Research Highlights

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Developing single organic molecular devices using chemical domino effect and soldering

"Single organic molecular devices offer a promising alternative to silicon-based devices, which are approaching their theoretical and technical miniaturization limits," says Yuji Okawa. While the development of single organic molecular devices is making slow progress, Okawa has developed a groundbreaking wiring technology using chain polymerization of molecules. The new technology is drawing attention as a major step toward the realization of the devices.

Many organic molecules possess electronically or optically useful functions. The concept of single organic molecular devices involves the use of those molecules as diodes, switches and transistors. They are promising materials for use in the development of compact, high-performance and energy-efficient information processors. However, Okawa was cautious. "It has been more than 40 years since the idea of single molecular devices was first proposed," he said. "Devices have not yet been realized despite active research efforts. The slow advancement is attributed to difficulty in attaching electric wires to single molecules, which is a critical aspect of the technology."

It is difficult to reduce the diameter of a metal wire to the size of a molecule. Instead of using metal wires, creating electrically conductive molecular wires has been regarded as a promising method. "To implement this, I came up with a strategy of creating conductive polymer wires and connecting them to single molecules directly on a substrate."

Okawa chose diacetylene compound molecules as a wiring material. To create the polymer wire, a film composed of orderly aligned diacetylene compound molecules was first created on a graphite substrate onto which single organic molecules were placed. A scanning tunneling microscope probe was then positioned in close proximity to the molecular film and used to apply a pulse voltage to it. The pulse voltage excited a molecule directly beneath the probe, causing it to form a bond with an adjacent molecule. This intermolecular bonding spreads outward from the probe in a kind of "domino effect." This reaction is called chain polymerization and leads to the formation of a single wire composed of conductive polydiacetylene (Fig.).

"When the chain polymerization reaches the single organic molecules, chemical reactions occur there, forming an automatic connection between the conductive polymers and single organic molecules. I have named this technique 'chemical soldering.' I have been using phthalocyanine as my choice of single organic molecules. A system composed of phthalocyanine connected to two polydiacetylene wires serves as a resonant tunneling diode and is anticipated to make ultra-high-speed communication possible. However, no one has actually confirmed this. I am currently conducting experiments to verify its functionality. This will require the measurement of electric current passing through single organic molecular devices on an insulating substrate. Okawa has already succeeded in creating polydiacetylene wires on an insulating, hexagonal boron nitride substrate. Once the functionality of a singular organic molecular device is demonstrated, the next step will be the development of device integration techniques.

"There is still a long way to go, but I really hope to put single organic molecular devices into practice."

(by Shino Suzuki, PhotonCreate)

Figure. Conceptual diagrams of molecular wiring using chain polymerization.