Research on Innovative ICT Hardware by Fusion of Novel Materials and Nano Technology

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The global information and communication network has become an indispensable part of the social infrastructure supporting people's lives. As the result of continual increases in the speed and capacity of Information and Communications Technology (ICT), represented by photonic network technology, it has become possible to instantaneously access advanced information from anywhere, anytime. E-commerce, TV conferences, video broadcasting services, etc., through the broadband network, unrestricted by time or distance, have now become a part of everyday life. At the same time, there has been a growing demand for even greater speed and capacity, spurred by the spread of advanced information terminals such as smartphones, tablets and PCs, and an increase in the volume of information and communication along with the diversification of services such as social networks and cloud computing. This type of acceleration and massive increase in the capacity of information and communication simultaneously leads to an increase in electric power consumption by network devices. The amount of electric power consumed by telecommunications has already reached significant levels, and reducing this thirst for power has become an important global issue from the perspectives of the practical limitation on power supplies and reducing the environmental burden. However, resolving these mutually opposing issues of achieving greater speed and capacity while limiting power consumption is difficult through simply improving existing technology. What is needed is innovation in ICT hardware technology and an advanced system based on that innovation.

At the Nano ICT Laboratory, we conduct research and development of innovative ICT hardware technology by making use of the excellent optical and electronic functions of organic molecular materials, superconducting materials, etc., and advanced nanostructure control technology, to boost photodetection efficiency, optical modulation speed, and power-saving functions to a level unachievable using traditional materials and technology. Compared to inorganic materials, organic materials show a faster and more efficient response to light, from the fact that the π-conjugated electrons within the molecules resonate with the electromagnetic field of light. Furthermore, superconducting materials have unique properties not found in other materials, such as perfect conductivity and the quantization of the magnetic flux. However, light essentially does not interact much with matter, so a simple boosting of material performance is not enough to draw out the full potential of materials. On the other hand, the latest nano processing technology has made it possible to precisely control the electromagnetic field of light and interactions between molecules. The objective of our research is to build minute nanostructures to innovate the performance of photonic devices through the boosting of efficiency in interaction between organic materials or superconducting materials with light by confining the light to microspaces or restricting the extent of interaction. NICT has been involved in research from the ground up for over 20 years, including fundamental and materials research fusing organic materials and superconducting materials with nanotechnology, and the results of some of our research areas have already been used in the practical application stage. For example, in the research on superconducting devices, technology for forming niobium nitride (NbN) thin films and nanowires was established to create the technology for superconducting devices that have outstanding electromagnetic and optical response properties. The Superconducting nanowire Single Photon Detector (SSPD) founded on this technical basis has achieved overwhelmingly high performance compared to the traditional avalanche photo diode, and it has already become indispensable as one of the key devices in quantum cryptography communication systems. The latest research has further advanced the high performance of the SSPD through improvements in the efficiency of photon detection and its high frequency properties, and great expectations are held for its development into a variety of applications that require the detection of weak light. In organic devices too, ultrafast optical modulation technology to achieve speeds of over 100 GHz using organic Electro-Optic (EO) polymers is on the verge of being realized. Success has already been achieved in developing organic EO polymers with electro-optical properties superior to the currently used inorganic material ($LiNbO_3$), and the work has already advanced to a stage where a high speed optical modulator is being manufactured on a trial basis. Research is also being carried out into miniaturizing optical modulators to one thousandth of the current size by combining silicon photonic crystals made through nano processing with organic EO polymers, and optical modulation is already confirmed with them.

In this special issue, we will report on the latest results of research being carried out at the Nano ICT Laboratory into organic nano devices, superconducting devices, and nano-bio fusion research, in three separate chapters. Regarding research on organic nano devices, we will first report on efforts to develop materials and evaluation technology for organic EO devices, and trial manufacture low-power driven, ultrafast optical modulators. We will also report on the technology to miniaturize the device by further boosting the efficiency of the advanced functions of organic molecules through their combination with inorganic nanostructures. Regarding research on superconducting devices, we will report on the high performance technology of the SSPD already being put to practical use in key devices for quantum information and communication technology. We will also report on interface technology between superconducting and optical signals that utilizes superconducting single flux quantum, and new technology for a photodetection device that uses an optical nano antenna. Nano-bio fusion research is a relatively new area of research that was turned into a project recently, but we are already on the verge of creating devices with new functions. π-conjugated electrons, which govern the optical and electronic functions of organic molecules, have the property of interacting easily between molecules because they are spread out across the entire molecule. For this reason, it is possible to improve the efficiency or realize new functions in groups of molecules by not only controlling molecular structures, but also the high degree of organization among molecules. However it is not easy to artificially control distances between molecules at nanometer scales or less. In biomolecules, proteins act like frameworks that ingeniously control interactions between functional molecules, and using not single functional molecules that have been organically synthesized, but using functional proteins that have been synthesized in advance to their superstructures is one of the effective alternative methods. In regard to nano-bio fusion research in this special issue, we will report on research into optical sensors using bacteriorhodopsin, which shows the same response to light as the photoreceptor cells of organisms.

There are a group of major obstacles, known as “death valley”, to be cleared before budding fundamental research develops into applied technology with practical uses. It is one of the important missions of NICT to overcome these difficulties to develop technology for practical application, and lead the way in realizing the ultimate information and communications technology. Comprehensive research covering everything from fundamental and materials research to applied and device technology is carried out at the Nano ICT Laboratory, and at the same time we are building a research system with the aim of launching products onto the market by bolstering collaboration with industries through research funding. The innovative ICT hardware technology reported here is the result of having established this kind of system, combined with many years of steady research, and we are convinced of being on the verge of a breakthrough in the technological innovation of information and communication systems, which will continue evolving into the future.

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