Front-line Researchers

Research Is Never Complete—It Will Finish When You Are Satisfied

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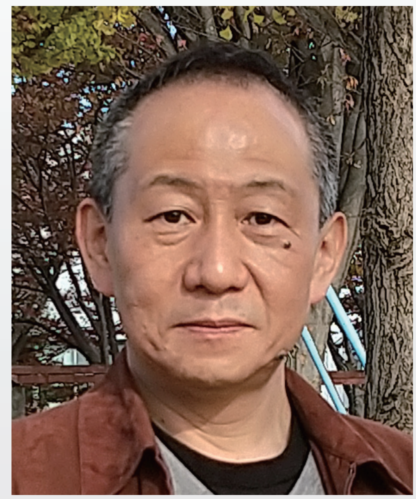


Abstract

To address the ever-increasing data-transmission capacity, it is necessary to develop technology that can increase such capacity 100 to 1000 times or more in the future. To meet this need, research on multi-core optical fibers is being conducted worldwide. Senior Distinguished Researcher Kazuhide Nakajima has developed multi-core optical fibers with transmission capacity more than 100 times greater than that of current optical fibers and the world's highest spatial-utilization efficiency and won top honors at a prestigious international conference. We interviewed him about the progress of his research and the attitude of a researcher aiming to achieve world firsts.

Keywords: multi-core optical fiber, space-division multiplexing, international standardization

Research and development of optical-fiber technologies that support continued development of optical-communication infrastructure

—Could you give us an overview of the research you are conducting and the activities you are involved in?

I'm involved in the research and development (R&D) of optical-fiber technologies that support continued development of optical-communication infrastructure that connects all types of people, things, and events. As traffic in core and submarine networks is expected to further increase, the current single-mode optical fibers will reach the limit of their transmission capacity, so technologies for higher transmission capacity will be required. Higher transmission capacity can be achieved by combining two technologies: for multiplexing and transmitting multiple laser beams and for increasing the number of cores (which are optical paths) in a single optical fiber. Working closely with related groups inside and outside NTT laboratories, we are researching and developing optical fibers having multiple cores in one optical fiber (i.e., *multi-core optical fiber*) for space-division-multiplexing (SDM) transmission. We are working on increasing the number of spatial channels and spatial-multiplexing density while fusing SDM optical-amplification technology and optical-control technology for transmission media. As we aim to implement these technologies, we are also researching and developing an innovative cabling technique that maximizes the characteristics of SDM optical fibers (**Fig. 1**).

Although we have developed optical fibers for

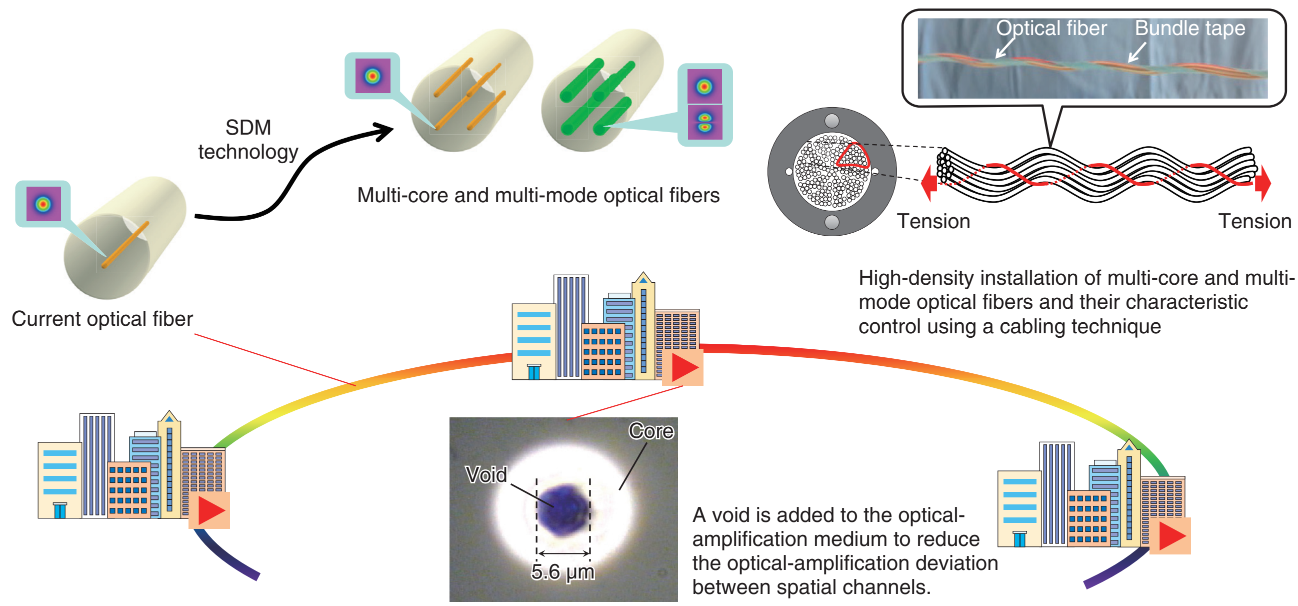


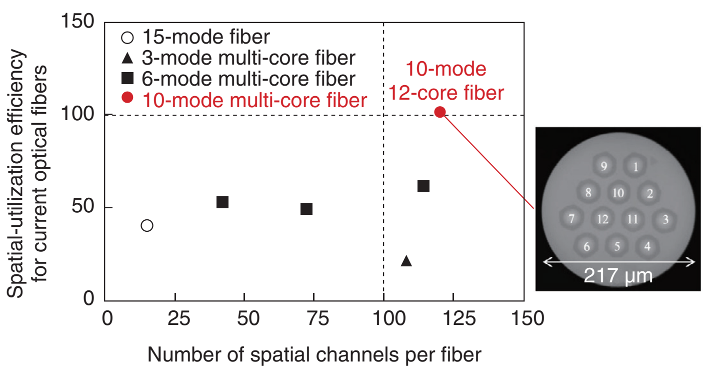
Fig. 1. Research on optical fibers for achieving SDM transmission.

increasing the speed and capacity of networks, such fibers can be used in other areas besides communications. The refractive index in an optical fiber slightly changes with a bending. External sound and vibration also cause a tiny change in the refractive index, and that results in the amplitude and phase variation in the scattered light in the optical fiber. Exploiting these characteristics would make it possible to use optical-fiber cables as sensors installed throughout society. Optical-fiber environmental-monitoring technology, which uses optical fibers as sensors, is expected to help address social issues such as managing facilities and predicting the deterioration of infrastructure (such as electric power, gas, water, and railways), understanding disaster situations, forecasting disasters on the basis of river and ground information, and providing city information such as traffic volume and traffic-jam forecast and weather forecasts. We are working on this new-value creation from the perspective of optical-fiber technology as one of our themes.

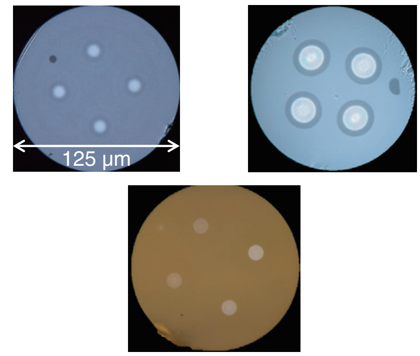
I am also involved in activities related to the international standardization of optical-fiber technology as my life's work. Once optical-communication infrastructure is installed, it cannot be easily changed or upgraded. For R&D of optical-communication infrastructure, therefore, it is essential to develop and introduce new technologies that are compatible with current technologies. This is a common issue worldwide, and international standardization is essential to ensure that optical-fiber networks around the world are interconnected. Therefore, I have participated in the discussions at the International Telecommunication Union - Telecommunication Standardization Sector (ITU-T), and since 2009, been leading discussions on international standardization of optical-fiber technology by serving as the chair (rapporteur) of the working group.

—All of these research activities are significantly contributing to society. To what specific level has your research progressed?

For about the past 10 years, we have been making world-leading achievements in the field of multi-core optical fibers, which has become a global trend. In 2017, by arranging 19 cores capable of 6-mode (channel) propagation in a cross-section of an optical fiber with a diameter less than 250 µm, we succeeded in arranging 114 spatial channels per fiber and creating a world-class ultrahigh-capacity-transmission optical fiber with mechanical reliability equivalent to that of current optical fibers. In 2018, we designed and prototyped a 10-mode, 12-core optical fiber as the world's highest-density SDM optical fiber. This fiber has more than 100 times the potential of current optical fibers in terms of both the amount of spatial multiplexing and spatial-utilization efficiency (spatial multiplexing per unit cross-sectional area) (**Fig. 2**).



World's highest number of spatial-multiplexing (12 cores x 10 modes = 120) multi-core multi-mode optical fibers



Multi-core optical fiber with the same diameter as current optical fibers
Transmission characteristics equivalent to those of current optical fibers for short- to 10,000-km-class long-distance transmission

Fig. 2.   Example study on a multi-core multi-mode optical fiber.

As the number of cores increases, the diameter of the optical fiber increases. The aforementioned diameter of 250 µm is almost twice that of current optical fibers, which reduces manufacturing efficiency. Given this drawback, we have also been attempting to increase the transmission capacity by fabricating multi-core optical fibers maintaining the same diameter as current optical fibers. Although further studies on, for example, mass production and connectivity, are needed for practical application of multi-core optical fibers, we have reported our research results concerning such fibers having excellent compatibility with current communication facilities and devices and can be applied to short- to 10,000-km-class long-distance transmission. As a result, we received prestigious awards, including the best paper award at the OECC (Optoelectronics and Communications Conference) in 2019.

Toward the implementation of the Innovative Optical and Wireless Network (IOWN), we aim to establish technology for four-core multi-core optical fibers having the same properties as current optical fibers by 2025. Then, by 2030, we hope to achieve a transmission capacity 125 times higher than current optical fibers by combining multi-mode and advanced optical-transmission technologies. Furthermore, we want to create the ultimate high-capacity-transmission optical fiber by integrating the holey fiber technology that we have been investigating.

Research themes can be found through hands-on experience

—Please tell us what you have been trying to do as a researcher.

What I have found to be very important and cherish is to approach various sources of information, such as papers and conference presentations, to find topics that interest me. Due to the COVID-19 pandemic, however, I get fewer opportunities for face-to-face discussions at conferences and fewer opportunities to stand around and chat during breaks, so I rely on email exchanges for stimulation. Through these exchanges, as well as by reading papers, I'm inspired by the research activities and perspectives of other researchers. Unfortunately, during online conferences and meetings, we are often momentarily distracted by the immediate tasks at hand and objects around our computers, missing out on important stimuli. Therefore, direct and on-site activities are the best.

One of the most important skills for researchers is the ability to determine what to aim for and what to investigate. To develop that skill, I have been trying to be aware of new things and challenge myself little by little. If you don't have enough flexibility, you can't come up with new ideas; therefore, I have been conscious of having enough flexibility to try and do a few different things, even if they seem useless at first.

From the lessons I learned above, I realize that investigating with your hands has the greatest benefit for researchers. This hands-on experience is very important because research themes and discoveries can be found in things that feel a little strange or uncomfortable.

Having been with NTT for 28 years, I have been working exclusively with optical fibers. The optical fibers in use today are outstanding and well designed, and optical-fiber technology has already been established in a sense. We have experienced an era in which we thought that we didn't need to pursue it any further. Nevertheless, from my many years of experience and intuition based on hands-on experience, I thought that optical-fiber technology would reach a limit, so I decided to pursue high transmission capacity. As it turns out, this prediction became a reality.

—What have you been keeping in mind regarding your research activities over the past 28 years?

Although I have been sticking to R&D on optical-fiber technology for communications, during my research activities, I have been keeping in mind the sense of "by-product," which means using the technology for other purposes. A little awareness and inspiration will gradually come to you if you are keeping it in mind. An NTT retiree, who was my senior concerning international-standardization activities, once told me, "Seize any opportunity by the back of the neck." Although Leonardo da Vinci said, "Seize fortune by the forelock," my senior used the phrase "the back of the neck." I felt the nuance in those words; that is, instead of constantly thinking about something, just somehow keep it in the corner of your mind and keep contact with it.

I often find that new ideas come to me at unexpected times, such as while eating or taking a bath. By keeping a research topic in a corner of your mind, you can find inspiration in a moment of everyday life. I feel this approach is connected to what I said earlier about ideas being born from flexibility by trying not to reduce too much waste. This approach especially works when you are conducting experiments, so if you are curious about something during an experiment, don't think of it as a detour, but find the time to investigate it. I feel that if you neglect this approach, your research will taper off. I want you to look at research activities from the viewpoints of a bug (micro), bird (macro), and fish (trend). Since we are working as a group, it would be best to leave the role of the bird's eye view to researchers who are somewhat senior and let the younger ones pursue their research with bug's eye view.

I was taught by my teachers and mentors that I was free to make proposals. I was always told that I should not think that I should not make proposals because I was a subordinate; rather, I should be involved in discussion by making proposals. I made an effort to think while listening to the experts and leaders in my group, and such discussions I had with them helped me a lot. Therefore, please try to make proposals and be engaged in discussions.

Have a strong sense of autonomy even though you are part of a team

—Such discussions with seniors and peers are unique to team-based research activities.

One of the major advantages of working in a team is that you can listen to the various opinions of your fellow team members. However, the division of tasks in the team sometimes becomes unclear, and that situation must be avoided. For instance, if it is not clear in regard to who is to be in charge of submitting a paper to a conference, you may not be able to be proactive or involved. Such autonomy is one of the attitudes that I hope young researchers will have as members of a team. Don't accept the results and numbers that come out of calculations or experiments without questioning. That is, originality lies in the perspective from which such results are examined, which will demonstrate your autonomy. Therefore, be extra aware of that fact.

I also believe that the key to pursuing originality and becoming a researcher with autonomy is to have interests and curiosity. Conducting an experiment just because your senior told you to do so indicates lack of interest and involvement. What researchers are required to do is not do what they are told to do; rather, interpret and process results while finding interest in what comes out. I think that is the most important requirement.

When I was younger, the group leader of an experiment that I was involved in would often return my reports back to me and say, "Look at it from various directions, up, down, left, right." It is quite difficult to interpret an experiment, but if you look at it from different directions then interpret it, you will discover something unexpected. Having said that, I still sometimes conduct an experiment without knowing what is going on, so I understand the feelings of young researchers. Also, like many of young researchers, I have experienced the feeling of shock by being told "no" by my seniors, so we seniors try our best not to say "no." Young researchers should keep trying and think that they are lucky if they have one success in ten tries.

—So young researchers are supported by this kind of encouragement from their seniors.

I believe that it is very important for researchers to be able to talk about their vision and directions—even if they belong to an organization. I joined NTT because I admired the mission of the Nippon Telegraph and Telephone Public Corporation, which was to widely spread information. I believe that it is of significance of delivering information via the transmission medium, i.e., optical fiber, and I want optical fibers to have a great impact on the people who use them. I hope that young researchers will have their own vision and directions.

Once again, I urge young researchers to conduct their research activities with a strong awareness of making proposals. Making proposals can be interesting. Even if one's proposal is rejected, I believe that pursuing the reasons for the rejection is one of the most exciting aspects of research. I'd like researchers to take pride in being the ones who are most familiar with the themes they are working on in their area—theoretically as well as experimentally—through their sweat, determination, and hands-on approach.

In my 28 years as a researcher, I have been able to get the bending loss-insensitive optical fiber we studied to be used, even if only partially, in NTT's network during the expansion of fiber-to-the home network. Unfortunately, since our seniors developed the optical fiber used in today's network, new optical fiber that surpasses it has not been introduced on a large scale. Even so, I remember being really happy that we were able to contribute to society, even if only partially. This experience has changed my mindset from pursuing research just because I'm curious about it to because it is useful to society. It also helped me develop a sense of by-product; that optical fibers could be used for purposes other than communications. I think that we now have a good opportunity to have such a mindset because IOWN has been announced and people are paying attention to information and communication technology, such as artificial intelligence and Internet of Things, and its peripheral fields.

Research is probably never complete. It will finish when you are satisfied. I think of it as a sound approach to think that research can last a lifetime. With that in mind, I want to continue to pursue optical-fiber technologies that connect all types of people, things, and events—through both R&D and international standardization—to support continuous development of optical-fiber networks.

■ Interviewee profile

Kazuhide Nakajima received an M.S. and Ph.D. in electrical engineering from Nihon University, Chiba, in 1994 and 2005. In 1994, he joined NTT Access Network Service Systems Laboratories, where he has been engaged in research on optical-fiber design and related measurement techniques. He is currently a senior distinguished researcher and group leader of NTT Access Network Service Systems Laboratories. He has been acting as a rapporteur of Question 5 of the ITU-T Study Group 15 since 2009. He is a member of the Institute of Electrical and Electronics Engineers (IEEE), Optica (formerly OSA), the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan and the Japan Society of Applied Physics (JSAP).