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Optical Physics

from Keio's Faculty of Science and Technology

Observing and controlling new physical properties being opened up by terahertz-wave technology

Shinichi Watanabe

Associate Professor
Department of Physics

Associate Professor Shinichi Watanabe is featured in this issue, whose field of research focuses on observing and controlling physical properties by means of terahertz light.

Investigating physical properties of condensed matters using light and controlling their properties

Observation and control of new physical properties being opened up by terahertz-wave technology

For a long time, humankind has used light with different frequencies (wavenumbers) to observe objects and change physical properties of things to improve living by harnessing electrical energy converted from light energy. In this context, coming into focus of attention is "terahertz light" that has longer wavelengths than visible light. We asked Associate Professor Shinichi Watanabe, a research specialist in THz spectroscopy about the terahertz-wave technology forefront.

What is terahertz light?

Light is indispensable for examining physical properties of things and for transforming such properties. Research based on light has developed in tandem with the development of technology to the extent that it is now contributing even to elucidating the origin of the universe – one of the greatest mysteries for humankind. Of the various kinds of light as a tool, terahertz light ("tera" signifies 10 raised to the power of 12) strongly comes into the limelight. Focused on studies based on terahertz light, Dr. Watanabe explains its advantages as follows:

"Terahertz light has extremely long wavelength, its frequency being 1/100 to 1/1000 that of visible light. Since light having a high frequency (wavelength is short) like X-ray has greater energy, we can say that terahertz light is light with a low level of energy.

The fact that its energy is extremely lower than that of X-rays means that terahertz light has significantly less adverse impact on the human body. This is why expectations are high for terahertz light as "safe light."

You can also say that examining physical properties of things is investigating their energy structure. For example, when attempting to examine low-energy objects like a superconductor, use of terahertz light is the only way to see it directly. In other words, each type of light has its specialty fields of application."

Moreover, terahertz light is very useful for penetrating materials, such as clothing, plastic packages and paper that do not transmit visible light. As such, much is expected of terahertz light for application to virtually all industrial fields – security check, semiconductor product inspection, non-destructive testing (on buildings, etc.), medical care and pharmaceutical development, to name a few. The study of terahertz light had remained unexplored until recently partly because the light can be absorbed with water and partly because it had been difficult to generate this light efficiently.

Dr. Watanabe continues: "An intriguing aspect of terahertz light is that its slow vibration allows us to observe its waveform (flying through the air) as is. I'm interested in both seeing physical properties of things and manipulating them. So it's very exciting to be able to see firsthand what's going on the moment light strikes an object and how they interact with each other. Due to its extremely low frequency, terahertz light also has properties very similar to radio waves. This makes it possible to produce similar effects – effects that could be obtained when an electric or magnetic field is given – without attaching an electrode to the object concerned. This is truly intriguing."

By having both the radio wave-like property of transmitting a variety of substances together with the property of travelling straight like visible light, terahertz light covers a wide range of measurement objects. This is the greatest characteristic of terahertz light.

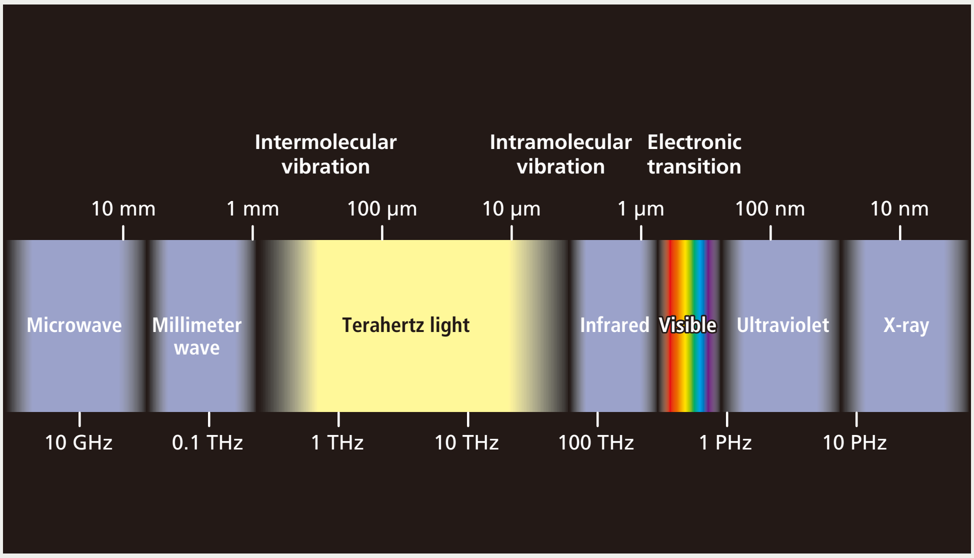


Fig. 1
What is terahertz light?
Its frequency centered around 10^{12} Hz, terahertz light has wavelengths 100 to 1,000 times longer than those of visible light and, as such, it is positioned at the border between radio waves and light waves. Having long wavelengths means its photon energy is low, which makes it possible for us to examine low-energy structures such as superconducting gap and intermolecular vibration.

Applying “terahertz time-domain spectroscopy”

The Watanabe lab currently employs a method known as the “terahertz time-domain spectroscopy.” By mixing long-wavelength “terahertz light” and short-wavelength “near-infrared light pulse” in a transparent substance known as the “nonlinear optical crystal,” this method allows us to identify terahertz light waveforms just like an oscilloscope (a waveform measuring device used to observe behavior of electrical signals).

He states: “In optical physics, we usually examine an object’s energy structure by exposing an object to light and determining how much the intensity of its reflected light or transmitted light has decreased. In addition to determining changes in light intensity, “terahertz time-domain spectroscopy” also allows us to stagger the timing of near-infrared light pulse irradiation. Thus we can obtain double amount of information – changes in “amplitude” and “phase” of light waves.”

Furthermore, by exercising additional ingenuity on this method, the Watanabe lab has succeeded in accurately measuring information relating to “polarization” in addition to amplitude and phase. By rotating at a high speed the semiconductor crystal for the terahertz pulse detection at a prescribed angular velocity, it has become possible to determine the magnitude and direction of terahertz light’s electric field vector simultaneously. Thus, we are now able to accurately analyze the direction of reflected wave vector component.

Highly sophisticated calculation had been required to analyze signals resulting from semiconductor crystal rotation. But Mr. Naoya Yasumatsu, then a senior, completed the task after struggling with enormous amount of calculation involved.

“This method made it possible to accurately measure the direction of electric field vectors (at a given time) of terahertz-wave pulse light irradiated from two points of different height, leading us to perform highly accurate testing on the contour and surface roughness of metallic objects. As a result, we became able to distinguish unevenness down to the depth of one-thousandth of the wavelength. This achievement was publicized on the American Optical Society’s ‘Optics Letters’ (online bulletin board version).”

Highly motivated, Dr. Watanabe said that he would like to expand application of this method even to the short-wave domains of infrared and visible light.

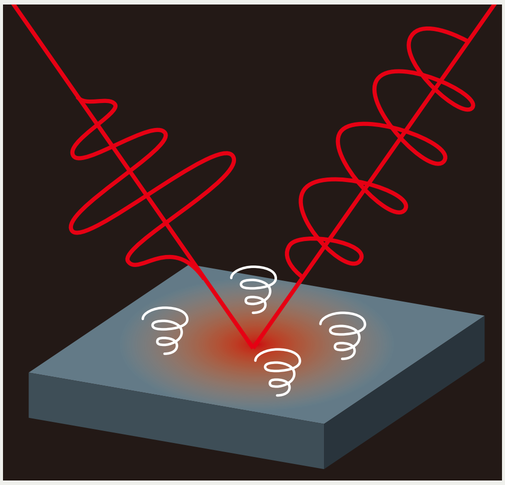


Fig. 2 Measurement of optical electric field vector waveforms

The Watanabe lab can display on monitor screen terahertz light’s electric field vector waveforms, just in a manner that you observe electrical signals on an oscilloscope. Adding information on “polarization” to “amplitude” and “phase” enables us not only to observe an object’s contour more in detail but also to examine what’s going on inside it, such as electron spin behavior and vibration of crystal lattice.

Transforming physical properties using terahertz light with large vibration amplitude

Dr. Watanabe’s research themes also include attempts to transform physical properties of an object by irradiating it with terahertz light with large vibration amplitude.

He continues: “Intrinsically, energy comparable to that of visible light is required to excite (to transfer from the ground state to the high-energy state) electrons in a semiconductor. However, terahertz light can do the same if we make its vibration amplitude extremely larger. What’s more, the great thing about terahertz light is that its waveforms are visible, which allows us to closely observe how the state of electrons changes and at which point of time.

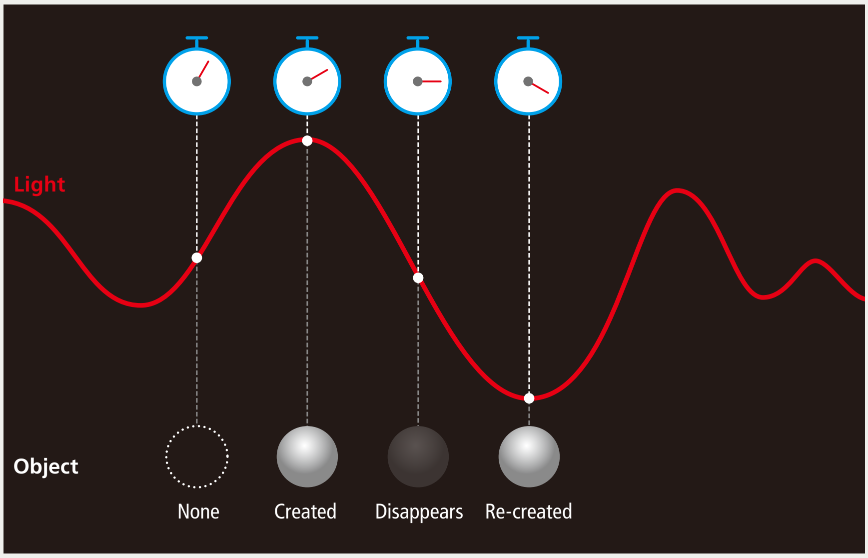
Since the frequency of terahertz light is close to the vibration resonance frequency of lattices that constitute an object, it is relatively easy to cause resonance. By swaying the lattice greatly, we can also expect to cause a structural change to the object. We are thus able to change physical properties of objects as desired, which is expected to lead to diverse applications to new physical sciences. I’m highly motivated to establish innovative methods for controlling physical properties of things.”

We would like to keep our eye on the development of terahertz light – a field of study with great potential.

(Reporter & text writer : Madoka Tainaka)

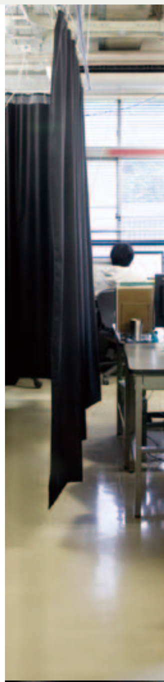
Fig. 3 Looking into physical phenomena that occur within one cycle of light wave

When an object is irradiated with light, what interaction between light and the object occurs within an ultimately short time scale? This is an intriguing aspect of optical physics. When ultra-short pulse laser, which has an extremely short pulse time width, is combined with the terahertz light generation technology, irradiation of an object with terahertz light elucidates in detail about new physical phenomena: for example, the point of time at which the electrons in the object are created or disappear.



Aiming to produce world-leading research achievements, driven by the passion "I wish to shed light on the truth behind things"

An encounter with one book completely changed the life of a boy who had disliked science. Highlighting warm-hearted research scientists dedicated to the pursuit of truth, the book deeply inspired the boy and changed his course of life into becoming a researcher himself. Striving in the highly competitive world of researchers, Dr. Watanabe could broaden and accumulate knowledge about how great scientists of the past as well as those researchers he had met while studying abroad identified their research themes and pursued their studies. Dr. Watanabe says that this knowledge has been very useful in guiding his life to this day.



What was your childhood like?

I was born as the first boy of self-employed parents engaging in electrical work business. As such, word processors and PCs were always around me in my childhood. This family environment naturally led me to take interest in computer programming.

Did you like studying?

Up to my high school days, I liked mathematics and world history but science was my weak point. Science is a subject handling natural phenomena that are complex as well as diverse. As opposed to the purely logical world of mathematics, science involved things still remaining unexplained; this is why I felt some "suspicion" about explanations provided in the science textbook. The science textbook also contained sections to be learned by heart, which seemed dry and dull to me.

As a third-year high school student, however, I happened to read a book entitled "From X-rays to Quarks" which I borrowed at a nearby public library. After reading it, I suddenly became fond of physics. The book was a fascinating account of how "Quantum Mechanics" – that great academic framework representative of the 20th century – came into being. Each and every physicist who appeared in the book was full of individuality and full of human traits. I really wanted to make friends and work with these physicists at some point in the future.

After entering the University of Tokyo, you chose the Department of Physics as a junior, is that right?

Yes. There were so many bright students around me and I was happy being able to study together with these excellent students. On the other hand, I was obsessed by a feeling that I wouldn't be able to survive in this competitive world as a professional if I did the same thing as them.

I made up my mind to study device physics at the graduate school whereas many others chose to major in particle physics or space physics. So, I advanced to the Institute for Solid State Physics at the University of Tokyo Kashiwa (Chiba Pref.) campus. Then, as a postdoctoral fellow, I went abroad to study at the Swiss Federal Institute of Technology (EPFL). In this way, I've been trying to walk a unique path of my own.

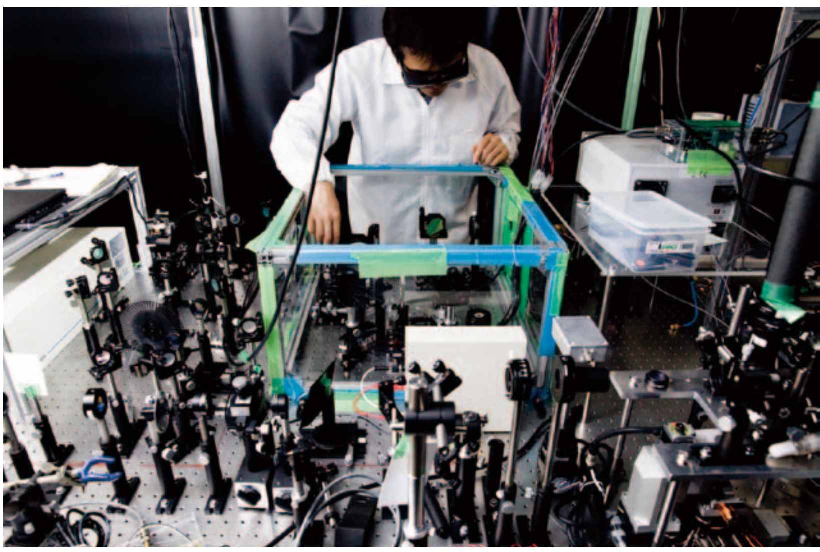
To tell the truth, I was at a loss which department to choose, the Department of Physics or Department of Applied Physics. This was because I was somewhat interested in a study that could be applied to the needs of the real world. On the other hand, I found in myself a persistent passion "I wish to shed light on the truth behind things." After hovering this way or that, I decided to choose the Department of Physics. It was in those days that I encountered "Optics." What attracted my interest in particular were research achievements of Dennis Gabor who had won the Nobel Prize for the invention of holography. This gave me strong motivation to become a researcher like Dennis Gabor, so I finally chose the study of optical science.

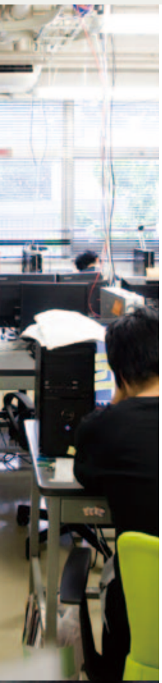
At the Institute for Solid State Physics, I studied fundamental physics of semiconductor laser structure under Associate Professor Hidefumi Akiyama.

I went to Switzerland to study not merely to learn measurement but also the "making of things" as well. Under the guidance of Professor Eli Kapon, I was able to participate in the manufacture of quantum dot of the world's highest quality, which was a truly valuable experience. It also remains a pleasant memory because I could work together with a number of highly individual postdoctoral fellows from many parts of the world.

Then I belonged to Professor Ryo Shimano's lab at the University of Tokyo Graduate School as a research associate, where I took up "condensed matter physics based on terahertz radiation" that led to my current main research theme.

In this manner, I was blessed with valuable opportunities to accumulate experiences – in both "optical measurement" and





I'd like my students to broaden their views of the world by actively gaining a variety of experiences.

Shinichi Watanabe

Born in Tokyo in 1974, Dr. Watanabe graduated from the University of Tokyo, Faculty of Science, Department of Physics in 1997. In 1999, he completed the master's course at the University of Tokyo, Graduate School of Science (Akiyama lab, the Institute for Solid State Physics). In 2002, he completed the doctoral course at the University of Tokyo, Graduate School of Science (Akiyama lab, the Institute for Solid State Physics). Doctor of Science. Then he successively served as a research fellow of the Japan Society for the Promotion of Science (JSPS), a research fellow of the JSPS Postdoctoral Fellowship for Research Abroad, a postdoctoral fellow of Swiss Federal Institute of Technology, a research associate for the University of Tokyo, Faculty of Science, Department of Physics (Shimano lab). In 2011, he assumed the current position as an associate professor at the Department of Physics, Keio University Faculty of Science and Technology.

"sample preparation" – at these world-leading labs, which has proved to be a great asset for me as a researcher.

Setting the course of study and identifying suitable study themes as a researcher is an exhaustive task, isn't it?

Given the highly competitive world of researchers, I'm always thinking about how I can survive the competition. In this sense, it's my policy not to take up themes that are "in fashion." If you jump at a theme "in fashion," you will eventually find yourself nowhere in terms of achievements. That said, it's true that "terahertz light" is "in fashion today." I know my remark sounds a bit contradictory. Yet, I can say I'm pursuing original research from my own unique approach.

By the way, at the Keio University Department of Physics, "reading original texts and making presentation" (students are required to read original papers in English – from every age and everywhere – and express their comments) is a compulsory subject for seniors. In this class, I join my students to learn how famous researchers of the past opened up their fields of study using their own strategies. To produce new ideas and approaches necessary for promoting research activities, following the footsteps of great figures of the past is the best shortcut. As such, I'm striving daily to produce breakthrough research achievements while learning strategies taken by our great predecessors.

What kind of research are you going to target in the future?

I believe that natural phenomena, though apparently complex, can be broken down into simple elements that could be explained by theories. I'd like to become the world's first to bring such "easy-to-understand theories" to light.

To refine and enhance experimental techniques is the best way to shed light on yet-to-be defined truths. Because experimental results contain a lot of clues to untangle complex natural phenomena, it's very exciting to use these clues to solve puzzles.

I'd like to continue to meet the challenge of yet-to-be-defined physical property problems taking advantage of our world's top-class techniques.

How are you spending your free time?

From junior high school days up to now, I have been an active member of an amateur brass band, playing the tuba.

Many of my favorite pieces of music are marches. Many of them, for which I play the tuba, are simple yet moving. It's fun. I like things simple just as I do when it comes to work.

What aspects do you think are good about Keio University?

My first impression of Keio upon assuming my post was that everything was well organized and everyone was cooperating with each other and appeared very eager to seek the highest possible achievements both in education and research. Given the superb educational environment, student's levels of basic scholastic ability and appetite for learning are also very high, which makes me comfortable when learning and doing research with them. Synergistic effects of cooperation between teachers and students characterize Keio's academic environment, ensuring high quality research.

◎ Some words from students ...◎

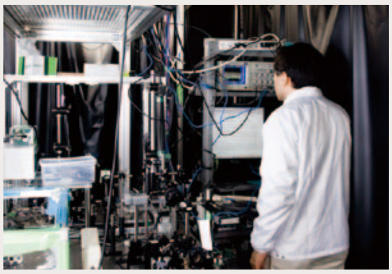
● It's no exaggeration to say that most of us, the Watanabe lab students, joined the lab first and foremost because of Dr. Watanabe's attractive character. He is a gentle as well as very caring teacher. He assigns each one of us themes according to our individual ability and interest, and follows up exactly as should be. No wonder our lab has a very good and comfortable atmosphere for us all.

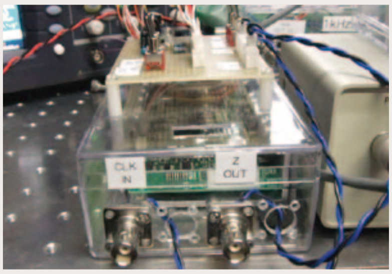
(Reporter & text writer : Madoka Tainaka)

For the full text of this interview
http://www.st.keio.ac.jp/kyurizukai

Watanabe lab: Scene 1

Many lenses and mirrors can be found inside our lab. Since these optical components are easily affected by dust, we installed a clean booth. As the space for our activity is decreasing gradually, we are trying to secure a space for experiments by making shelves and so on.





Watanabe lab: Scene 2

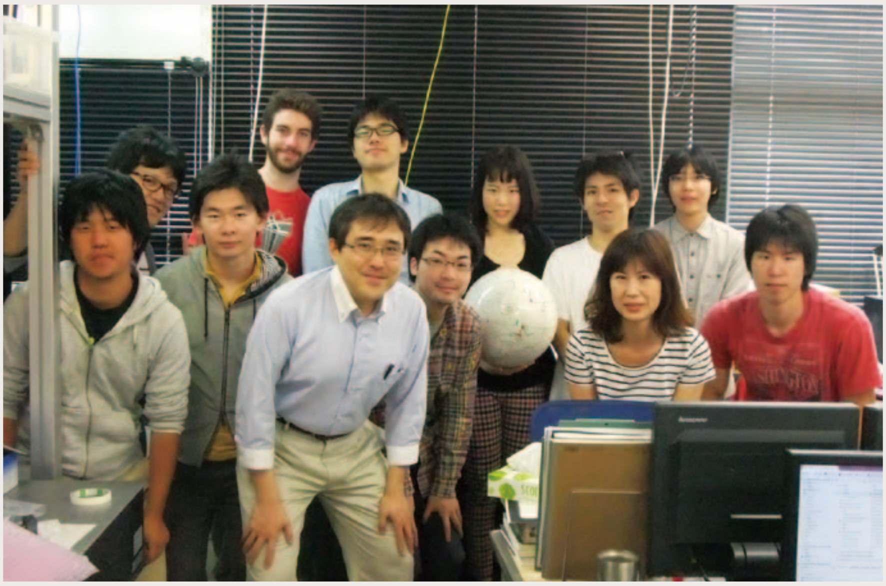
Watanabe lab's hidden strength is the ability to design and assemble highly complex electronic circuits on our own. This enables us to immediately put newly arising ideas through verification tests. Producing results first, then re-verifying them using commercially available more sophisticated measurement equipment . . . This is our basic strategy.

International conference "CLEO"

I often participate in the laser-related international conference "CLEO" held in the United States. Up-and-coming researchers from around the world delightfully present their papers there, which is very impressive. With participation in this conference as momentum, I made up my mind to proceed to the doctoral course. Photo shows Dr. Akiyama, my respected teacher, standing by me.

Shinichi Watanabe's ON and OFF time

Here I'd like to introduce scenes from the Watanabe lab ON time, and snapshots from my personal ON and OFF time – from both the past and present.



Watanabe lab members, 2014

Shown here are Watanabe lab members for the academic year 2014. For the past three years since our lab's establishment, we have made a variety of spectrum measurement equipment and imaging apparatuses in cooperation with our excellent lab members. Please expect a lot of Watanabe lab's activities in the future.

Scenery of suburban Lausanne

I spent my postdoctoral years at EPFL (Swiss Federal Institute of Technology in Lausanne). During my two and a half year stay, I could build up a very good relationship of trust with my teammates, which resulted in a number of achievements.

A corner in my parents' home

My parents were running an electrical business, so in my house I could find a variety of electric toys, such as a radio-controlled robot and a toy mouse that moves along walls. As such, word processors and PCs were always around me in my childhood. Perhaps this family environment made me immune from allergic reaction to making electronic circuits.

Practicing the tuba

Over 25 years have passed since I took up wind-instrument music as a junior high school boy. Throughout this period, I've been in charge of the tuba part. Though my skills are decreasing year by year due to a shortage of practice time, I'm still sticking to this pastime.

私の本棚

My favorite books

Novel: An Epitome of Eighteen Historie

During my college days I came across this novel and found it very interesting, so I read all six volumes. It's a vivid description of what strategies historical figures in China took to get into power and challenges they faced after becoming rulers. As a postdoctoral fellow staying overseas, I read this book again and again to learn what course of action I should take to overcome difficulties due to differences in cultural background.

Fundamentals of Optical Physics

When advancing from basic subjects for undergraduates to graduate school specialized subjects on optical physics, special care must be taken to ensure that there is no significant gap between the two. I came across this book when I was looking for a suitable book that would bridge between basics and the forefront of research. This book introduces, in an easy-to-understand way, a wide range of themes from basics of electrodynamics to topics relating to the latest research on optical pulse propagation. I refer to this book as needed when teaching optical physics.

From X-Rays to Quarks

This book highlights leading physicists of the early 20th century. While addressing their individual humane nature, it describes how they strove and accomplished their historical achievements. Abundant photos make this book readable even for students who are weak in physics. This book aroused my interest in physics when I was a high school student.

Solid-State Physics

This book is an easy-to-understand introduction to the fundamentals of solid-state physics. Unlike other textbooks that typically begin with the explanation of general crystal structures, this book begins with the Bloch's theorem (regarding characteristics of a wave function of electrons within a crystal). I feel that this book's approach would better allow students to enter into the world of condensed matter physics, so I often refer to this book in my lecture for the "Condensed Matter Physics I" class. A friend of mine recommended this book when I was a research associate and we studied it together.

Principles of Optics

This is the representative textbook on the field of optics. While its Japanese version consists of three volumes, the original English version is a thick single-volume book, making the reader feel assured that everything about optics is explained in this book. I keep this book ready in hand because recently I felt the need to understand wave-like properties of light in detail. I have both the Japanese version (which I acquired during my college days) and the original English version. I heard that the latter had been updated to introduce the latest topics.

Quantum Mechanics

As a "standard" textbook on quantum mechanics, this book explains fundamentals through to the quantum theory on interaction between light and objects. Because of its elaborate explanation of the basic knowledge required to understand optical properties, I've read it again and again since my college days. In Japan there are many good textbooks written in Japanese by Japanese authors, which made my friends from other Asian countries envious. Indeed, it's a great thing that we can study in our own language.

Optoelectronics

This book gives a truly easy-to-understand explanation of nonlinear optical physics and their applications. Whenever explaining frequency conversion technologies (such as the second harmonic generation and generation of terahertz waves) based on nonlinear optics, I usually refer to this book. This book is valuable for me as a physics specialist because a Department of Physics in general rarely handles optoelectronics.

Nothing to fear once you've known "Patterns"

Are you weak in making an ad-lib speech, or are you not?

Associate Professor Watanabe, introduced in this issue, says he is not good at making an ad-lib speech in public without preparing a manuscript. "But I'm good at making presentations at academic conferences," he says. This is because papers that are read at academic conferences have certain "patterns" and he knows them. He says he can read papers without difficulty by preparing the manuscript and practicing it over and over again.

Generally speaking, "new ideas" required for various research projects never come from out of nowhere. Any new idea is the result of a new research achievement added to the wisdom that has been accumulated by generations of predecessors. As such, the best shortcut for creating a "new idea" is to learn from the footprints of predecessors' endeavors. Dr. Watanabe often puts it like this: "I like reading biographies of great figures of the past because I can learn a lot about how these predecessors strove to create revolutionary ideas."

He continues, "Our students are very bright and armed with the basic academic ability sufficient enough to create such 'new ideas.' So, when dealing with my lab students, I usually like to learn together with them, spending more time to introduce them to 'patterns required for research' rather than teaching knowledge of physics."

"Patterns required for research" to create "new ideas" include: ① how to gather information; ② how to obtain experiment data; ③ how to make presentations at academic conferences; and ④ how to write scientific papers. Dr. Watanabe thus revealed some of the tips for guiding his students, saying, "I can convey these 'patterns' to my students because I've lived twice as long as them and have accumulated much experience."

He continues, "Once they are armed with these 'patterns,' the students, who are sufficiently knowledgeable and have a voracious appetite for learning, will become able to gather up-to-date information and use it effectively to create new ideas." About the research activities with his students, Dr. Watanabe delightfully commented, "It's very enjoyable to be able to work with these enthusiastic young students."

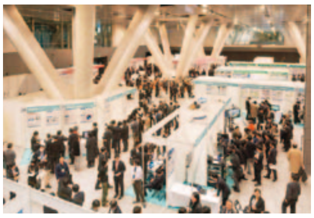
Science and Technology **Information**

Keio's Faculty of Science and Technology celebrates its 75th anniversary in 2014

The KEIO TECHNO-MALL, held in December every year, is an event to widely disseminate achievements of the Keio University Faculty and Graduate School of Science and Technology while serving as a venue for encounters that will promote joint research projects, technology transfer and industry-academia collaboration.

At exhibition booths, visitors will find both researchers as well as students making presentations of their research achievements through exhibits and demonstrations. Every year, this event receives many visitors, including those from industries, government agencies and other universities.

Date: December 5 (Fri.), 2014 10:00 ~ 18:00
Tokyo International Forum (Exhibition Hall 2, B2F)
Contents: Exhibit- and demonstration-oriented booths along with attractive special events
Admission free. *No prior registration required.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Editor's postscript

Since issue #10, we have included on the front cover a photo of the featured researcher with something in his or her hand. For this particular issue, Associate Professor Watanabe brought a red rod (simplified wave testing equipment), which impacted us with its unique shape. We couldn't tell what the equipment was until we were given an explanation. Only a small part of it is captured in the photo; the whole of it is much longer and larger. The photo adopted for the front cover is not a composite picture but a real one – one selected from the many photos filmed after trial and error, with a person holding the end of the equipment to create delicate waves.

Having prepared many memos for the interview, Dr. Watanabe answered our questions prudently (in choice of words) and calmly. He was really sincere and gentle true to his reputation among his lab students that they had joined the lab because of his personality. (Yuko Nakano)

Front cover for this issue

The equipment is simplified wave testing equipment used to observe how a transverse wave propagates. We adopted this photo image for the front cover to reproduce the electric field waveform of invisible terahertz light.

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