Dr. Takuo Tanaka

Team Leader of the Innovative Photon Manipulation Research Team in RIKEN Center for Advanced Photonics (RAP) and Chief Scientist of the Metamaterials Laboratory in RIKEN Cluster for Pioneering Research (CPR).

During this interview, we visited RIKEN and had the opportunity to speak with Dr. Takuo Tanaka about his research on metamaterials among other topics.

Brief History

Mar. 1996	Graduated from the Department of Applied Physics, Graduate School of Engineering, Osaka University, Ph.D. (Engineering)
Apr. 1996 – Mar. 2003	Assistant Professor, Graduate School of Engineering, Osaka University
Apr. 2003 – Mar. 2005	Specially Appointed Associate Professor, Graduate School of Engineering, Osaka University
Apr. 2003 – Mar. 2005	Researcher, Nanophotonics Laboratory, RIKEN
Apr. 2005 – Mar. 2008	Senior Researcher, Nanophotonics Laboratory, RIKEN
Apr. 2008 – Mar. 2017	Associate Chief Scientist, Metamaterials Laboratory, RIKEN
Apr. 2010 – Mar. 2019	Adjunct Professor, Research Institute for Electronic Science, Hokkaido University
Apr. 2010 – Present	Adjunct Professor, Graduate School of Science and Engineering, Saitama University
Apr. 2012 – Mar. 2023	Lecturer, Department of Physics, Faculty of Science, Gakushuin University
Apr. 2014 – Present	Team Leader, Innovative Photon Manipulation Research Team, RIKEN Center for Advanced Photonics
Apr. 2017 – Present	Chief Scientist, Metamaterials Laboratory, RIKEN
Sep. 2017 – Present	Visiting Professor, National Tsing Hua University, Taiwan
Mar. 2019 – Present	Visiting Professor, Post-LED Photonics Research Institute, Tokushima University
Apr. 2019 – Present	Visiting Professor, University of the Philippines Diliman
Apr. 2023 – Present	Visiting Professor, Department of Physics, Faculty of Science, Gakushuin University

“Our objective is to create completely new optically functional materials”

▶ Please introduce us to your current research.

I am affiliated with two groups within RIKEN: the Innovative Photon Manipulation Research Team of the RIKEN Center for Advanced Photonics and the Metamaterials Laboratory of RIKEN Cluster for Pioneering Research. Both groups focus our research on “metamaterials” which is a field initially developed within the microwave domain that has mainly been active in Europe and the United States since around 2000. I first started studying metamaterials around 2003 to 2004. At the time, research into optical domain metamaterials was non-existent so it’s still relatively young field of study.

There is no universally accepted definition on metamaterials but in a nutshell, metamaterials are a pseudo-substance that controls the properties of a substance by artificially introducing structures finer than its wavelength, which impart special properties that exceed the limits of a simple composite. Until now, it has been believed that the electromagnetic properties of a material are inherent to that material and are automatically determined once that material has been selected. In the metamaterials laboratory, we use nanostructures to artificially control the optical properties of materials such as permittivity and permeability, which were previously thought to be inherent. Our objective is to create completely new optically functional materials that can manipulate light, paving the way for groundbreaking advancements in photonics research.

Additionally, at the Innovative Photon Manipulation Research Team, we study the interactions between metamaterials, ultra-fine structures on the sub-wavelength scale and the resulting optical phenomena and functions. Our goal is to advance technologies that enable the creation and manipulation of photons at will. Using this new optical science technology, we are expanding applications to the development of optical processing technologies capable of fabricating three-dimensional structures with extremely fine nanoscale structures and ultra-sensitive optical sensing technology that can detect and identify individual molecules.

Figure 1 shows an electron microscope image of the RIKEN logo composed of light absorbers made from sub-wavelength-sized aluminum structures. Despite being significantly smaller and thinner than the wavelength of light, these structures almost entirely absorb specific wavelengths of light based on their dimensions and shapes. Figure 1(b) displays the structure illuminated with white light, reproducing the original colors with high precision. By varying the size of the structure, a range of colors covering the entire visible spectrum, as shown in Figure 1(c), can be generated.

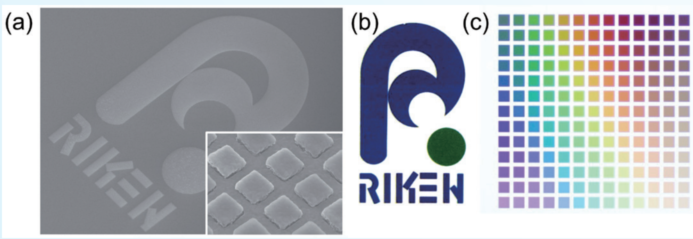


Figure 1. “Color” using metamaterial light absorbers with subwavelength aluminum structures

▶ Please describe how your research journey began and how it has led you to your current position.

When I was a student at Osaka University, the research lab I belonged to conducted research on optical microscopy, focusing on two significant challenges. The first challenge involved the limitation of optical microscopy in visualizing three-dimensional structures. To observe objects such as plant cells or the stomata of leaves, it was necessary to slice these three-dimensional structures into two dimensions, which made it impossible to observe their full three-dimensional form. The second challenge pertained to the inability of optical microscopy to visualize objects smaller than the wavelength of light. My research focused on overcoming the first of these challenges. The technology we developed during this research is now commercially available in advanced microscopes that can directly visualize three-dimensional samples, such as confocal and two-photon microscopes.

In my doctoral studies, I expanded my research focus to explore other potential applications of microscopy. I began investigating optical data storage, including CDs, DVDs, and Blu-ray discs which utilize laser beams to measure minute bumps on their surfaces to read stored information. The optical systems used in these discs are remarkably similar to those in optical microscopes. A key advantage of optical discs is their ability to read information without physical contact, which allowed CDs to be portable and used for music playback on the go. On the other hand, similar to optical microscopes, optical discs are limited to recording information in a single layer. Given that a CD is approximately 1 mm thick, but only 1 μm of that thickness contains information, the design is inefficient, with 99.9% of the CD serving merely as a support structure. I thought that if we could apply three-dimensional microscopy to optical discs, it would be possible to store information in multiple layers. This led to my research on optical media and optical recording, ultimately resulting in my doctoral degree in multilayer optical memory. Subsequently, I became an assistant professor at Osaka University, where I continued my research on optical memory and developed a medium capable of recording information in three dimensions through the interaction of gold ions and fluorescent dyes. Reflecting on my time at Osaka University, I attribute much of my success to my mentor, Professor Satoshi Kawata (now Professor Emeritus at Osaka University and Honorary Researcher at RIKEN), who significantly influenced my decision to pursue a research career.

In 2003, I joined the laboratory Professor Kawata had established at RIKEN the previous year. This transition coincided with the handover of our optical memory research to an external company and my desire to engage in more fundamental research. This marked my initial encounter with metamaterials. With a background in optics, I was particularly interested in integrating metamaterials into the optical domain. Through theoretical analysis, I demonstrated that metamaterials could be engineered not only in the microwave region but also in the optical region. At that time, copper was the predominant material used in the microwave region, but our research showed that gold and silver, with their extremely low electrical resistance, were more suitable for optical applications. Despite the challenges of creating extremely fine structures three-dimensionally, I conducted research that fused the technique of reducing metal ions to metal at specific locations, a technique I had used in optical memory research, with metamaterials. Since then, I have continued to explore various methods for advancing metamaterials research and am currently working on scalable, self-organizing production techniques.

Recently, there has been growing interest in the practical applications of my research. Although I have primarily focused on basic research since joining RIKEN, it has been nearly 25 years since metamaterials gained prominence. I believe the time has come to demonstrate the real-world applications of metamaterials, and we are now accelerating our research efforts with a focus on practical implementation.

> **“Samco’s systems have proven to be highly user-friendly, consistently delivering reliable results and data, even when used by students.”**

▶ Please discuss the future prospects of your research.

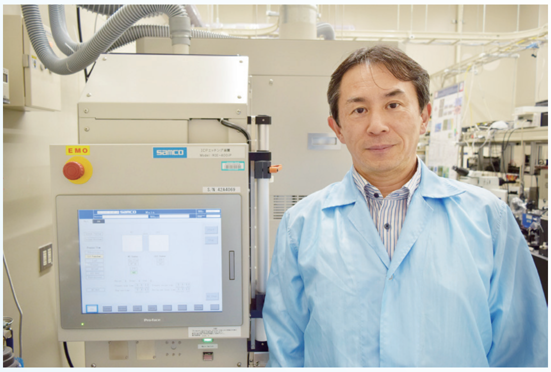
In academic research, trends like those seen with artificial intelligence (AI) and quantum mechanics often dominate the field. While these trends cannot be overlooked, it is essential not to be swayed solely by their popularity. My objective is to leverage these developments to create technologies that will be beneficial in the future. At RIKEN, my laboratory is categorized as engineering, so our first priority is to develop practical and applicable technologies, with the ultimate goal of advancing metamaterials into a functional and impactful technology.

Currently, my research focuses on “background light-free ultra-high-sensitivity infrared spectroscopic systems using metamaterial absorbents,” a project initiated under the Strategic Basic Research Programs for Evolutional Science and Technology (CREST) by the Japan Science and Technology Agency (JST) in 2019. As this project reaches its final year, our goal is to significantly enhance measurement sensitivity by using metamaterial absorbents composed of metallic nanocavities, which suppress unnecessary background light in infrared spectroscopy and selectively detect signal light. This advancement aims to pave the way for an ultra-sensitive molecular detection system.

The research into metamaterials is progressing worldwide, and we have teamed up with researchers at the National Taiwan University, the National Cheng Kung University, and the Australian National University to jointly develop metalenses capable of controlling focal length. This innovation holds the potential to revolutionize the design of ultra-small digital cameras, optical microscopes, and optical sensors, contributing to the development of compact and high-performance optical systems. Moreover, international efforts extend beyond optical metamaterials, exploring applications such as water wave metamaterials designed to protect oil drilling plants from tsunamis and seismic wave metamaterials intended to safeguard buildings against earthquakes—innovations that traditional materials cannot achieve.

▶ Could you please share your thoughts on using our systems?

At RIKEN, our laboratory utilizes several Samco systems as shared resources, particularly the ICP-RIE system RIE-400iP, and the RIE system FA-1. The RIE-400iP is especially critical for producing metamaterials, enabling high-precision nanoscale processing at scales of 10 nm or 20 nm. This system has proven invaluable in our joint research with international universities, particularly in etching gallium nitride (GaN). Furthermore, the system’s compact design was advantageous during installation in the clean room, allowing



Dr. Tanaka with ICP etching system RIE-400iP

it to fit within the limited space available. Samco's systems have proven to be highly user-friendly, consistently delivering reliable results and data, even when used by students.

▶In your daily research, what do you focus on?

Since becoming the Principal Investigator, my main priority has been ensuring safety. While it may seem self-evident, I am committed to preventing any accidents that could result in harm within my laboratory. When I was a student, all the systems were manually operated, and I personally managed all the overhauls. This hands-on experience allowed me to fully comprehend the composition and functionality of these systems. However, with the advent of fully automated systems, there is a risk of them becoming "black boxes." It is particularly concerning that younger generations do not appear to recognize the potential dangers associated with this lack of transparency.

Another key aspect of my daily work is finding enjoyment in research. In this field, if research does not bring joy, it becomes a lost opportunity. Therefore, I make it a point to ensure that my work remains fulfilling.

▶Please tell us your motto.

Are you familiar with the saying, "You will become good at what you enjoy doing?" This proverb suggests that individuals naturally excel at activities they are passionate about, and I believe this concept applies to research as well. Given that most experiments do not yield immediate success, maintaining motivation after failure is crucial. For this reason, I encourage young researchers and university students to engage in research that genuinely interests them, allowing them to pursue their passions fully.

▶How do you spend your holidays?

My house is only a few minutes away by bike, so I often find myself going to work even on my days off. I find it challenging to engage in telework, so even during the COVID-19 pandemic, I made excuses to visit the office, sometimes being the only person in the building. (laughs)

My hobbies include watching movies and listening to music. I watch and listen to anything, regardless of genre. If I had to pick one, it would be science fiction movies. I also frequent the Wako City Gym, which is conveniently located across from my workplace. I enjoy doing various workout programs and go about three times a week. I get to know people from a completely different community from that of my workplace and even get some innovative ideas. Although my wife thinks it would be best to not get too fixated on the gym, I find it beneficial. The bestselling book "Undou Nou" also mentions the benefits of exercise that include building resilience to stress, stimulating brain cell growth, and improving memory.

▶Lastly, could you share a few words about Samco?

To reiterate, Samco's advanced etching systems are indispensable to our research into metamaterials. Although the concept of metamaterials may seem new, it likely originated with researchers 100 to 200 years ago, albeit without the necessary processing, analyzing, or design technologies to advance it. However, with the development of related technologies, we are now finally in an era where we can explore the potential of metamaterials. At the same time, I have misgivings that cutting-edge systems made in Japan are increasingly becoming unavailable at domestic institutions and are instead being exported to overseas competitors. As a Japanese systems manufacturer, I hope that Samco will continue to develop technologies that support pioneering research and development within Japan.

Thank you very much for taking the time out of your busy schedule to speak with us.

> **"As a Japanese systems manufacturer, I hope that Samco will continue to develop technologies that support pioneering research and development within Japan."**

Samco Inc.

For more information please email: sales@samcointl.com

Japan (Headquarters, Kyoto)
Phone: +81-75-621-7841

South Korea (Suwon)
Phone: +82-70-8252-7841

Taiwan
Hsinchu Office
Phone: +886-3-516-5100
Tainan Service Office
Phone: +886-927-607-351

China
Beijing Office
Phone: +86-10-8219-4215
Shanghai Office
Phone: +86-21-6249-4662

Singapore
Phone: +65-6465-4220

Malaysia
Phone: +603-7629-7560

US, Canada & Latin America
West Coast Office, California
Phone: +1-408-734-0459
East Coast Office, New Jersey
Phone: +1-631-464-0664

samco-ucp ltd. Liechtenstein
Phone: +423-377-5959
Email: info@samco-ucp.com