with students. I'm glad that they listen when I tell them my thoughts on what they should do now. We were also planning to visit India and Brazil; unfortunately, due to the coronavirus pandemic, those trips have been put on hold.

An essential quality of a researcher is persistence

—What would you like to say to young researchers?

Researchers today find it difficult to find time for their research activities, so I fully understand their feeling of impatience. However, in my case, I was able to achieve my current results with a theme launched after I became a midcareer researcher; therefore, I'd like to tell them that they don't have to worry if they don't seem to have enough time or accumulated knowledge.

I work with the belief that what I am doing will go well, and maybe this mindset is what led to my achievement thus far. I think whether you can believe that things will go well affects your motivation. Of course, plenty of studies won't go well even if you believe in them, and I think a large part of success depends on chance and luck. No matter how brilliant you are, some things can go wrong, and some things can go right. I don't know what's causing what, and there is no point thinking negatively, so I'm researching and trusting that it will go well. However, even when it goes well by chance, the sense of not letting go of the opportunity in front of you is crucial. Therefore, it is necessary to collect information. In addition to participating in conferences, actively becoming a committee member or organizer of a conference will greatly expand your opportunities to collect information.

An essential quality of a researcher is persistence. Naturally, research doesn't always go well, and sometimes you will feel pressure from the people around you; however, you can handle that pressure by persistently maintaining your core skills and ideas while being flexible enough to adapt to the times and environment.

Moreover, you should remember that we are members of society. Explain to your immediate seniors and the people around you about what you want to do and convince them of the significance of your research. If you don't have their understanding, you can't continue your research. Then, listen to and incorporate the opinions of those around you as you proceed with your research. It is important to have a sense of balance between assertiveness and acceptance to build a cooperative relationship with the people around us.

One last thing, from the lessons I have learned through my international activities, it is better to polish your English skills from a younger age. If you develop an open mind that lets you talk easily with researchers from all over the world, your future research activities will be more enjoyable. I also believe that casual conversations between researchers in preparation for and after a conference presentation can lead to opportunities for joint research and expand your research activities. Therefore, cherish the friends you make at conferences.

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■ **Interviewee profile**
Shinji Matsuo
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He received a B.E. and M.E. in electrical engineering from Hiroshima University in 1986 and 1988, and Ph.D. in electronics and applied physics from the Tokyo Institute of Technology in 2008. In 1988, he joined NTT Optoelectronics Laboratories, where he researched photonic functional devices using multiple quantum-well p-i-n modulators and vertical cavity surface emitting lasers. In 1997, he researched optical networks using wavelength-division multiplexing technologies at NTT Network Innovation Laboratories. Since 2000, he has been researching high-speed tunable optical filters and lasers at NTT Photonics Laboratories and NTT Device Technology Laboratories. He is an IEEE Fellow and a member of Japan Society of Applied Physics and the Institute of Electronics, Information and Communication Engineers.