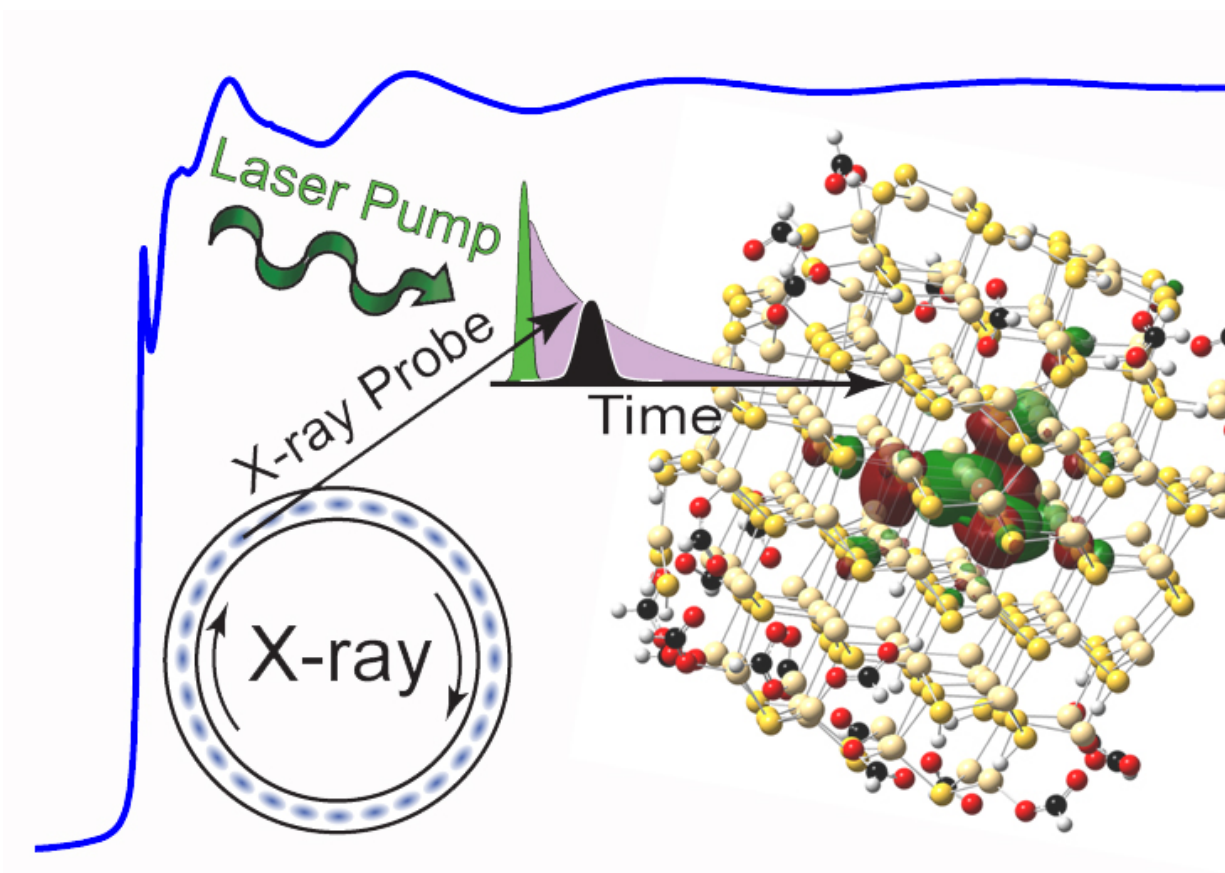


Newly-discovered semiconductor dynamics may help improve energy efficiency

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The atomic structure of a tiny semiconductor is X-rayed. Credit: University of Illinois at Chicago

Researchers examining the flow of electricity through semiconductors

have uncovered another reason these materials seem to lose their ability to carry a charge as they become more densely "doped." Their results, which may help engineers design faster semiconductors in the future, are published online in the journal *ACS Nano*.

Semiconductors are found in just about every piece of modern electronics, from computers to televisions to your cell phone. They fall somewhere between metals, which conduct [electricity](#) very well, and insulators like glass that don't conduct electricity at all. This moderate conduction property is what allows semiconductors to perform as switches and transistors in electronics.

The most common material for semiconductors is silicon, which is mined from the earth and then refined and purified. But pure silicon doesn't conduct electricity, so the material is purposely and precisely adulterated by the addition of other substances known as dopants. Boron and phosphorus ions are common dopants added to silicon-based semiconductors that allow them to conduct electricity.

But the amount of [dopant](#) added to a [semiconductor](#) matters - too little dopant and the semiconductor won't be able to conduct electricity. Too much dopant and the semiconductor becomes more like a non-conductive insulator.

"There's a sweet spot when it comes to doping where the right amount allows for the efficient conduction of electricity, but after a certain point, adding more dopants slows down the flow," says Preston Snee, associate professor of chemistry at the University of Illinois at Chicago and corresponding author on the paper.

"For a long time scientists thought that the reason efficient conduction of electricity dropped off with the addition of more dopants was because these dopants caused the flowing electrons to be deflected away, but we

found that there's also another way too many dopants impede the flow of electricity."

Snee, UIC chemistry student Asra Hassan, and their colleagues wanted to get a closer look at what happens when electricity flows through a semiconductor.

Using the Advanced Photon Source Argonne National Laboratory, they were able to capture X-ray images of what happens at the atomic level inside a semiconductor. They used tiny chips of cadmium sulfide for their semiconductor "base" and doped them with copper ions. Instead of wiring the tiny chips for electricity, they generated a flow of electrons through the semiconductors by shooting them with a powerful blue laser beam. At the same time, they took very high energy X-ray photos of the semiconductors at millionths of a microsecond apart - which showed what was happening at the [atomic level](#) in real time as electrons flowed through the doped semiconductors.

They found that when electrons were flowing through, the [copper ions](#) transiently formed bonds with the cadmium sulfate semiconductor base, which is detrimental to conduction.

"This has never been seen before," said Hassan. "Electrons are still bouncing off dopants, which we knew already, but we now know of this other process that contributes to impeding [flow](#) of electricity in over-doped semiconductors."

The bonding of the dopant ions to the semiconductor base material "causes the current to get stuck at the dopants, which we don't want in our electronics, especially if we want them to be fast and efficient," she said. "However, now that we know this is happening inside the material, we can design smarter systems that minimize this effect, which we call 'charge carrier modulation of dopant bonding'."

More information: Asra Hassan et al. Charge Carriers Modulate the Bonding of Semiconductor Nanoparticle Dopants As Revealed by Time-Resolved X-ray Spectroscopy, *ACS Nano* (2017). [DOI: 10.1021/acsnano.7b04414](https://doi.org/10.1021/acsnano.7b04414)

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