Concluding Remarks

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Today the gathering of information and real time communication has become possible on a global scale with rapid advances in information and communication technology (ICT) in recent years, and its applications and uses continue expanding even now. Technology enriches people's lives, while on the other hand it has created a digital divide and a variety of other problems such as energy issues. In particular, increases in energy consumption in accordance with increased traffic, and stress on the capacity of communications infrastructure are issues that need to be resolved urgently. For the sustainable growth of the ICT society, the contradictory issue of a rise in utility to the extent that increased use puts strain on the network must be solved, and what is needed is discontinuous technological development based on an idea hitherto unheard of, or a revolutionary breakthrough. The key to achieving this undoubtedly lies in materials that will produce new functions, and precision processing technology will draw out their full potential.

It was based on these perspectives that we reported, in this issue, on a part of the current state of affairs, results, and direction of the research and development which has been carried out over the course of many years at the Nano ICT Laboratory. Organic materials for making organic EO devices that we are developing as a means of simultaneously achieving high speed and low electricity consumption in high-speed optical communication, have a theoretical performance index that is far superior to that of the $LiNbO_3$ material that is currently the mainstream. In addition, great expectations are held for even higher performance by controlling microscopic arrangement and structures on molecular scales. Furthermore, the size and performance of optical communication devices are limited by the wavelength of light used, but these limitations can be overcome by controlling the speed and dispersion relation of light through the application of nanoscale processing technology. Superconducting thin films too, can be made into photon detectors of ultimate sensitivity through precision processing to give them a nano-level thin line pattern. In this way, the nanoscale formation and processing of materials with superior potential is on the verge of producing numerous high performance devices that will surpass all preconceptions. Finding superior materials and establishing precision processing technology are inseparable in the development of nano devices, and they form the Nano ICT Laboratory's technological foundations, which have been cultivated over a long time. Technological development to advance nanoprocessing technology itself is also important. An example of this is the technology to create new functions from the bottom up by building on atomic or molecular-level structures to create higher structures. To address this issue, the Nano ICT Laboratory has focused and carried out research on the self-organization phenomenon of organic molecules. This is technology to create higher structures spontaneously by precisely controlling the fundamental parts of organic molecules such as their shape or position of dipole moments, based on chemical synthesis methods. It allows the creation of molecular wires and molecular grid structures several nanometers in width, and photochemical switches consisting of several molecules, without relying on complicated lithographic processes. In the future, technological strategies will become important for creating useful functions by combining higher structures.

Biomaterials will provide good examples in terms of creating new functions. All materials, structures and functions that make up organisms are formed by the combination of individual molecules based on genetic information. In that sense, it can be said that biomaterials are ultimate molecular machines made from the bottom up. Biological systems skillfully combine the physical and chemical properties of molecules that are simple on their own, to achieve performance that is equal or superior to devices made from the integration of state-of-the-art technology. Let us take a look at the power of vision for example. The human retina has 100 million rod cells to detect light and darkness, and 6 million cone cells to detect colors. The cone cells are directly related to vision, so comparing this to a digital camera will mean it has image sensors for 6 million pixels. However, the photoreceptor cells on the retina, or in other words the individual imaging cells, make use of the isomerization of retinal by light, which is not so powerful and cannot keep track of rapid changes. To overcome this problem, neighboring imaging cells carry out a calculation-like process among themselves to ultimately transmit information of around 1.2 million pixels to the brain. Looking at it this way, it may seem like human vision is structurally inferior even to digital cameras of 10 years ago, but functionally, it is the same or even superior to the specifications of the latest industrial-use cameras of several tens of million pixels. In terms of the low resolution of eyesight too, the transmission of just 1.2 million pixels of data to the visual cortex can be interpreted positively as a way of reducing the burden on the nerves, which form an extremely low performance infrastructure for communication. It is worthy of note that functions equivalent to those of advanced imaging sensors made by making full use of micromachining technology have been attained through the assembly of relatively simple molecular structures. The mechanism behind this has not been thoroughly elucidated, but it seems certain that information supplementing by the brain plays a vital role.

As another example, let us focus on the sense of smell. A variety of technologies which mimic the sense of smell are currently being proposed, but there are still none that surpass that of a living animal. The basic mechanism behind the sense of smell is based on receptor cells that bond selectively to molecules that produce smells, to send out signals. This is a type of antibody response, and it is the reason for the high sensitivity of organisms to smell. It is worthy of noting that it is not just the sensitivity, but also the ability of organisms to differentiate between smell signals. Recent molecular-biological research has shown that in the case of human beings, there are 388 different types of these receptor molecules. Relative to this, it is said that the number of different smells that can be differentiated is over 100,000. Even smells that are smelled for the first time can be differentiated by their subtle differences, and analogies can be drawn to other smells from past experiences. Research so far has shown that the way the sense of smell works is based on pattern recognition through space-time correlation of output signals from the numerous receptor molecules on the olfactory bulb, which form a network-like structure. This is similar to the gathering of information through a sensor network or ascertainment and prediction of conditions based on that information, in other words, the application of big data, within the field of ICT. Devices that are created by taking advantage of the characteristics of biomaterials are not only efficient and functional, but they also have the characteristics of interfaces that naturally mimic and recreate the perceptions of organisms. There is a need for this as a method of communication in a network society. For example, based on information from sensors that are in current use, there is a gap between the perceptions one gains from information transmitted or shared between users through the network and ICT sources, and the perceptions one gains from the real world. Smell, the sense of touch, and sense of taste are examples of perceptions that are difficult to gain through explanations based on just words or movies. For example, gaining a feeling of being in the real world when shopping in virtual space requires the creation of sensing technology that is closer to the sensory perceptions of organisms. The creation of technology that enables the sharing of this kind of information from the virtual world and information from the real world will no doubt lead to the creation of a new business based on ICT resources.

Furthermore, this may be a somewhat imaginative conjecture, but organisms are said to possess a sixth sense. Everyone has probably experienced feeling uneasy about a place despite not being able to say why, or experienced sensing some kind of danger. This sense sometimes helps us to avoid potential dangers, or predict disasters before they strike. In reality, this is not a sixth sense. It is more appropriate to think of it as the result of information from the five senses being inputted into the biological system consisting of the brain and nerves, and being processed holistically before a judgment is made, and conclusions are drawn from it. It can be called a survival mechanism or instinct developed by organisms over a long time. It will no doubt be useful to examine and gain an understanding of how organisms obtain and process information, and how they judge something to be dangerous in such situations. For example, if we could artificially create a sensor network consisting of devices that mimic the sense organs of organisms, and apply an algorithm that mimics the information processing of the brain, to gain an understanding of the level of sensitivity of organisms to outside stimuli, what information they gain from the stimuli, and how they process the information to sense danger, we may be able to use this knowledge in the future to predict disasters.

The variety of sense organs and systems that support the activities of organisms skillfully combine simple functions to achieve both necessary functions and high efficiency, despite not being very powerful. At times, current technology cannot even hope to compete with the level of their performance. However, the mechanisms behind their performance have not yet been fully elucidated, and we still have a lot to learn from them.

It is extremely important to have competitive and unique materials. It is also important to have the (nano) technology to refine the material to a high level. We will skillfully combine these two to create new, useful functions, and develop ways of making use of them to present new technological standards. This is the mission of the Nano ICT Laboratory.

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