UC SANTA BARBARA

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# Just Add Water

Semiconductors — and our mastery of them — have enabled us to develop the technology that underpins our modern society. These devices are responsible for a wide range of electronics, including circuit boards, computer chips and sensors.

The electrical conductance of semiconductors falls between those of insulators, like rubber, and conductors, like copper. By doping the materials with different impurities, scientists can control a semiconductor's electrical properties. This is what makes them so useful in electronics.

Scientists and engineers have been exploring new types of semiconductors with attractive properties that could result in revolutionary innovations. One class of these new materials is organic semiconductors (OSCs), which are based on carbon rather than silicon. OSCs are lighter and more flexible than their conventional counterparts, properties that lend themselves to all sorts of potential applications, such as flexible electronics, for instance.

In 2014, UC Santa Barbara's Professor Thuc-Quyen Nguyen and her lab first reported on doping of OSCs using Lewis acids to increase the conductance of some semiconducting polymers; however, no one knew why this increase happened until now.

Through a collaborative effort, Nguyen and her collages have parsed this mechanism, and their unexpected discovery promises to grant us greater control over these materials. The work was supported by the Department of Energy and the

findings appear in the journal Nature Materials.

Researchers at UC Santa Barbara collaborated with an international team from the University of Kentucky, Humboldt University of Berlin and Donghua University in Shanghai. “The doping mechanism using Lewis acids is unique and complex; therefore, it requires a team effort,” Nguyen explained.

“That’s what this paper is all about,” said lead author Brett Yurash, a doctoral candidate in Nguyen’s lab, “figuring out why adding this chemical to the organic semiconductor increases its conductivity.”

“People thought it was just the Lewis acid acting on the organic semiconductor,” he explained. “But it turns out you don’t get that effect unless water is present.”

Apparently, water mediates a key part of this process. The Lewis acid grabs a hydrogen atom from the water and passes it over to the OSC. The extra positive charge makes the OSC molecule unstable, so an electron from a neighboring molecule migrates over to cancel out the charge. This leaves a positively charged “hole” that then contributes to the material’s conductivity.

“The fact that water was having any role at all was really unexpected,” said Yurash.

Most of these reactions are performed in controlled environments. For instance, the experiments at UC Santa Barbara were conducted in dry conditions under a nitrogen atmosphere. There wasn’t supposed to be any humidity in the chamber at all. However, clearly some moisture had made it into the box with the other materials. “Just a tiny amount of water is all it took to have this doping effect,” Yurash said.

Scientists, engineers and technicians need to be able to controllably dope a semiconductor in order for it to be practical. “We’ve totally mastered silicon,” he said. “We can dope it the exact amount we want and it’s very stable.” In contrast, controllably doping OSCs has been a huge challenge.

Lewis acids are actually pretty stable dopants, and the team’s findings apply fairly broadly, beyond simply the few OSCs and acids they tested. Most of the OSC doping work has used molecular dopants, which don’t dissolve readily in many solvents. “Lewis acids, on the other hand, are soluble in common organic solvents, cheap, and available in various structures,” Nguyen explained.

Understanding the mechanism at work should enable researchers to purposefully design even better dopants. “This is hopefully going to be the springboard from which more ideas launch,” Yurash said. Ultimately, the team hopes these insights help push organic semiconductors toward broader commercial realization.

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## About UC Santa Barbara

The University of California, Santa Barbara is a leading research institution that also provides a comprehensive liberal arts learning experience. Our academic community of faculty, students, and staff is characterized by a culture of interdisciplinary collaboration that is responsive to the needs of our multicultural and global society. All of this takes place within a living and learning environment like no other, as we draw inspiration from the beauty and resources of our extraordinary location at the edge of the Pacific Ocean.