R&D Spirits

Contributing to the Evolution of Wavelength Division Multiplexing through Silica-based Optical Waveguide Technology

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The silica-based optical waveguide is expected to be a key technology for rapidly expanding optical communication networks. To respond to advanced network needs predicted for the near future, NTT has been actively researching the practical application of devices using optical waveguide technology. We sat down with Hiroshi Takahashi, group leader of the Lightwave Circuit Research Group, to ask him about the state of optical waveguide technology, current issues, and international trends in this field.

Promoting research on the application of optical waveguides centered on AWG technology

—Dr. Takahashi, what is your current area of research?

In the Lightwave Circuit Research Group that I am currently leading, we are researching and developing planar lightwave circuits (PLCs) that use silica-based optical waveguides. This field encompasses a wide range of themes from fundamental to applied technologies, but the area that I am particularly involved in is arrayed waveguide grating (AWG) technology. An AWG is composed of a lot of waveguides created in a silica-glass cladding layer formed on the surface of a silicon substrate. It can be used to construct a wavelength multiplexer/demultiplexer that uses an optical interference effect to break up light like a prism (**Fig. 1**). This device is becoming indispensable to communication systems based on wavelength division multiplexing (WDM). In addition to research on the AWG itself, we are involved in the development of optical switches and other optical devices and in the integration of these circuits and devices. And recently, we have begun to research new optical circuits using NTT's original wavefront matching

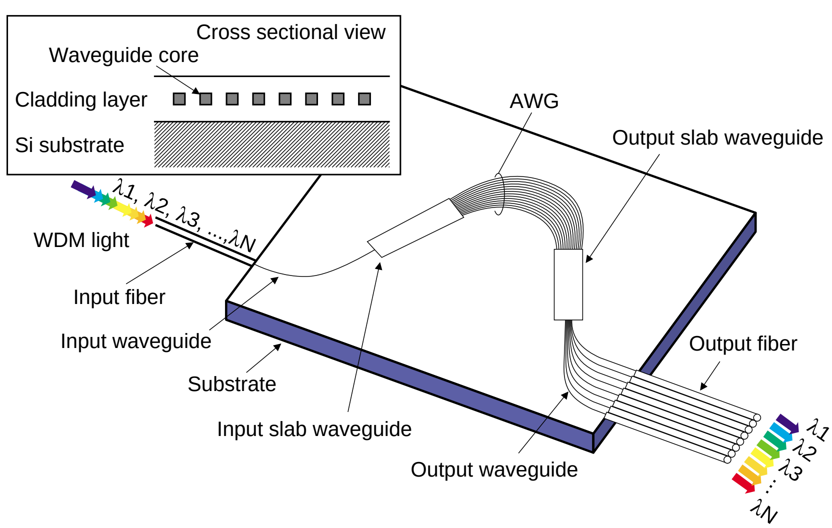

Fig. 1. AWG-type wavelength multiplexer/demultiplexer using PLC. Input light is demultiplexed into different outputs thank to the prism-like dispersion function of the AWG.

method for optical waveguide design.

Now, it may sound like all of this is being handled by just our group, but actually the research on silica-based optical waveguides at NTT is being pursued by three groups including ourselves. These three groups work closely with each other with some areas that even overlap. This makes for a relatively flexible R&D system, which is one of the features of NTT Laboratories.

—What are some key technical points in optical-waveguide research?

Silica-based optical waveguides exhibit excellent optical characteristics and reliability, and they can be used in practical applications. But I don't think they are a spectacular breakthrough as such. What I really find significant here is the selection by senior researchers of silica glass as the material for optical waveguides. Optical circuits are based on technology that forms a thin glass film on top of a silicon substrate. Silica is extremely reliable, as it has to be, given the need for optical fiber in actual communication networks to last more than 20 years without degradation. The use of the same material for both optical fiber and optical waveguides also leads to superb coupling efficiency. Needless to say, these features support the expansion of optical-waveguide research.

But looking to the future, if anything is to be considered a breakthrough, perhaps it's the wavefront matching method that I just mentioned [1]. This method was proposed by a young researcher in our laboratory. It's a computational scheme for creating the optimum shape for waveguides to enable light to pass in the most efficient manner possible. In the past, the only way to create waveguide patterns was by trial and error. The wavefront matching method, in contrast, enables an optimal core pattern to be automatically generated by first setting conditions and requirements and then performing inverse calculations. Because of this capability, the wavefront matching method has been attracting attention even at academic societies as a promising waveguide technology for the future (**Fig. 2**).

—What form do you think this technology will take three and five years down the road?

Our waveguide technology has already been deployed in optical-fiber communication networks where it is serving a very useful purpose for all of us.

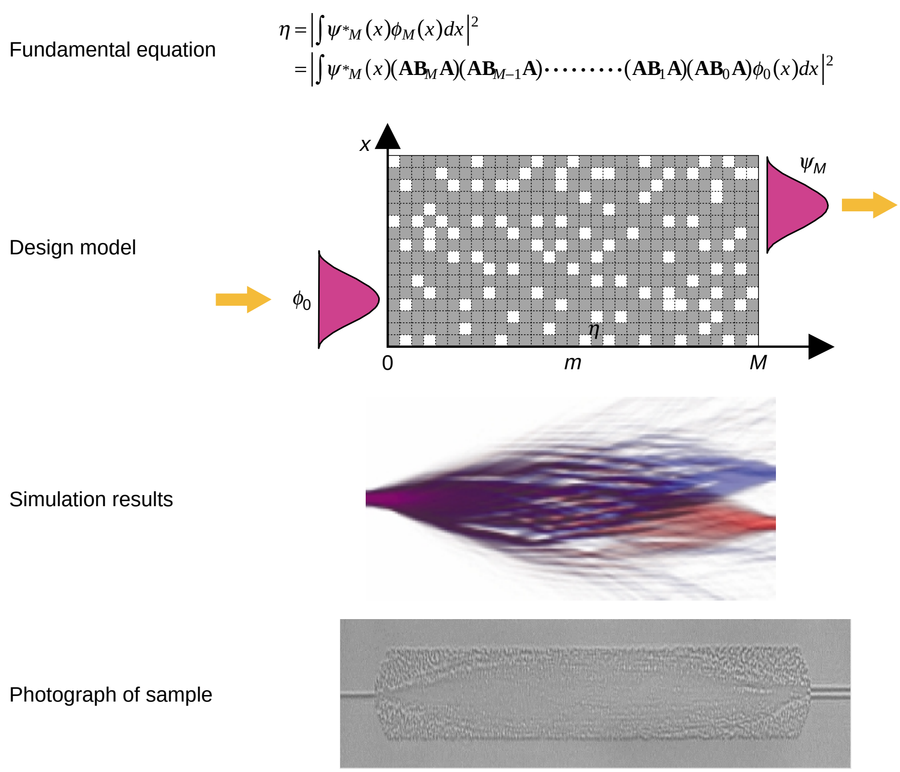

Fig. 2. Generation of waveguide pattern by wavefront matching method. A waveguide pattern is automatically designed by inverse-calculation for maximum η. The pattern shown in the picture can separate 1.3- and 1.5-µm lights.

For example, whenever you connect to the Internet and click on a link on the screen, the information that you request will pass through an AWG or optical switch that we created. But some technical issues still remain such as how to improve the operating characteristics. There is also an urgent need to lower costs because the range of applications of waveguide technology is expanding rapidly, from the trunk network to regional and access networks. It is therefore highly likely that research on enhancing this technology will make great strides in three or five years' time. And as I mentioned before, we are also moving forward on the R&D of new technology. I see no reason why we should not be able to develop and deploy novel optical circuits using the wavefront matching method.

—What do you see as future issues and how do you plan to deal with them?

The biggest issue, I believe, is integration. It is extremely important that various waveguide elements and devices be integrated so as to provide value-added products. This is because it is cheaper to prepare waveguides and optical switches together than to fabricate them separately. In addition, separately prepared devices require more space if they are to be interconnected by optical fiber. Integrating devices eliminates this requirement while making it easier to achieve a more compact product.

The problem here, however, is that the conditions for fabricating an optical waveguide differ slightly from one device to another. In other words, if we were to focus on the fabrication conditions that suit the characteristics of a certain circuit, the characteristics of another circuit might be hampered. Preparing multiple circuits on one silicon substrate therefore requires the control of very difficult fabrication conditions. Finding a way to overcome this hurdle is a major technical issue. To this end, we are working on solutions from both the fabrication and design perspectives.

Experiencing all phases of implementation from theoretical research to technology sales

—How did you become involved in your current line of research?

Well, AWG was the first research theme that I was assigned to on entering NTT, which was 18 years ago. At that time, there were great expectations for WDM, which was called a "dream transmission system." But on the other hand, user needs had not yet reached a point where such a system was actually needed. Against this background, I happened to receive a novel idea from one of my superiors, and I began to research it. To tell the truth, I did not know much about optics at the time, so I began to study optical principles and learn measurement methods, fabrication methods, and other techniques one by one with lots of hands-on experience. This is how my research progressed.

—What other research themes have you taken up?

For the first several years, I performed basic research on waveguides, as I just mentioned. I did not have access to sufficient facilities at the time, and I would sometimes construct measurement equipment on my own. "Ah, so this is research," I thought, and I became happily engaged in this work. In the end, I became one of the three researchers in the world credited with creating the AWG, a development that attracted much interest from around the world. The other two researchers worked at Bell Laboratories and Delft University of Technology in the Netherlands. Although we were all working on the same type of AWG, each of our prototypes was slightly different from the others, and I think that we were not so much rivals as researchers with a mutually respectful relationship. After completing my work with AWGs, I was assigned for two years to NTT Transmission Laboratories (now NTT Network Innovation Laboratories) for more training, and it was there that I began my research on WDM in earnest. I performed various system experiments using the AWG that I developed, and the experience that I gained there proved to be immensely useful in my later research.

Next, in 1995, with my research on AWG completed for the time being, it was time to tackle a new research theme. I became involved in research on lasers with external resonators, working alongside young researchers new to the company. At first glance, one would think that AWGs and external resonators have nothing in common, but that is not the case. Their basic substrate structures are actually the same. Consequently, thinking that I could study what for me was a new technology while, at the same time, making use of my AWG know-how, I selected this type of laser as my next research theme. However, just as I began to make progress in this research, WDM began to be deployed on a large scale, and I was rushed off to NTT Electronics (NEL), an NTT group company, where plans were being made to mass produce the AWG-type wavelength multiplexer/demultiplexer. There, I took on a variety of tasks to help put those plans into action.

I returned to NTT Laboratories in 2001 and again took up research on PLC-related topics. Although the theme was the same, various aspects of AWGs had, of course, evolved. In particular, the Mach-Zehnder-interferometer type of optical switch was under development. An optical switch, though using basically the same fabrication techniques as an AWG, can switch optical paths in a non-mechanical manner by utilizing the optical property that the transmission speed changes with temperature. While a mechanical optical switch can deteriorate due to defective parts or a buildup of dust, the PLC-based optical switch is completely immune to such problems—it is a highly reliable device. In addition, a matrix switch, which integrates many optical switches, holds much promise for the future as a device that can perform large-scale switching (**Fig. 3**). We have so far reached the 16 × 16 level of integration [2], but we are researching ways of integrating an even larger number of switches.

—Is there anything in your R&D career that has left a lasting impression on you?

In the sense of an invaluable experience, yes. My stay at NTT Electronics left a big impression on me. At that time, I did just about everything including product development, implementation of fabrication techniques, design, and technology sales. For example, in technology sales, I made the rounds of system vendors in North America in a rental car along with a representative from a partner trading company. I came to experience what it must be like to be a sales representative for a start-up company. Also, in connection with the actual delivery of products, I became involved with quality-control matters such as the inspection of packaging materials. This was, of course, somewhat different from my main line of work, but being able to experience with my own eyes the process of taking a product from the R&D stage to actual delivery was extremely worthwhile.

—Dr. Takahashi, what motivates you in R&D?

I would say "making something useful." I've had an interest in engineering-related things ever since I was a child, and I was a tech-oriented teenager that enjoyed building his own transistor radios. This interest expanded to electrical communication engineering, and at university, I researched measurement methods using ultrasound. This research was quite interesting, but in reality, I had a very strong desire to

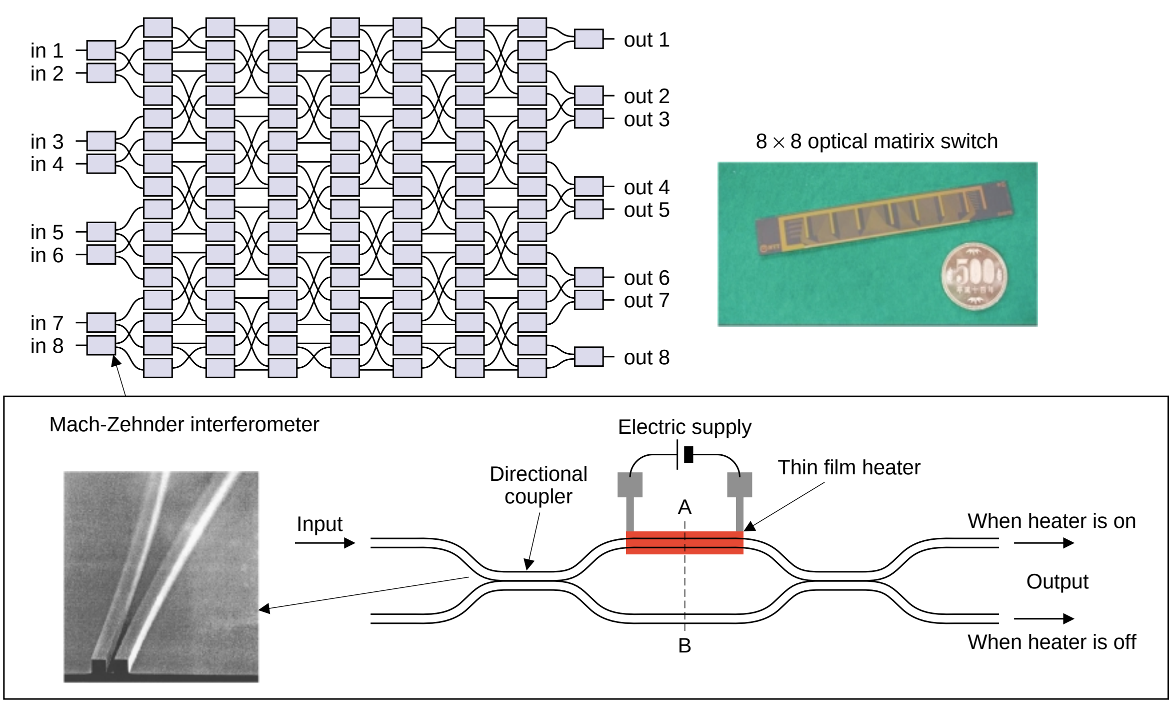

Fig. 3. Structure of a Mach-Zehnder-interferometer optical switch (8 × 8). The device divides input light along two optical waveguides and switches the output port according to the phase difference between the two signals after merging. A phase difference is generated by changing the temperature of a waveguide using a heater (on/off operation). Integrating a large number of these switches (as shown by the matrix switch in the upper left) leads to large-scale switching.

make things that could find widespread use in the outside world. Thus, when it came time to look for work, I decided on NTT, which was setting out to construct a new communication network using light, an electromagnetic wave expressed by the wave equation just like ultrasound, my major at university. Through all these years at NTT, I have held on to this desire to make optics-related things that are useful to society.

Participating in academic societies and other international activities as an authority on AWG

—What is the worldwide trend in waveguide research?

If anything, waveguide research is a field dominated by know-how as opposed to theory. At the same time, there has been little discussion at academic societies on fabrication techniques. Most research institutions, moreover, are conducting research on practical application of optical waveguides while simultaneously searching for future devices.

But with that said, I would like to point out here that waveguide research is not that busy at present compared with the past when many research institutions and communication-equipment and optical-component makers were actively researching optical waveguides in addition to NTT. Why is this? One reason is that the prices of optical devices dropped across the board after the bursting of the telecom bubble. In other words, to survive the resulting low-cost competition, it was better for a company to purchase finished products than to pursue R&D. At the same time, surviving makers have manufacturing departments in addition to research departments and it is easy for them to commercialize such devices. Furthermore, the large-scale makers carry out production in China, Taiwan, and elsewhere where labor costs are much lower than in Japan, so that it is rather difficult to beat them in a price competition. However, NTT's waveguide technology, if I may say so, is the most advanced in the world at the fundamental level, and I can feel a shift toward R&D that is oriented to winning through superb functions and characteristics rather than competing in the war of attrition for cost reduction.

—Are you collaborating with other companies or research institutions?

As far as makers are concerned, there are hardly any cooperative projects since they are basically our competitors. But with NTT Electronics, the major equipment maker in the NTT Group, it goes without saying that we have a close working relationship. We also engage in joint research with universities from time to time, and as they are academic institutions, the content of that research often deals with the search for future research themes dealing, for example, with design methods and materials as opposed to fabrication techniques.

—What kind of response have you received to your research achievements to date?

Well, first of all, as one of the first researchers to create an AWG, my name is known in the field of waveguide research. In fact, some people familiar with my papers knew my name long before meeting me. As a result, I am sometimes invited to speak. For example, last year, I attended meetings of the IEEE Lasers and Electro-Optics Society (LEOS) and Optical Fiber Communications (OFC). And several years ago, I was asked by a university professor to discuss this field with his students. There are also overseas students that have sent me their doctoral theses. This kind of response is a real pleasure for me, and holding discussions with a variety of people is quite stimulating. Talking with many researchers and students in this manner is one thing that I truly look forward to when traveling overseas.

—Could you tell us about your activities at academic societies and elsewhere?

In Japan, I served as secretary of the Technical Committee on Opto-Electronics at the Institute of Electronics, Information and Communication Engineers up until May of this year. And overseas, I am serving on the 2007 program committee at OFC, the largest international conference in the field of optical communications.

—Based on your international experiences, how do you think NTT is viewed from overseas?

There is a true sense of NTT as a top runner in the optical-device field. For example, there are many NTT researchers serving as directors of academic societies, and there are many member of societies that say things like "NTT always makes top-quality things." But this praise includes expectations of further progress, and it won't do to simply be satisfied with words of praise. I want to meet those expectations by making full use of NTT's strengths to develop novel products like a totally new type of circuit.

Asking young researchers to think creatively and challenge themselves daily

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

Competition in the AWG market is severe, and no matter how you look at it, current research in the field is leaning toward fabrication techniques. I cannot deny the feeling that there is a slight disparity between this and the true meaning of "research." Of course, R&D with the aim of beating the competition is a prime mission of a research laboratory that is part of a private enterprise. But charging ahead on that mission alone hinders creativity in research. It is therefore my desire from here on to create a balance between research on fabrication techniques and basic research. I would like to concentrate my efforts on new circuits and new design techniques. I also think that the cultivation of application fields for our technology is very important. It's too early to discuss specifics, but in broad terms, I am thinking about using waveguides to achieve devices that are conventionally configured with elements other than waveguides.

—What is your ultimate dream as a researcher?

I really don't think that far ahead. I would rather devote all my energies to what I see in front of me in the present!

—What is it like working at NTT Laboratories for you personally?

NTT Laboratories is a place where I can put my skills to work. It's a great environment from both a human and material perspective. It has a deep understanding of research that enables researchers to engage in world-class research. Applying my own ideas to produce something that the world has never seen before is what makes R&D interesting. And a researcher is certainly blessed if that something proves to be useful to society. NTT Laboratories can make me feel that way. It's a workplace that can make a researcher feel very worthwhile to society.

—Dr. Takahashi, could you leave us with a message for young researchers?

Of course. First of all, please get into the habit of thinking freely about all kinds of things. Practice "brainstorming" inside your head and check out for yourself anything that attracts your interest. Then, if you believe it to be promising idea, try testing it with an experiment. In short, create small challenges for yourself on an everyday basis. I've recently noticed that young people, for some reason, are not very aggressive in their pursuits. When I ask university professors that I meet at research meetings about this, they tell me that students are quite serious about the work assigned to them but rarely challenge themselves to achieve bigger and better things. If you only take up themes that you are given, you will prevent any possibilities that you encounter from taking root and blossoming. That is a big danger. Perhaps this problem can be traced to the present trend in society of relying on sure results to avoid failure. Nevertheless, I would ask you to challenge yourself to come up with new ideas. You'll never know what research theme is the right one for you if you don't follow up on your ideas. If your ideas are regarded as simply a delusion, don't let that bother you. By all means, think for yourself and challenge yourself often, even in small ways. Give yourself great expectations!

References

[1] H. Takahashi, T. Saida, Y. Sakamaki, and T. Hashimoto, "Novel Optical Waveguide Design Based on Wavefront Matching Method," NTT Technical Review, Vol. 4, No. 2, pp. 54-59, 2006.

[2] H. Takahashi, T. Watanabe, T. Goh, S. Sohma, and T. Takahashi, "PLC Optical Switch that Enhances the Optical Communication Network," NTT Technical Review, Vol. 3, No. 7, pp. 17-21, 2005.

Interviewee profile

■ Career highlights

Hiroshi Takahashi received the B.E. and M.E. degrees in electrical engineering and the Ph.D. degree for research on arrayed waveguide grating wavelength multiplexers from Tohoku University, Miyagi, in 1986, 1988, and 1997, respectively. Since joining NTT Laboratories in 1988, he has been engaged in research on the design and fabrication of silica-based optical waveguide devices including wavelength multiplexers, optical switches, and WDM transmission systems. He is interested in the creation of new functional optical devices based on PLC technology. He received the NTT President's Award from NTT in 2000, National Invention Award from the Ministry of Economy, Trade and Industry in 2000, and the Electronics Letter Premium Award from the Institution of Electrical Engineers in 1997. He wrote parts of the Encyclopedic Handbook of Integrated Optics (Taylor & Francis). He is a member of IEEE, the Institute of Electronics, Information and Communication Engineers of Japan, and the Japan Society of Applied Physics.