R&D Spirits

Research on Large-capacity Photonic Routers toward Optical Packet-switched Networks

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An optical packet-switched network using asynchronous bursts is often called the "ultimate network." To this end, the All-optical Processing Research Group of the Advanced Optoelectronics Laboratory at NTT Photonics Laboratories is researching large-capacity photonic routers. To find out how this research is progressing and what significance it holds in the world at large, we talked with senior research engineer Ryo Takahashi, the unifying force of the All-optical Processing Research Group.

Achieving a 40-Gbit/s photonic RAM with optical/electronic hybrid technology

—Dr. Takahashi, please give us an overview of this research.

Our ultimate goal is to construct a large-capacity photonic packet router that can process high-speed optical packets as needed. To deal with the explosive growth of IP traffic, it is essential that link capacity be increased by wavelength division multiplexing (WDM) while simultaneously increasing the packet transfer speed at nodes. That is why R&D in large-capacity photonic networks using optical technology has become quite active. Of particular interest here are optical packet-switched (OPS) networks that we expect to be the wave of the future. The key elements of such a network are large-capacity photonic packet routers. Their development, however, means solving a number of technical problems, such as clock extraction from asynchronous-burst optical packets, high-speed optical label processing, large-capacity optical buffer memories, and bit-rate conversion. We certainly have a difficult journey ahead of us.

—How will the network change if OPS can be achieved?

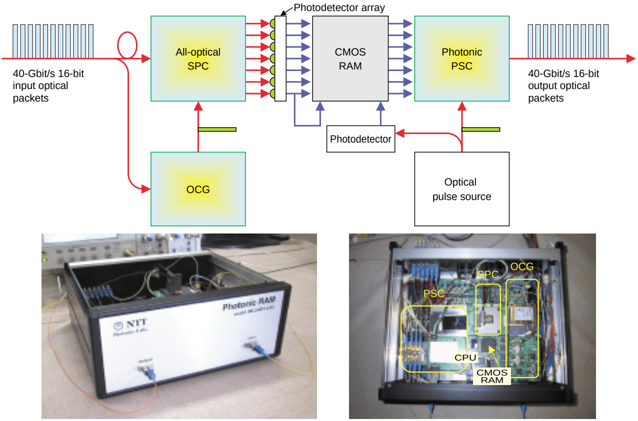
The current network uses optical fiber on links, but at nodes, it uses ATM or other types of electronic switches to switch paths. The next-generation network will set and switch optical paths by means of a G-MPLS (generalized multiprotocol label switching) router that treats wavelength as a label. This scheme can reduce transmission delays and significantly increase throughput. It does not, however, use wavelengths efficiently. To make more efficient use of wavelengths, the successor to this network, the so-called burst-switched network, will switch a single path at fixed time intervals. This network will in turn be followed by the OPS network, the target of our research. An OPS network transfers all packets in asynchronous burst mode making the above circuit switching unnecessary. In other words, the OPS network can achieve maximum network efficiency, which explains why it is called the "ultimate network."

—What are some important technical points of this research?

While light can be used to perform simple processes at high speeds, it is not very adept at complex operations. In short, it would not be wrong to say that using only optical means to achieve the functions of a large-capacity photonic router is essentially impossible, at least for the present. Faced with this problem, I considered the merits of using the beneficial features of electronics instead of pursuing all-optical processing at all cost, and decided to use a complementary metal oxide semiconductor (CMOS) electronic circuit for advanced operations. CMOS technology can also be used for fabricating memory and for creating compact, low-cost, and low-power-consumption devices. A CMOS circuit, though, cannot be directly connected with high-speed optical packets, and for this reason, we developed an all-optical serial-to-parallel converter (SPC) and a photonic parallel-to-serial converter (PSC). These converters and an optical clock-pulse generator make up a photonic RAM (random access memory) (Fig. 1). They are constructed using original devices that we developed. Another important technical point here is a surface-normal optical switch called LOTOS in the all-optical SPC. LOTOS can achieve a switching time of 250 fs and has demonstrated ultrafast parallel conversion of optical packets at 1 Tbit/s. No other surface-normal switch in the world has yet achieved such high-speed operation.

—How far do you think this technology will progress in three- or five-years time?

To date, we have successfully tested basic operations using prototype equipment, and while we have not yet reached full-packet operation, we have achieved a photonic RAM for 40-Gbit/s, 16-bit optical packets. We have also prepared basic tools that we plan to use to test various aspects of this equipment. Assuming steady progress, I believe that, in three to five years, we can achieve a router that can easily handle 40-Gbit/s optical packets, which would be of a practical level. Keep in mind, though, that, as I mentioned earlier, this router is targeted for use in the OPS network scheduled to follow the third-generation network. Whether or not this router will ever find use remains to be seen. Nevertheless, my colleagues and I would like to be the first in the world to achieve this photonic packet router even if only by one day.



SPC: serial-to-parallel converter PSC: parallel-to-serial converter OCG: optical clock-pulse generator

Fig. 1. Structure of Photonic RAM.

From materials to devices and systems—a step-by-step broadening of research interests

—Dr. Takahashi, what stimulated your interest in ultrafast photonics?

At university, I majored in electronic engineering thinking that "the age of light is coming." At that time, I had no particular research theme in mind, but as the main keyword associated with light happened to be "high speed," I naturally turned my attention to that aspect of optical systems. In time, I came to think that, by using light, I would like to do something not simply at high speeds but at ultrahigh speeds! Consequently, in graduate school, I conducted research on short-optical-pulse generation and optical-pulse compression in semiconductor lasers, and on ultrafast measurement of electrical signals using light. Since then, I have been engaged exclusively in the research on ultrafast photonics.

—What kind of research in particular have you been involved with up to now?

On entering NTT, I was initially occupied with finding a means of achieving an ultrafast surface-normal all-optical switch. This type of device would require high-speed materials, so I began my research from a position of preparing materials. The materials used in a surface-normal optical switch require extremely large optical non-linearity, and I found that using exciton absorption saturation in multiple quantum wells (MQW) was a good way to meet this requirement. However, the lifetime of excited carriers was long, making high-speed operation impossible. I then changed the MQW growth temperature from the usual 500°C to 200°C and doped the material with beryllium (Be). With this approach, I succeeded in shortening the carrier lifetime by four orders of magnitude, thereby achieving high-speed operation. Expanding on this, I succeeded in fabricating the LOTOS planar optical-optical switch having an on/off ratio greater than 40 dB (Fig. 2). After these achievements, I spent two years in the personal development department of NTT's Tokai Office and returned to NTT Laboratories in 1998. In just six months, though, I was off again, this time to Stanford

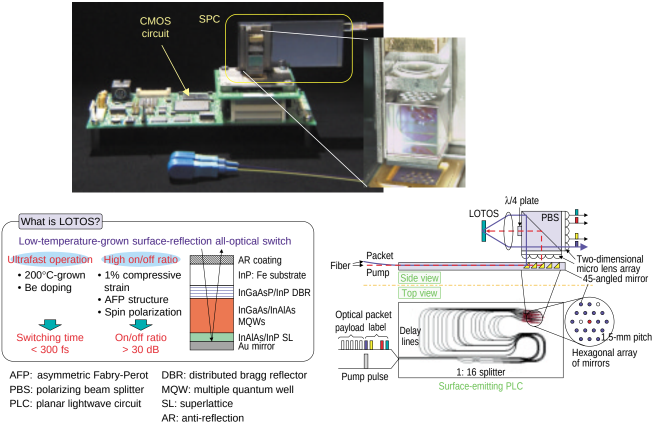


Fig. 2. All-optical serial-to-parallel converter and LOTOS.

University for a one-year stay as a guest researcher. I returned to Japan in 1999 and soon began my present line of research.

—Please tell us what got you started in your current research?

Ever since I joined the All-optical Processing Research Group, I have been researching ways of achieving ultrafast control of optical signals by light itself. At first, I felt that even optical packet processing could be performed using light alone, but this was easier said than done. It was at that point that I went to Stanford University and encountered the research theme of converting ultrafast signals from analog to digital using light. It was Professor David A. B. Miller's idea that analog electrical signals could be sampled by an ultrafast photoconductive sample-and-hold circuit and then converted to digital signals by a CMOS circuit. I did not fully understand the significance of this idea at first, but as my research continued, my thinking went through a radical change. "The use of light is not the objective, it is simply a means!" I had to learn this obvious truth for a second time, but it signaled the beginning of my current research in which I deal with more than just light.

Keeping one step ahead of a growing number of competing researchers through original ideas

—Tell us something about international and domestic trends in this research.

The concept of OPS networks has been around since the 1980s, but not much specific research has actually been done. Recently, though, I have felt that more and more research is focusing on optical packet processing, which means that an increasing number of competing researchers should be entering this field. While I am happy to see research in this field becoming mainstream, I do not intend to give up our leadership here so easily. This is because we are still at the stage at which various ideas are being proposed, and it is still too early to tell which will dominate. In this environment, I believe our group is still out in front. In optical label processing, for example, we are implementing high-speed serial-bit label processing, which has been difficult to achieve in the past, in a compact all-optical serial-to-parallel converter. In buffering, moreover, we are using CMOS circuits as memory to construct buffers that satisfy all the standard requirements including large capacity, long-term storage, and anytime access.

—Is your group engaged in joint activities with overseas research institutions or are you competing with them?

Because our research involves many patents, I guess I would have to say that all other research institutions are our competitors. It is therefore not easy to engage in joint research activities. We have actually received some offers, but had to refuse in the end. Personally, I have no hesitation about joint research if I feel that something of benefit could be obtained. In the past, when I was conducting research on my own, I sometimes wanted to pursue collaborative research somewhere to speed things up. My group has since grown to six members, however, all of whom are excellent researchers. At present, I am satisfied with the present situation.

—What do you know of other researchers' work?

Of course I survey other people's research, and if the circumstances warrant it, I would be inclined to evaluate certain work constructively. But as to imitating certain research, I think not. That is because I have always thought that unoriginal research is hopeless. Refraining from copying other people's research is my research spirit and my most basic policy. At the same time, I do not make it a point to hide my current research activities at all times. While I do not usually partake in exchanges with overseas researchers involved in similar research, I do interact with many people here in Japan such as researchers that I meet through academic societies and friends from my university days. Whenever I have the opportunity to go out for a drink with such people, our conversation tends to be quite open. At any rate, my group's research is not something that can be easily imitated from just conversation.

—Has your research to date had an influence?

After submitting our paper on experimental results with a prototype to Optical Fiber Communication (OFC), we received mail from a journalist at the Optical Society of America (OSA). It was agreed that materials and information would be collected for a story in conjunction with the presentation that I would be giving at OFC in March of this year. As luck would have it, the outbreak of the Iraq war prevented me from taking an overseas trip, and as the only other alternative was to give a video presentation, we eventually decided to cancel. At that time, equipment had already been forwarded with the aim of giving a dynamic demonstration as well. But as we ourselves could not go in the end, the demonstration could not be given either. We therefore had no choice but to have the container holding this equipment returned without even being opened. In many aspects, but especially in terms of not being able to experience firsthand the response to our presentation, we were all quite disappointed. Since then, however, we have received two invitations to international conferences, as well as many requests for papers. In fact, a paper for next year's OFC is already in the works. I therefore sense real interest in our research from the world at large.

Contributing original and innovative devices to science and business

—In what direction would you like to take your research in the years to come?

When I first entered NTT, I wanted to create useful and innovative world-class devices, and that desire hasn't changed at all. My main goal is therefore to take my research as far as practical, working devices. I hope to create devices that can actually be used by NTT, a private company, and that can make a real contribution to business. At the same time, I enjoy the challenge of overcoming technical difficulties and achieving ultrafast processing. Of course, developing practical devices operating at 40 Gbit/s is now the correct path to be on, but I still would like to hold a world record at ultrahigh speeds on the Tbit/s level. Looking a bit further into the future, though I have said that I am no longer obsessed about doing everything by only light, I am still deeply involved in optical research, and I would love to someday achieve all-optical ultrafast logic processing. While that may be impossible without a major breakthrough, it has been my dream for many years.

—Based on your experiences as a visiting scholar and a participant in academic conferences, how is NTT viewed by the outside world? What expectations do people have of NTT?

NTT's contributions at international conferences in the field of communications are well known by just about everyone. At such conferences, there is not likely to be anyone that has not heard of the name "NTT." It is widely known that NTT is the only telecommunications carrier having a basic-research group in components and materials, and NTT researchers get due respect. There are also many overseas researchers who would like to visit NTT. As an organization, however, NTT and other companies and institutions are naturally competitors, and I'm not sure what kind of expectations others might have. NTT is certainly viewed as an important research institution, at least in Japan. Our mission is naturally to make NTT a leader in the field of communications, and others around NTT probably expect the same.

—Dr. Takahashi, what is it like working at NTT Laboratories?

I think it's a great research complex covering a wide range of fields on a large scale and assembling a great group of brilliant researchers. As far as I know, NTT Laboratories has the best working environment in Japan. While in university, I had the opportunity to conduct some experiments at what was then NTT's LSI Research Laboratory. I was very impressed with the superb research equipment and facilities that I was able to use. If I was to pursue research in Japan, I wanted to do it at the best research institution in the country, so I entered NTT Laboratories. Although research among many high-caliber people can be extremely competitive, such an environment is highly stimulating, providing ideal conditions for self-growth.

Interviewee profile

■ Career highlights

1987 B.E. from the University of Tokyo, Dept. of Electronic Engineering.

1989 M.E. from the University of Tokyo, Dept. of Electronic Engineering.

1992 D.E. from the University of Tokyo, Dept. of Electronic Engineering.
Joined NTT Optoelectronics Laboratories, Kanagawa, Japan.

(1996-1998 Associate Manager, Personal Development Department, Tokai Regional Communications Sector)

1998-1999 Visiting scholar at Ginzton Laboratory, Stanford University, Stanford, CA.

1999- Currently with NTT Photonics Laboratories, Kanagawa, Japan and engaged in ultrafast all-optical devices and optical signal processing for photonic packet-switched networks. Dr. Takahashi is a member of the Japan Society of Applied Physics and the Institute of Electronics, Information and Communication Engineers of Japan.

■ Major awards

1994 NTT Optoelectronics Laboratories Director Award

1995 NTT Optical Network Systems Laboratories Director Award

1996 Japan Society of Applied Physics Award

2003 NTT Photonics Laboratories Director Award