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New Research Advances Understanding of Lead Selenide Nanowires

The advancements of our electronic age rests on our ability to control how electric charge moves, from point A to point B, through circuitry. Doing so requires particular precision, for applications ranging from computers, image sensors and solar cells, and that task falls to semiconductors.

Now, a research team at the University of Pennsylvania's schools of Engineering and Applied Science and Arts and Sciences has shown how to control the characteristics of semiconductor nanowires made of a promising material: lead selenide.

Led by Cherie Kagan, professor in the departments of Electrical and Systems Engineering, Materials Science and Engineering and Chemistry and co-director of Pennergy, Penn's center focused on developing alternative energy technologies, the team's research was primarily conducted by David Kim, a graduate student in the Materials Science and Engineering program.

The team's work was published online in the journal ACS Nano and will be featured in the Journal's April podcast.

The key contribution of the team's work has to do with controlling the conductive properties of lead selenide nanowires in circuitry. Semiconductors come in two types, n and p, referring to the negative or positive charge they can carry. The ones that move electrons, which have a negative charge, are called "n-type." Their "p-type" counterparts don't move protons but rather the absenceof an electron -- a "hole" -- which is the equivalent of moving a positive charge.

Before they are integrated into circuitry, the semiconductor nanowire must be "wired up" into a device. Metal electrodes must be placed on both ends to allow electricity to flow in and out; however, the "wiring" may influence the observed electrical characteristics of the nanowires, whether the device appears to be n-type or p-type. Contamination, even from air, can also influence the device type. Through rigorous air-free synthesis, purification and analysis, they kept the nanowires clean, allowing them to discover the unique properties of these lead selenide nanomaterials.

Researchers designed experiments allowing them to separate the influence of the metal "wiring" on the motion of electrons and holes from that of the behavior intrinsic to the lead selenide nanowires. By controlling the exposure of the semiconductor nanowire device to oxygen or the chemical hydrazine, they were able to change the conductive properties between p-type and n-type. Altering the duration and concentration of the exposure, the nanowire device type could be flipped back and forth.

"If you expose the surfaces of these structures, which are unique to nanoscale materials, you can make them p-type, you can make them n-type, and you can make them somewhere in between, where it can conduct both electrons and holes," Kagan said. "This is what we call 'ambipolar.'"

Devices combining one n-type and one p-type semiconductor are used in many high-tech applications, ranging from the circuits of everyday electronics, to solar cells and thermoelectrics, which can convert heat into electricity.

"Thinking about how we can build these things and take advantage of the characteristics of nanoscale materials is really what this new understanding allows," Kagan said.

Figuring out the characteristics of nanoscale materials and their behavior in device structures are the first steps in looking forward to their applications.

These lead selenide nanowires are attractive because they may be synthesized by low-cost methods in large quantities.

"Compared to the big machinery you need to make other semiconductor devices, it's significantly cheaper," Kagan said. "It doesn't look much more complicated than the hoods people would recognize from when they had to take chemistry lab."

In addition to the low cost, the manufacturing process for lead selenide nanowires is relatively easy and consistent.

"You don't have to go to high temperatures to get mass quantities of these high-quality lead selenide nanowires," Kim said. "The techniques we use are high yield and high purity; we can use all of them."

And because the conductive qualities of the lead selenide nanowires can be changed while they are situated in a device, they have a wider range of functionality, unlike traditional silicon semiconductors, which must first be "doped" with other elements to make them "p" or "n."

The Penn team's work is a step toward integrating these nanomaterials in a range of electronic and optoelectronic devices, such as photo sensors.

The research was conducted by Kim and Kagan, along with Materials Science and Engineering undergraduate and graduate students Tarun R. Vemulkar and Soong Ju Oh; Weon-Kyu Koh, a graduate student in Chemistry; and Christopher B. Murray, a professor in Chemistry and in Materials Science and Engineering.

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Journal Reference: 1. David K. Kim, Tarun R. Vemulkar, Soong Ju Oh, Weon-Kyu Koh, Christopher B. Murray, Cherie R. Kagan. Ambipolar and Unipolar PbSe Nanowire Field-Effect Transistors. ACS Nano, 2011; 110321110927018 DOI: 10.1021/nn200348p