

Showcase on Research from the Laboratory



Breakthroughs in Photonics ICT The forefront of Nano ICT research

—Utilizing the world’s most advanced ultra-microfabrication and nanophotonic device technologies to create ultrafast, high-sensitivity, low-power consuming, innovative optical ICT core technology that surpasses the limitations of current silicon devices—

Left / Shin-ichiro Inoue, Ph.D. (Engineering) Senior Researcher, Nano ICT Laboratory, Advanced ICT Research Institute
Right / Shigehito Miki, Ph.D. (Engineering) Senior Researcher, Nano ICT Laboratory, Advanced ICT Research Institute

Here at the Nano ICT Laboratory, Advanced ICT Research Institute, we are conducting research that aims to establish innovative optical control technology that enhances optical modulation speed, optical detection efficiency, and power consumption performance to levels difficult to reach with existing technology by taking advantage of superior organic material with optical-electronic capabilities, superconducting materials, and nanostructured unique optical-electronic device capabilities in order to control environmental load and, at the same time, realize high efficiency and speed of information-communications.

Now let’s take a look at leading-edge research in “Organic Nano ICT” and “Single-Photon Detection Technology.”

Holding the Key to “Overcoming Limitations” Nanophotonic Devices

Researcher: Shin-ichiro Inoue

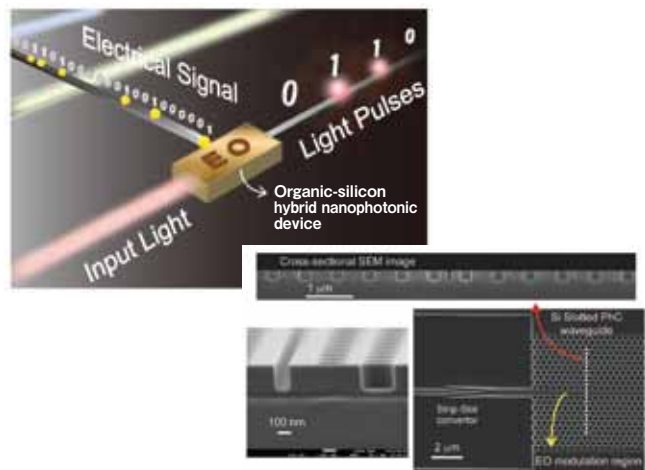
■ Integration of ultrafast nanophotonic devices through a hybrid of organic material and silicon photonics*1

In the midst of huge expansion and diversification of information-communications networks exemplified in recent years by cloud computing and smartphones, information-communication volume is expected to rapidly increase, leading to an explosive rise in network device power consumption. Conventional electronic router systems and silicon CMOS technology*2 are already reaching their physical limits in order to meet the conflicting performance demands of both accelerating information-communications speed-volume and energy-conservation requests from society. To address these problems, it is essential that we make a fundamental shift away from traditional electrical signal processing towards optical signal processing.

*1 Silicon Photonics
Technology that integrates differing functions in various optical devices on a single silicon chip. It has superior integration and can realize mass production and low-cost of components by diverting from existing CMOS processes.

*2 CMOS (Complementary Metal Oxide Semiconductor) Technology
A silicon LSI chip fabrication technology that uses CMOS, a standard semiconductor structure.

As information processing becomes more optical, not only thermal and processing-speed issues will be resolved, but also power consumption can be drastically reduced. However, optics has properties such as diffraction limits and little interaction between materials, and with existing technology, sizes in electronic components will become much larger. In order to realize genuine integrated optical circuits such as on-chip ultrafast optical communications, a critical challenge is how to realize optical devices on an extremely small scale similar to electronic devices. For this, the key to further rapid progress in future information-communications is research in “nanophotonic devices” that enable optical confinement and control in micro-sized spaces. At the Nano ICT Laboratory, we believe that the “integration of organic materials and silicon photonics” will lead to revolutionary breakthroughs in optical integration and optical signal processing, and we are undertaking research on unique nanophotonic devices. To advance optical information processing, development of technology that integrates electronic integrated circuits with superior complex signal processing performance and optical integrated circuits with exceptional high-speeds and energy-conservation is indispensable, particularly important being the integration of an electrooptic (EO) modulator that converts electronic signals to optical signals. In conventional optical modulators that use lithium niobate (LN) and silicon, optical modulation speeds are limited to approximately 40GHz, but with the use of organic EO polymer, ultrafast optical modulation speeds above 100GHz are possible. Moreover, it has a much larger EO coefficient than those of LN, which enables low-voltage devices. Conversely, we once thought that organic material was not suitable for integration due to its small refraction index. However, light can be confined in the nanoregion by realizing a silicon-hybrid structure because organic material can combine with various types of other materials. Therefore, by integrating the advantages of both silicon photonics and organic material technologies, we believe that the integration of ultrafast optical control devices can be realized for the first time.



● Schematic diagram of an EO optical integrated chip and electron micrograph of a silicon-integrated nanophotonic component

The nanophotonic structure also enables the creation of terminable optical states called “slow light” where optical speeds are artificially decelerated to approximately 1/100. This uses a periodic structure of the order of light wavelength called “photonic crystal,” and, by using the slow light effect, the Nonlinear Optical Effects of materials are substantially enhanced. Thus, it further reduces optical device size and

makes significant low-power consumption feasible. Combining these technologies is expected to minimize the size of electronic and optical devices and enable the development of ultimately ultrafast integrated optical/electronic circuits that replace bottlenecked parts of electronic integrated circuits on a single chip with optics.

■ Building Nano-Optical Devices Establishment of processing technology and process development

In order to realize the ultimate nano-optical device, hybridization of technology and development of extremely high-precision, ultrafine processing technology on a nano-order-scale are essential. However, organic material differs from semiconductor material in that microfabrication processes have not been established and many issues such as processing damage and control of polar orientation of chromophores in the nanoregion make it difficult to be processed. Optical device theoretical calculation processes are also very critical factors. We proceed with a layout of the optical device structure by 3-dimensionally designing various device structure models and testing and analyzing the actual device characteristics in a computed simulation. The important point here is that we have to replicate with high-accuracy the organic/Si-hybrid optical device structure designed on a nano-order-scale within the actual microfabrication process.

To overcome these technical problems, a cleanroom environment is essential where the entire process can be done consistently, including material development, nano-processing, and evaluation. NICT is the only research group worldwide comprehensively advancing research from this type of organic material development to nanophotonic device production/evaluation, expanding highly characteristic research as it strengthens both technologies and facilities.



● Cleanroom

■ Future Prospects

More than 60 years have passed since the technology changed “from vacuum tubes to transistors.” It is possible in the next 10 years that, like the revolutionary development of electronic computers, a fundamental change in information-communications technology will occur due to a shift “from electronic to optical chips” along with the new silicon photonics trend. At the Nano ICT Laboratory, making the integration of silicon photonics and organic materials our keyword, we are realizing low-power consumption, integration, and ultra-high speeds in optical modulation devices, and moreover, working towards solving important issues focused on the application of long-term durable, reliable organic nanophotonic devices, taking advantage of the strength of having a research lab environment where the entire process is consistent, from material development to device production/evaluation.

Hybrid devices of organic materials and silicon photonics use the optical functionality of organic material and allow development towards unprecedented, new optics technologies such as all-optical switches, optical buffers, and ultrasensitive biological sensors. Integrating the mutual advantages of both organic optical functionality and nanophotonic device technology is expected to make great contributions in a wide range of optical ICT fields such as next-generation ultrafast optical communications above hundreds of Gbps, high-capacity green ICT, and advanced optical sensing networks.



Shin-ichiro Inoue

Senior Researcher, Nano ICT Laboratory,
Advanced ICT Research Institute

Profile

After completing a doctoral course at Tokyo Institute of Technology and serving as RIKEN (The Institute of Physical and Chemical Research), Special Postdoctoral Researcher and Assistant Professor, Institute for Materials Chemistry and Engineering, Kyushu University, Inoue joined NICT in April 2010. He is engaged in research and development in optical electronics, nano-microfabrication, organic nonlinear optics, and nanophotonic devices. He holds a concurrent position as Associate Professor, Graduate School of Engineering Faculty and Engineering, Kobe University. He has received many awards including the Tejima Doctoral Dissertation Award, Funai Information Technology Promotion Award, Ando Incentive Prize for the Study of Electronics, The 3rd RIKEN FRS Promotion Award, and Research Award by Research Foundation for Opto-Science and Technology. When not immersing himself in work, he enjoys spending time with his children.

Remark from Researcher

Nanophotonic device and optical/electronic fusion technology not only contributes to low-power consumption and faster information-communications networks but also enables flexibility and diversified applicability of optics, and by spreading to all information equipment and advanced technology, from within LSI chips to biochips, it holds the potential for revolutionary breakthroughs in our ever-expanding advanced information society. Pursuing a wide range of fundamental research from nano and bio ICT to brain information, the Advanced ICT Research Institute utilizes the characteristics unique to micro-sized, high-performance, flexible organic nanophotonic devices to continue contributing to new technological innovations in information communications from ultrafast, extremely-low-power consuming optical integrated devices to the realization of bio-optical chip integration.

Establishing Next-Generation Photon Detection Technology in Superconductive Device Research

Researcher: Shigehito Miki

Detecting single photons with superconducting material exhibiting unique physical properties [SSPD]

Superconducting materials exhibit unique physical properties not shown in other materials such as perfect conductivity, perfect diamagnetism, and flux quantization. At the Nano ICT Laboratory, research and development is being conducted on various sophisticated devices using these physical properties. The fact that superconducting devices must be cooled to ultra low temperatures is often seen as a drawback, but because ultra low temperature environments can minimize thermal noise to an extremely small scale, it is the best for producing ultrasensitive “detectors” otherwise impossible with other materials. In particular, the superconducting nanowire single-photon detector system (SSPD) is currently gaining attention from various research fields such as quantum information communications as a technology that provides much higher performance compared to the traditionally used avalanche photodiode (APD).

The electrical resistance of superconductors becomes zero below superconducting critical temperature (T_c), however when a single photon enters, the superconductive state is destroyed locally. It is essential that the superconductor is processed into the nanowire in order to generate electric resistance caused by the breakdown of this local superconductive state and detect single photons with high-sensitivity. Moreover, in order to cause photon incidence efficiently onto the ultra nanowire, arranging the nanowire in a meandering shape and enlarging the light-receiving area are also necessary.

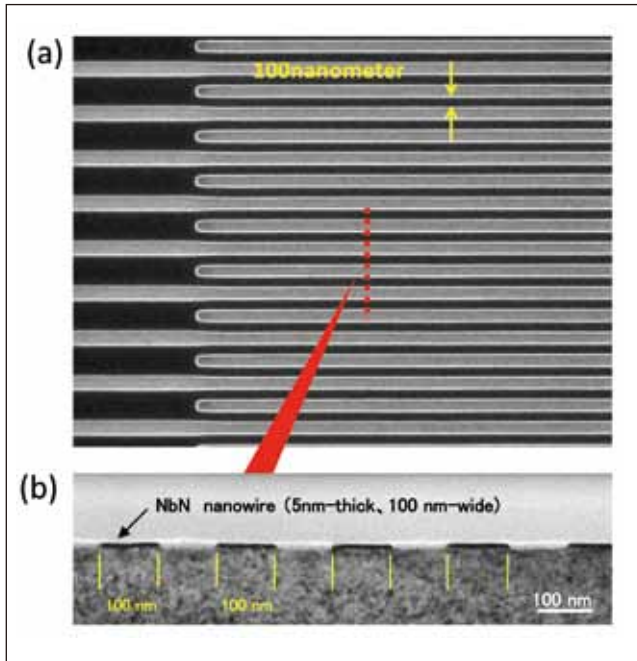
Creating Superconductive Nanowire in a Cleanroom

As previously mentioned, in order to efficiently detect photons, you must produce narrow and long superconductive nanowire. At the Nano ICT Laboratory, we are developing superconducting devices in the Advanced ICT Research Institute’s cleanroom laboratories equipped with the world’s most advanced technology in terms of niobium nitride—single crystal thin film deposition technology. With this film-formation technology,



● Superconducting niobium nitride film-generating instrument in a cleanroom

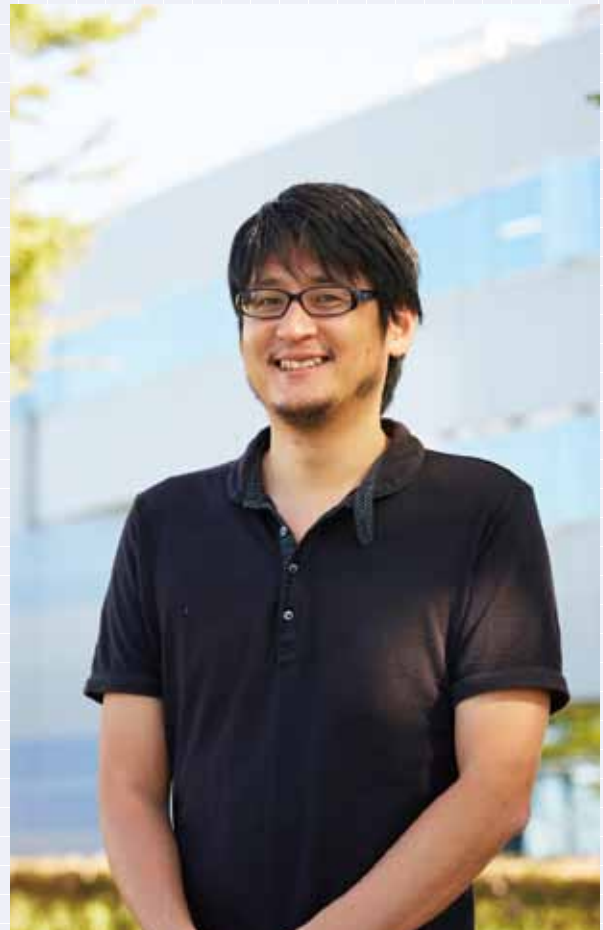
we can produce NbN film that can demonstrate superconductivity even in 4-nanometer-thick film composed of several atomic layers. Furthermore, using ultra-microfabrication technology that utilizes electron beam lithography systems and etching equipment, we have achieved fabricating nanowire of approximately 100 nanometers in width and realized SSPD devices. At this time, the total distance of one nanowire within a SSPD component is almost 20,000 times that of the nanowire width, extending up to 2 millimeters. The entire SSPD component fabrication process can be done inside a cleanroom using various tuned and constructed instrumentation, and therefore, test production of devices with new structures and optimized device designs can be rapidly performed.



● SSPD diagram

Further Advancement of Photon Detector Performance

Beginning in 2006, SSPD research and development at NICT brought about a cooling system for SSPD in 2008 and succeeded in capturing a value of approximately 1-2% in system detection efficiency at a communication wavelength band (1550nm). At this stage, it is still a low detection efficiency compared with the rival component, APD, however, when we considered its characteristics such as the overwhelmingly low dark count and comprehensively evaluated it, we showed that SSPD has substantial advantages. Moreover, thanks to later structural revisions, detection efficiency reached over 20% mid-2010 and showed just by this efficiency rate that it exceeded APD values. Here at the Nano ICT Laboratory, we aim to make large contributions to the development of future information-communications technology by realizing single-photon detectors with ultimate performance that can respond to the needs of various fields including quantum information-communication technology.



Shigehito Miki

Senior Researcher, Nano ICT Laboratory,
Advanced ICT Research Institute

Profile

After completing a doctoral course at Graduate School, Kobe University and serving as a researcher of Basic Research Program (CREST) at the Japan Science and Technology Agency, Miki joined NICT in October 2005. As a student, he belonged to a collaborative course between Kobe University and NICT and since then has been engaged in superconductivity at the Advanced ICT Research Institute, first as a trainee. He received the 146 Committee award, Japan Society for the Promotion of Science, encouragement award for outstanding lecture, Japan Society of Applied Physics, The Best Paper Award of Superconducting Division, Japan Society of Applied Physics, as well as The Young Scientists' Prize of the Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology. No matter how busy, he values spending time with his family on days off and enjoys visiting many different places together.

Remark from Researcher

With the aim to create new information-communication device technology, we are conducting fundamental optical-electromagnetic-quantum devices that use superconductivity circuit technology research, superconductive-optical interface research-development, and applied research for quantum-information communications/ultrafast photonic networks. High-speed, highly-sensitive photon detection technology is a critical component in various research fields including quantum information-communications technology, and photon detectors using superconductivity have advantages in wideband, high-sensitivity, and speed that outdo existing semiconductor photon detectors. We are conducting research and development on superconducting nanowire single-photon detectors system (SSPD) in order to realize photon detectors whose ultimate performance exceeds the limits of conventional photon detectors.