R&D Spirits

Developing New Photonic Semiconductor Devices for Photonic Networks

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At NTT Photonics Laboratories, the research and development of modulators, the core device of photonic networks, is giving birth to a novel product: the semiconductor Mach-Zehnder modulator. What changes will this new device bring to optical communications, and what problems must still be solved before actual implementation? We put these questions to Senior Research Engineer, Hiroshi Yasaka, the leader of the High-speed Semiconductor Photonic Device Research Group.

Development of optical modulators to meet the demand for long-distance, large-capacity communications

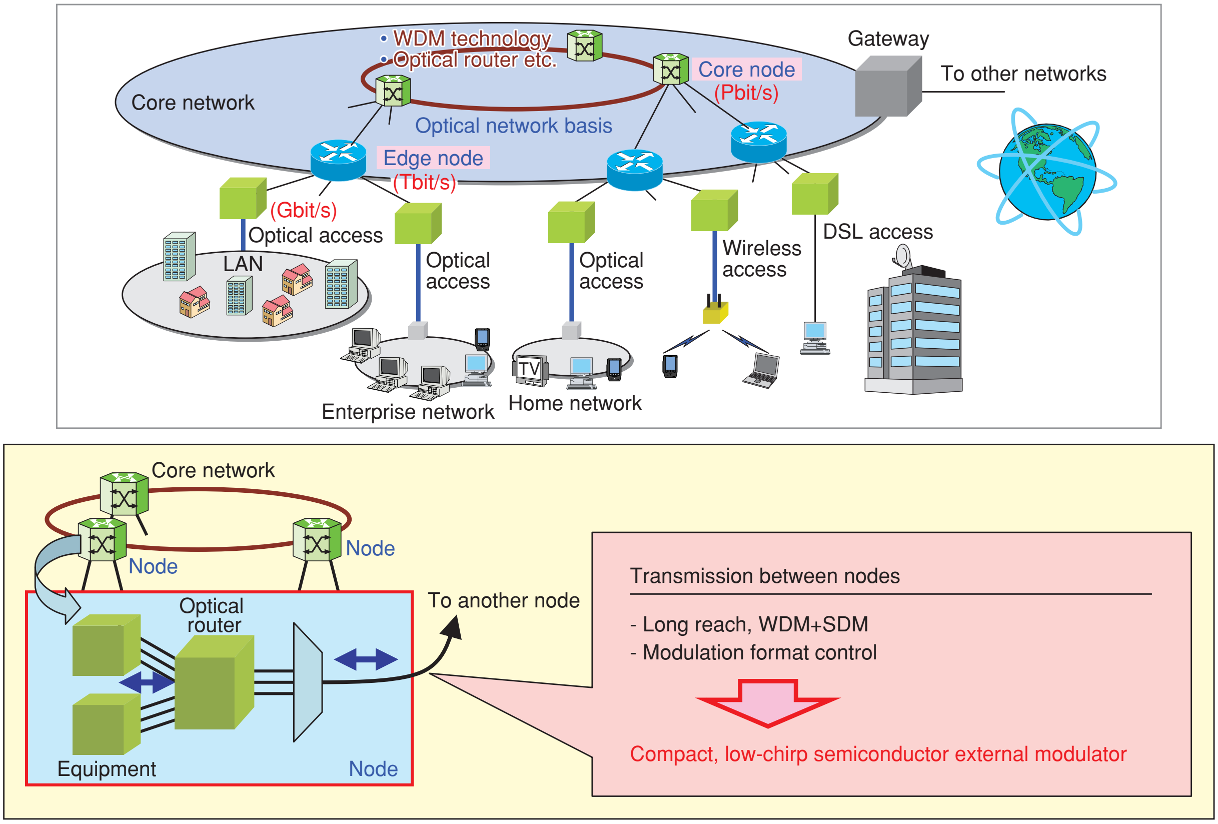
—Dr. Yasaka, please describe your current R&D efforts for us.

Our group researches and develops semiconductor optical components for use in optical communication systems. The spread of the Internet is generating a dramatic increase in the amount of information flowing through the network, and to support this increase, we must find ways of increasing network capacity and speed. Of particular importance here is the development of a high-capacity core network (**Fig. 1**). There is therefore a strong need for high-speed, low-loss photonic devices, and making devices of this type is foremost in our minds in our daily R&D activities.

Specific products include semiconductor lasers and modulators as well as integrated devices that combine these products. At present, we are putting much of our energy into modulators that use semiconductors. Let me point out here that modulators come in various types, from those used for short-distance applications such as interconnecting equipment in the home to those used for interconnecting long-distance nodes in the core network. The type that we are focusing on is the latter. Modulators used for long-distance transmission on the order of several tens of kilometers require modulation control to negate the effects of nonlinearity in optical fiber. And these modulators must, of course, be able to support wavelength division multiplexing (WDM). To meet these needs, we are developing a semiconductor Mach-Zehnder (MZ) modulator [1].

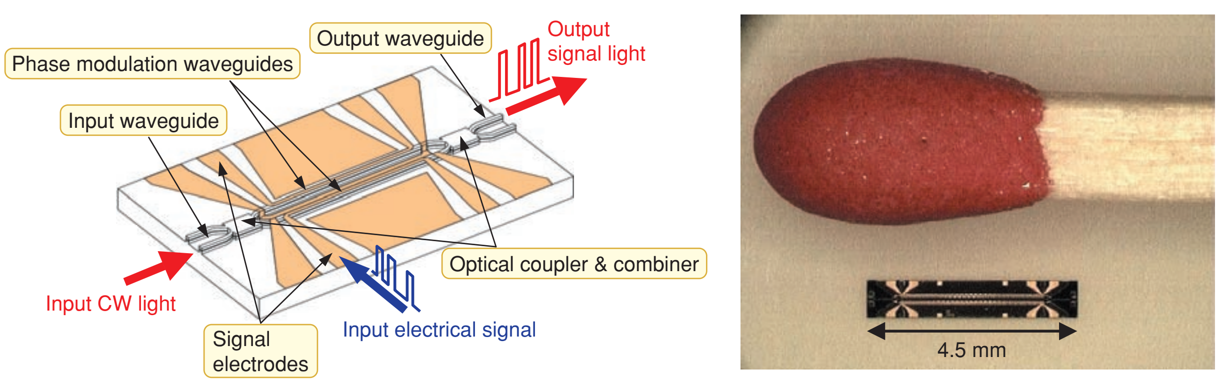
—In what ways do you think this R&D work is useful?

First of all, it will enable modulation appropriate for longer transmission distances. In a semiconductor MZ modulator (**Fig. 2**), input light is divided in two optical waveguide branches each paired with a signal electrode. Applying a voltage to a waveguide changes its refractive index, thereby changing the phase of the light passing through it. The two optical signals are finally recombined before output. As a result, light is output if these two optical signals are in phase, and no light is output if their phases are out of phase. This is the basic operating principle of the device. Compared with electroabsorption type semiconductor modulators that are now in common use in Metro area net-



DSL: digital subscriber line
LAN: local area network
SDM: space division multiplexing

Fig. 1. Photonic network systems. Optical access is up to 1 Gbit/s, an edge node handles several hundred terabits per second, and a core node handles several petabits per second.



CW: continuous wave

Fig. 2. Semiconductor MZ modulator.

works, this semiconductor MZ modulator can inhibit spectrum broadening by using special modulation formats, so the output has a low chirp characteristic suitable for long-distance transmission. Another benefit of our R&D work here is cost reduction. With a chip size of 0.8×4.5 mm^2 and driving voltage of less than 1.5 V_{pp}, we have achieved a compact device that saves space and consumes less power.

—What are the key technical features of the semiconductor MZ modulator?

The most outstanding feature is the use of semiconductor material. Most MZ modulators available on the market use a dielectric material, usually lithium niobate ($LiNbO_3$; hereafter, LN). Instead, we use indium phosphide (InP), a semiconductor material, which enables us to make a smaller device with a lower driving voltage. Moreover, since it's the same material as used in lasers, there are good prospects for optical integrated circuits in the future.

Another major feature is the introduction of a new "n-i-n" (negative-insulator-negative) cross-sectional structure in the optical waveguides. Existing semiconductor MZ modulators use a "p-i-n" (positive-insulator-negative) structure in which a p-InP cladding layer, an i-MQW (multiple quantum well) optical core layer, a semi-insulating InP layer, and an n-InP cladding layer are grown on an InP substrate in that order. This structure, however, suffers from large loss in both electrical and optical signals due to the p-InP cladding layer. In response to this problem, we decided to form an n-type semiconductor layer, whose signal loss is about 1/20 that of a p-type semiconductor layer, on both the signal-electrode and ground-electrode sides. We also inserted an Fe-doped semi-insulating InP layer between the optical core layer and upper n-InP cladding layer to complete this new n-i-n waveguide structure. This structure enables us to make a device having low wavelength dependency, low temperature dependency, low loss, and high breakdown voltage.

—How is development progressing?

In terms of characteristics, our semiconductor MZ modulator has reached the working level. However, a transponder that actually incorporates the device has not yet been commercialized, and we are very eager to develop and market the world's first transponder of this type ahead of our competitors. But there is not much time. Competition has intensified over the last two years or so, and we have been focusing our efforts on developing smaller modules because module size has been an obstacle to commercialization. We have reduced the module size from about 100 mm to almost 20 mm (**Fig. 3**). And regarding performance, we have already confirmed through experiments that the device generates good eye patterns, indicating good signal band characteristics. All in all, I am confident that our approach will lead to a device suitable for practical applications.

—What issues must be addressed toward commercialization?

We must ensure that all characteristic parameters are equivalent to or better than those of the LN-type of MZ modulator. Although our semiconductor MZ modulator is definitely superior to the LN MZ modulator in terms of major requirements including a compact configuration, we cannot say that our device is not inferior in other respects. Being superior in some ways while having worse characteristics in other respects is not what I would call advanced technology development. To reach a true stage of practical

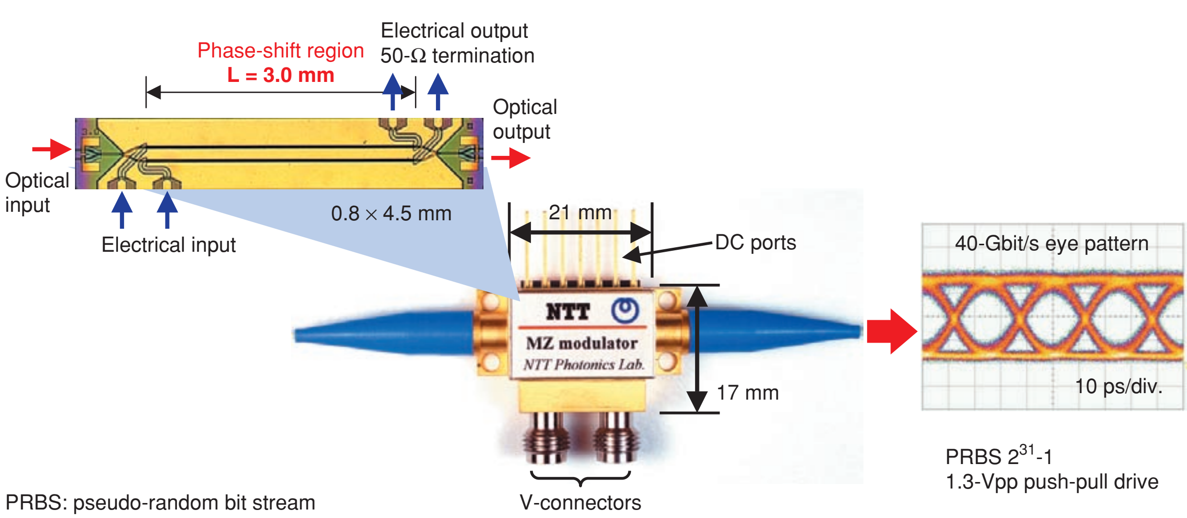


Fig. 3. Semiconductor MZ modulator module.

deployment and make inroads into the market, we must produce a device that is superior in all aspects.

—Where do you think this technology will be three and five years from now?

Our objective at present is to integrate a laser and modulator on the same semiconductor substrate. This is our target for the next one to two years. Until then, I cannot talk about specific product details, but I believe we will see much more functionality than is possible with our current devices. At the same time, enabling device control to be performed directly by optical signals instead of having to first convert optical signals to electrical signals as is done now will mark a great leap in performance. We have therefore made that a target as well.

Receiving international praise amidst difficult R&D trends

—Dr. Yasaka, what international trends can be seen in this R&D field?

In the world of photonic devices, whether it be lasers or modulators, fierce competition in development is now taking place at research institutions and device makers throughout the world. There is also a move by some makers to buy out other makers that have developed novel photonic devices. Such shrewd purchases are made because photonic devices have a direct effect on the performance of photonic transmission systems and buyouts can greatly speed up device development.

As for the type of modulator that we are currently working on, there is no doubt that size reduction has become a worldwide development theme. The current objective is a module of the size of a business card, and it is commonly recognized that this cannot be done without the use of semiconductor material because there is a limit to how small the LN MZ modulator can be made. At standardization meetings, discussions have begun on the feasibility of achieving a module that integrates a laser and modulator. At the academic level, our group and other companies have been presenting research results, but a practical level of operation has yet to be reached. From here on, we plan to accelerate our research and devote our efforts to achieving, as soon as possible, an integrated module that can stand the test of practical application.

—How do you think NTT is ranked in this field?

Over the last two to three years, our papers have been accepted annually at the Optical Fiber Communication Conference & Exposition (OFC), the leading conference in this field. And at last year's conference, we gave an invited talk. So I believe we are getting some degree of recognition on the international level. Actually, we get lots of questions every time we present our research results. In addition to making formal replies to inquiries during the presentation session, it is not uncommon for us to get approached with questions by individuals afterwards. Researchers sometimes ask point-blank questions like "How can that result be achieved?" This, of course, tells us that there is interest in our work, and while we cannot answer every question due to prohibitions on releasing know-how, we greatly enjoy the chance to hold energetic discussions with other researchers on our work.

—Are you collaborating with other research institutions or companies?

Not especially at present, but we have received offers from foreign companies. For an offer from a university in Japan that wishes to use our modulator, discussions are under way. In device development, it is essential that a new device be tried out at as many sites as possible. There is always the possibility that another party can uncover problems that we had not considered or think up new applications. I therefore think that it is important for us to expand our work to include such cooperative relationships.

From basic materials research to the development of semiconductor devices

—Dr. Yasaka, please tell us about your technical background.

At university, I was enrolled in the physics department and studied material properties. My special field of interest was not semiconductors but rather insulators, and I researched the structural phase transitions that take place in ferroelectric materials at different temperatures with an optical probe. Since my current R&D theme concerns the control of light through appropriate semiconductor properties, I would say that the only direct connection between this work and my university research is the use of light. Nevertheless, I can view this as a beneficial progression from a basic research field dealing with materials to an application field both centered about light.

—Why did you select NTT Laboratories as a site to conduct R&D?

I felt that NTT Laboratories had more of an academic atmosphere than a private research laboratory and that it could be a place where I could settle down and do some serious research. I was first assigned to Atsugi Electrical Communications Laboratories, and I became a member of the semiconductor laser group. I initially wanted to take on a more basic theme dealing with material properties, but I soon saw the positive aspects of progressing to application-oriented research as I just mentioned. Looking back, I probably could have done basic research too by coming up with some clever way of establishing my research themes, but at that time, I was hardly that resourceful and the thought of attempting such a thing never crossed my mind. At that time, moreover, semiconductor laser research was on the brink of producing practical, working products, and that made my work extremely interesting. Since then, my research themes at NTT have dealt with light exclusively, and that brings me to the present.

—What specific research themes have you been involved with up to now?

My work has involved two key themes: the research of semiconductor laser control and the development of highly functional photonic semiconductor devices. One example of a commercial product coming out of this research is a distributed-feedback laser diode (DFB-LD) integrated with an electroabsorption (EA) modulator. This product is still on the market.

—What gave you the idea of taking on your current research theme?

It all began with attempts to overcome the drawbacks of existing modulators. In particular, the fact that existing modulators are limited in distance prevents them from being applied to optical communication systems that need to support ultralong distances. Thus, on starting out to investigate what type of modulator could meet the needs of future systems, the idea that popped into my head was an MZ modulator using semiconductor material. This modulator has, in principle, no wavelength dependency, which opens up all kinds of possibilities. It is also a promising device for modularization together with the tunable laser that our laboratory had developed. For these reasons, this was something that I felt should be achieved with great urgency, and we began development work.

—What has been your prime goal in your R&D life up to now?

For me, this work of mine is practically a hobby. I think about work at the laboratory, of course, but quite frequently at home too. When I was single, I was completely immersed in my work, almost forgetting to eat and sleep. If it's just work, it can be suffocating, but if it's something that you truly enjoy, then stress and fatigue are minimal, I believe. Asking myself "Why?" and coming up with an explanation one step at a time is a very enjoyable process for me. For example, if a device that we are researching fails to work according to principle, nothing can please me more than using a trial-and-error approach to find an answer. I also find it very interesting to examine a phenomenon that is not yet understood and try to come up with a theory to explain it. This kind of challenge is very enjoyable and no doubt the reason I entered the world of R&D.

Recommending original and independent R&D whatever the target

—In what direction would you like to take your research from here on?

Whenever I'm asked what our research on photonic semiconductor devices will be like in the future, I have to honestly say that I don't know. This is such a fast-moving field that there's always the possibility that a completely new form of technology will appear and shake the very foundation of existing techniques. Because our group is an R&D team that aims to produce commercial products, we usually think in terms of a one-to-three-year time span. With that said, I would say that improving the functionality and integration of our photonic semiconductor devices is one direction that we plan to take. And though this is product-oriented research, it goes without saying that we have to keep in mind future ways of linking our technology to other technologies and devices. In this regard, we are thinking of establishing the principle technology behind our semiconductor MZ modulator as an elemental technology that can be applied to other devices. We would also like to link this technology with various future devices by applying it to passive devices and switches, for example.

—What is your ultimate dream as a researcher and developer?

Well, to begin with, I would love to discover a theory that overturns what is considered to be common knowledge as established by others in the past. Even if one finds a way to quantify a phenomenon of some complexity, it cannot be called a breakthrough overturning the work of your predecessors if your findings conform to an existing theory. I would say that you are performing truly advanced R&D when you discover a phenomenon that contradicts existing principles and come up with an original theory to explain it. In a similar vein, though closer to the commercialization aspect of our work, I would like to leave behind some kind of achievement that no one else had a hand in. In this sense, I am an *amanojaku* (a mythical Japanese demon known for its mischievous and contrarian nature), but sometimes "thinking outside the box" is necessary. Of course, going with the flow can also be important, but I myself would rather pursue R&D without following anyone else as much as possible.

—What value does NTT Laboratories hold for you as a place to work?

It's a wonderful think tank! For me, it's like having a living encyclopedia at my disposal. Whenever there is something that I don't understand, there is always a "professional" in that area that I can go to with questions. Being able to ask questions whenever one has a problem enables a researcher to give 100% to his or her field of specialization without having to exert more effort than needed. And while I often hear from others that they would like to travel abroad to do work at other research institutions, I believe that there is no other research site in the world that covers such a wide range of research fields as NTT Laboratories. It is because of this wealth of technology that NTT can provide such a wide array of services as a carrier. This is why there is a great need to inherit and improve technology.

—Dr. Yasaka, what would you say to young researchers?

I would say find something that you can immerse yourself in to the point of forgetting about life's basic comforts. It is difficult to exert 100% of your energy when simply going with the flow, but if you find something for which you can say "this is it," you will put out 200 or 300%. In short, find a topic that you can totally immerse yourself in and focus all of your concentration. It doesn't matter if your initial target is a small one. If you can decide on one target, even if small, the next one will come naturally. If you follow this path, your research cannot help but become increasingly interesting.

Reference

[1] E. Yamada, K. Tsuzuki, N. Kikuchi, and H. Yasaka, "Compact Low-power-consumption Optical Modulator," NTT Technical Review, Vol. 3, No. 3, pp. 41-45, 2005.

Interviewee profile

■ Career highlights

Hiroshi Yasaka received the B.S. and M.S. degrees in physics from Kyushu University, Kyushu, in 1983 and 1985, respectively, and Ph.D. degree in electronics engineering from Hokkaido University, Hokkaido, in 1993. In 1985, he joined NTT Atsugi Electrical Communications Laboratories. Since then, he has been engaged in R&D of semiconductor photonic devices for optical fiber communication systems. From 1996 to 1998 he worked in NTT Optical Network Systems Laboratories, where he engaged in R&D of photonic transport systems. He is now a Senior Research Engineer, Supervisor in NTT Photonics Laboratories and is engaged in R&D of semiconductor photonic devices and their monolithically integrated devices.