Think about Your Definition of a Good Idea and Believe in Your Idea

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Abstract
Today, everything is digitalized. In the creative process, however, not only digital thinking but also analog thinking, which captures events as they are, is considered important. Toshikazu Hashimoto, a senior distinguished researcher at NTT Device Technology Laboratories, is researching and developing optical circuits to enable new information processing using the analog characteristics of light. We interviewed him about the progress of his research activities and his attitude as a researcher.

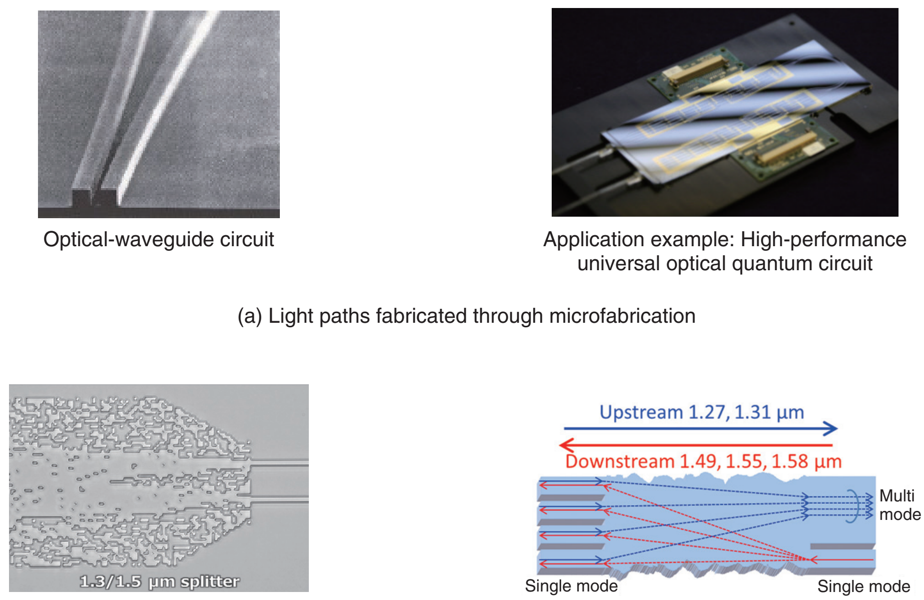
Keywords: optical circuits, planar lightwave circuit, quantum teleportation

Optical circuits for new information processing by manipulating light waves

—Tell us about the research you are currently working on.

I am researching optical circuits that enable a new type of information processing by manipulating light as waves. What I mean by "manipulating light as waves" is to use the analog nature of light. In the case of digital computation, for example, it is necessary to use two values (bits), "1" or "0," in a sequence such as "010110..." to represent a number. In analog computation, however, it is only necessary to use a single value, for example, "0.10110..." (i.e., the number itself). If we use analog computation skillfully, we may be able to conduct calculations faster, reduce the number of calculation steps, and save the labor involved in calculations. However, as you can easily imagine, when a number is represented by an analog signal such as light intensity, the last digit after the decimal point would lose its information due to noise. Information processing using analog computation, which is susceptible to noise, is difficult to scale up and has not been applied to computing.

Despite the above-mentioned drawback, for computations to extract properties independent of minor differences, as is the case with artificial intelligence (AI), or computations by using the superposition of many quantum states while suppressing noise in the quantum state, as required with quantum computers, analog computation is more significant because it is possible to execute many calculations at once, albeit at the expense of accuracy, or manipulate quantum states without destroying them. In other words, rather than exceeding the limit of digital-information-processing capacity by using analog computation, we carry out a different type of processing using analog computation for information with different quantity and quality than before. This is the "new" information processing using light waves that I am aiming for. To make such information processing a reality,



Optical-waveguide circuit

Application example: High-performance universal optical quantum circuit

(a) Light paths fabricated through microfabrication

Optical circuit with complicated pattern

Application example: Lossless multi-mode wavelength multiplexers/demultiplexers

(b) Example of an optical circuit device that controls light waves (also using scattered light)

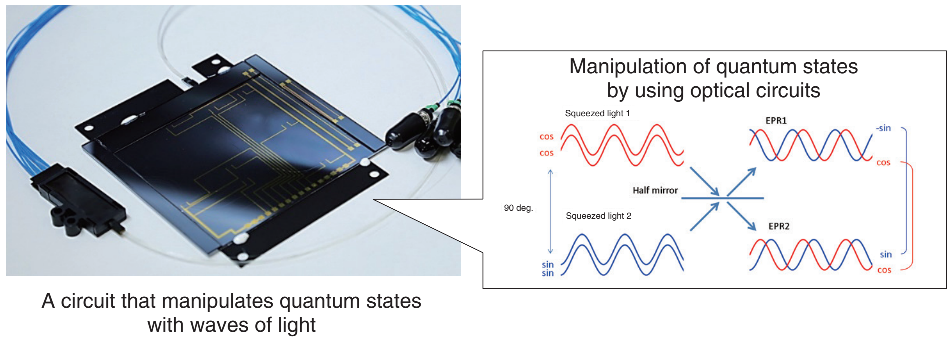
Fig. 1. Newly designed, ultra-low-loss optical device technology.

we are proceeding with research and development (R&D) with a focus on the following two technologies.

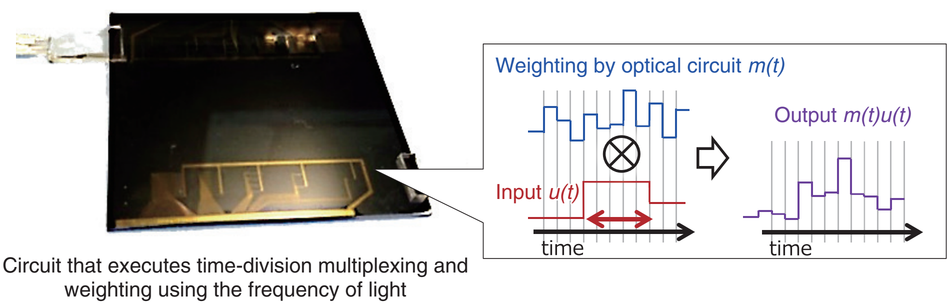
The first technology is newly designed, ultra-low-loss optical device technology (**Fig. 1**). It might seem contradictory to what I said earlier, but as noise becomes lower, the calculation performance improves, so the first step is to minimize loss—which constitutes noise—in an optical circuit as much as possible. Therefore, we are working on a new device design that enables significantly reducing the loss and signal processing by capturing the light scattering of the optical circuit that causes the loss. The optical-circuit technology that I am researching targets optical fiber communications, and I have been pursuing low-loss characteristics so that the optical signal does not weaken. However, I am aiming for technology that reduces losses by an order of magnitude and enables large-scale circuits and high-performance optical circuits.

The second technology is light-wave computing technology, which uses light waves for computations (**Fig. 2**). The challenge is to devise a computational method for exploiting the advantages of light as physical light. We are proposing light-wave information-processing technology using optical device technology. To develop the world's first and highest-performance computing technology using light waves, we are attempting to demonstrate the basic operation of optical information processing using technology based on the light paths (optical waveguides) in current devices.

Of course, lowering the loss of optical circuits also reaches a limit, and electrical control is essential to fully use light waves; accordingly, it is important to create new optical circuit technology by combining the features of both digital and analog computations. One example application of this new type of information-processing technology using light waves is a large-scale, fault-tolerant universal optical quantum computer, which is expected to be developed around 2050. A quantum computer capable of large-scale, universal computation is expected to enable the development of innovative materials and the design of chemical reactions that have been difficult to carry out with conventional supercomputers. It is also expected to contribute to solving global issues such as energy problems. As a participant in one of the Moonshot Research and Development Programs of the Japan Science and Technology Agency, which started in 2020, we are developing optical-circuit device technology for quantum information processing



(a) Continuum-quantum optical quantum information-processing circuit (quantum teleportation circuit)



(b) Optical-frequency-domain-weighted up-sampling processing circuit

Fig. 2. Example of light-wave computing technology.

to enable a large-scale, fault-tolerant and universal quantum computer that exploits the properties of light as a wave and can operate at room temperature.

—It is fascinating that your research on optical circuit technology could contribute to achieve large-scale quantum computers. Can you tell us about one of your achievements in other applications?

The optical circuit that I am researching is called a planar lightwave circuit (PLC). As a component technology for optical fiber communications, a PLC integrates an optical-waveguide circuit (namely, a path of light) on a silicon substrate. The application of PLC includes optical branch circuits and wavelength multiplexers/duplexers. Developing PLC technology to create optical circuits with even higher performance was the essence of my research. This high-performance optical circuit technology can control light with wavelengths less than half that of the light used for optical fiber communications (visible light). It is therefore being applied not only to optical computation but also to ultra-compact RGB (red, green, and blue) laser light sources for smart glasses. Semiconductor lasers using the three RGB primary colors are beginning to be used in a variety of situations as single-color lasers; however, to combine them and create an RGB light source, it is important to devise an optical system (optical circuit) technology that uses the characteristics of the laser light by means of interference and other phenomena. Conventionally, the optical system was made up of lenses and mirrors, which are bulky and difficult to assemble. We have therefore applied our visible-light PLC technology for those parts and created the world's smallest optical system that forms the basis of an ultra-compact light-source module that fits in the temples of smart glasses.

Making sure that the limits of my imagination do not become the limits of my research

—How do you find research themes?

Optical circuit technology—which is the basis of my research—has matured as a device technology for optical fiber communications, so it can be said that it is difficult to propose new ideas. Therefore, I started to think that what type of light to input into an optical circuit is more important than what type of optical circuit is possible. This way of thinking is the same as I mentioned at the beginning of this interview, namely, it is important to know what kind of information to handle to take advantage of the characteristics of analog computation. By inputting visible light, which has a different wavelength from that used for optical communications, into an optical circuit, we would be able to consider applications such as RGB light sources. Also, by devising ways to put information on optical signals, analog computation with optical circuits becomes possible. We might also be able to create an optical quantum computer by inputting quanta of light (photons) into an optical circuit. I believe that inputting new light into an optical circuit is the source of creating a new optical circuit.

To foster different perspectives, I am paying attention to the trends of deep-tech ventures involved in AI, quantum computers, and so on. Although it is a mixture of good and bad, the ability of such venture companies to quickly commercialize basic technology (such as AI and quantum computers) is remarkable. Collaboration is also important because through collaboration, it will be possible to apply the optical device technology we have developed thus far to completely different fields. I have been greatly stimulated by collaboration with other researchers and companies, which is true joy of research.

—Do you feel that you have any advantage as a researcher working at NTT laboratories? In addition, could you tell us about the attitude that you value in your research activities?

I think that various applications and collaboration are possible only with outstanding optical circuit technology that is difficult for others to imitate. The optical-component technology of the research laboratory to which I belong represents research results accumulated for half a century. With such a foundation, adding a little more value or doing something slightly different will lead to top-notch research results. (Of course, there have been many cases in which our approach has not worked.) We also have a full range of research facilities that are necessary for manufacturing, and such an environment is a huge advantage in regard to advancing device research. To put that another way, I believe that NTT researchers have the mission to develop the technologies that we have developed thus far and implement them in society. Through such efforts, we will be able to consolidate various technologies and create the direction of technology trends.

Of course, it is not possible to conduct research by only using the advantages of our laboratories; you need to create value on your own accord. One of the most important points that I keep in mind is to make sure that the limits of my imagination do not become the limits of my research. For example, the study of optical circuits deals with the natural phenomenon of "light." Natural phenomena are far beyond my imagination, and many unexpected things can happen. I think it is important to start your research with the mindset "It would be great if that happened" instead of "This is a natural phenomenon, so anything otherwise cannot happen." The design method shown in Fig. 1(b) was developed on the basis of this mindset. That is, by using light scattering, we can design optical circuits with desired characteristics. The conventional idea behind optical circuits is to minimize as much scattering as possible because scattering usually results in loss. Instead of adopting that mindset as a starting point, we devised the design method shown in the figure by first thinking about how to create an optical circuit with the desired characteristics. Even if you take this attitude, it does not mean it is always the right way; even so, I think that is okay. I believe that it is okay to make mistakes without hesitation because natural phenomena will correct our wrong ideas after we conduct calculations and experiments. Instead of thinking about what is correct, it is important to think hard about what you wish would happen.

First, let's consider the definition of a "good idea"

—What are some of the challenges you face as a researcher?

It is normal for research to go wrong and for researchers to struggle, so I tend to think positively and try to persevere. I think that has always been the case. My first research theme was hybrid optical integration of optical waveguides and semiconductor lasers, which is a technology for assembling optical components. Since such integration involved combining multiple optical components, it was necessary that all the components were aligned and fixed properly. At first, it looked like it would be easy to do it in my mind because it was like putting together building blocks; however, it did not go well, and I struggled for over a month. I researched the cause of the problem, thought about it thoroughly, and corrected it. When I was finally able to assemble all components properly, I let out a shout with tears swelled up, and I would have surprised anyone if they had been around. Although it may have been a minor success, I remember how happy I was to think that I was the first person in the world to know that I have achieved this.

Since having such experiences, I have come to believe that rather than just trying to do what you can do to break free of difficulties, it is better to face those difficulties and think carefully about them. To do that, it is important to be persistent in thinking things through and optimistic in finding the right way forward. If that approach still does not solve the problem, I try not to get stuck by changing my interpretations or assumptions and stay optimistic. For example, I try to find value and meaning in work that I dislike by viewing it from a different perspective. I believe that there is a lot to learn by doing so, and by expanding my work in this way, I will be able to meet more people and come into contact with a wider variety of ideas.

—Would you say a word to future generations of researchers?

I joined NTT and was assigned to a research laboratory, and since then I have been mostly engaged in R&D. Along the way, there were times when I did not know what I wanted to do as a researcher, and sometimes I felt that research was "just a job." More than 20 years have passed, and sometimes I look back on those early days. I feel that I have come to understand the joy of research a little more by going back to my original intentions and approaching my research from that standpoint. I think it is very effective to go back to your beginning from time to time to look at yourself objectively.

In the past, I have been asked by a young researcher about my ideas for finding research themes. I think that person was just trying to come up with a new research theme. I answered, "The idea itself is natural, and you will come up with some sort of idea soon," and I still wonder if that was good advice. Now, I think I would answer, "First, think about the definition of a 'good idea'." The definition of a good idea varies from person to person; for example, a good idea may be one that can make money from patents or can be cited in many other studies. My definition of a good idea is one that I like. If you deeply like an idea, you can discuss it with others with passion and can overcome difficulties to make it happen. If you define ideas in this way, I think it is important to think things through in your own way and have your own conviction, even if you cannot prove or explain the idea fully; in other words, believe in your ideas, without worrying about the results or what people around you think.

My message to young researchers would be that if you keep your original intentions in mind and passionately discuss good ideas with others, you will surely enjoy your research.

■ Interviewee profile

Toshikazu Hashimoto received a B.S. and M.S. in physics from Hokkaido University in 1991 and 1993. He joined NTT Photonics Laboratories in 1993 and has been researching hybrid integration of semiconductor lasers and photodiodes on silica-based PLCs and conducting theoretical research and primary experiments on the wavefront-matching method. He is a member of the Institute of Electronics, Information and Communication Engineers and the Physical Society of Japan.