Future of portable electronics: Novel organic semiconductor with exciting properties

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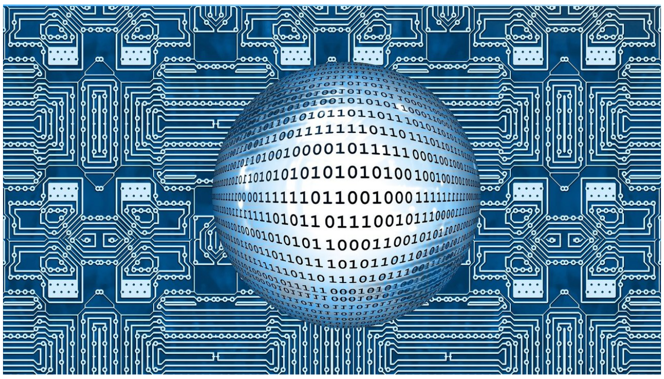

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Semiconductors are substances that have a conductivity between that of conductors and insulators. Due to their unique properties of conducting current only in specific conditions, they can be controlled or modified to suit our needs. Nowhere is the application of semiconductors more extensive or important than in electrical and electronic devices, such as diodes, transistors, solar cells, and integrated circuits.

Semiconductors can be made of either organic (carbon-based) or inorganic materials. Recent trends in research show that scientists are opting to develop more organic semiconductors, as they have some clear advantages over inorganic semiconductors. Now, scientists, led by Prof Makoto Tadokoro of the Tokyo University of Science, report on the synthesis of a novel organic substance with potential applications as an n-type semiconductor. This study is published in the journal *Organic and Biomolecular Chemistry*. According to Prof Makoto Tadokoro, "organic semiconductor devices, unlike hard inorganic semiconductor devices, are very soft and are useful for creating adhesive portable devices that can easily fit on a person." However, despite the advantages of organic semiconductors, there are very few known stable molecules that bear the physical properties of n-type semiconductors, compared to inorganic n-type semiconductors.

N-heteroheptacenequinone is a well-known potential candidate for n-type semiconductor materials. However, it has some drawbacks: it is unstable in air and UV-visible light, and it is insoluble in organic solvents. These disadvantages obstruct the practical applications of this substance as a semiconductor.

A team of Japanese scientists—Dr. Kyosuke Isoda (Faculty of Engineering and Design, Kagawa University; ex-Tokyo University of Science), Mr. Mitsuru Matsuzaka (ex-Tokyo University of Science), Dr. Tomoaki Sugaya (Chiba Institute of Technology, ex-Tokyo University of Science), and Prof Tadokoro—aimed to bridge this gap, and identified a novel substance called C^6OAHCQ, derived from N-heteroheptacenequinone, that overcomes the drawbacks of N-heteroheptacenequinone.

To obtain this substance, N-heteroheptacenequinone was made to undergo a four-step process of chemical reactions involving repetitive refluxing, evaporation, recrystallization, and heating. The final product achieved was C^6OAHCQ, a red solid. C^6OAHCQ has a unique crystalline near-planar structure involving two tetraazanaphthacene "backbones" and one benzoquinone backbone. It has eight electron-deficient imino-N atoms and two carbonyl moieties.

To confirm its electrochemical properties, C^6OAHCQ was made to undergo a series of tests including a UV-visible absorption spectroscopy in the solution state, cyclic voltammetry, and theorical calculation of electrostatic potential. It was also compared with a tetraazapentacenequinone analog.

These tests revealed some unique properties of C^6OAHCQ. The electron-deficient imino-N atoms and two carbonyl moieties in C^6OAHCQ provide it with an electron-accepting behavior. In fact, the number of electrons accepted by C^6OAHCQ is more than that by fullerene C^{60}, which suggests improved conductivity. Cyclic voltammetry showed that C^6OAHCQ exhibited reversible four-step, four-electron reduction waves, which indicated that C^6OAHCQ is stable and has good electrostatic potential; the UV-visible spectroscopy also showed its stability in UV-visible light. C^6OAHCQ also showed electrochromic properties, which enable its potential application in many specialized areas such as the development of smart windows, electrochromic mirrors, and electrochromic display devices. C^6OAHCQ was also found to have excellent solubility in common organic solvents. It was overall found to be advantageous and had improved properties compared to the tetraazapentacenequinone analog.

The synthesis of organic C^6OAHCQ is a new step forward in semiconductor research, due to its distinctive properties that distinguish it from existing organic semiconductors. C^6OAHCQ is also a revolutionary step in the current research scenario dominated by inorganic semiconductors. Prof Tadokoro and team assert the importance of this novel substance, stating, "the identification of this organic acceptor molecular skeleton that has the property of stably receiving electrons is very important, as it can be used to develop molecular devices with new functionality. These devices are soft, unlike hard inorganic semiconductor devices, and can help to create portable devices."

More information: Kyosuke Isoda et al, Synthesis and electrochromic behavior of a multi-electron redox-active N-heteroheptacenequinone, *Organic & Biomolecular Chemistry* (2019). DOI: 10.1039/C9OB01323G

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