New material could hold key to reducing energy consumption in computers and electronics

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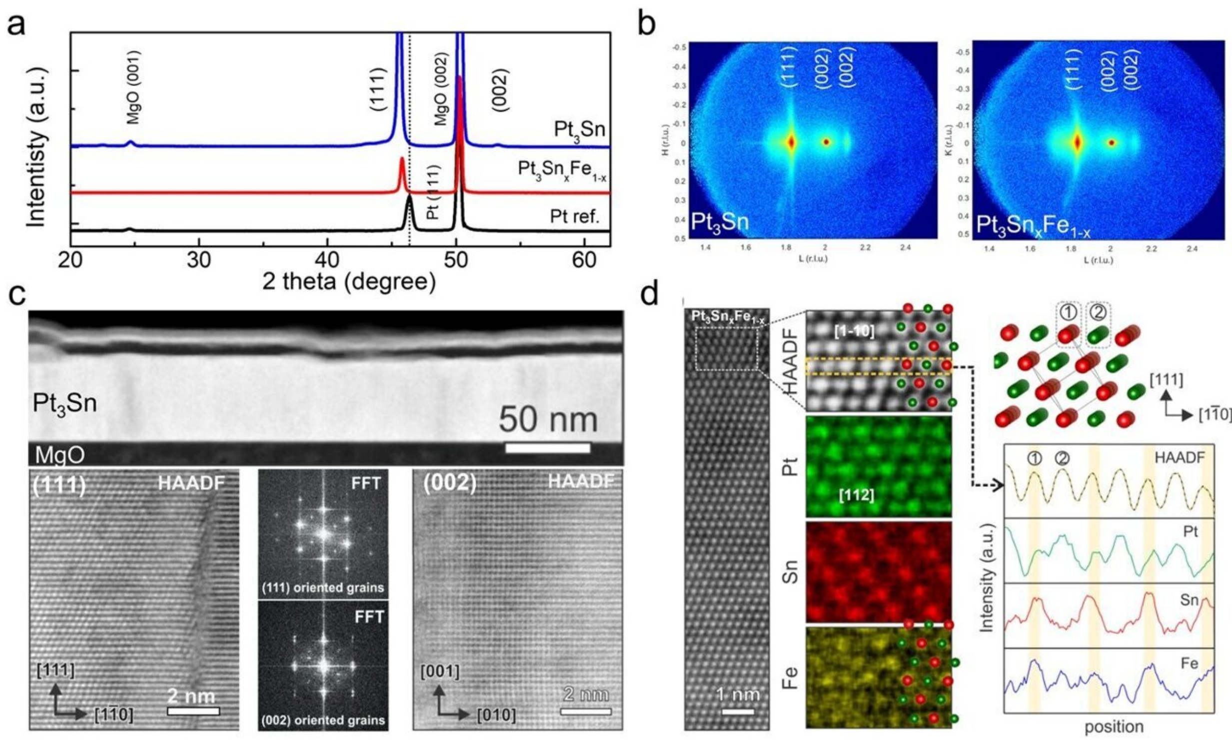

Crystalline structure of the Pt_3Sn samples. **a** Specular (θ−2θ scans) XRD patterns of the Pt reference, Pt_3Sn and $Pt_3Sn_xFe_{1-x}$ thin films. **b** Reciprocal space maps (RSM) around the (002) Bragg reflection of the MgO substrate of the Pt_3Sn and $Pt_3Sn_xFe_{1-x}$ thin films. Both the Pt reference and the Pt_3Sn and $Pt_3Sn_xFe_{1-x}$ thin films grow epitaxially on the MgO substrate along the (111) direction. The XRD experiments show a small amount of (001) oriented grains. **c** HAADF-STEM images of the Pt_3Sn thin film on the MgO substrate. Low-magnification image (top panel) shows the Pt_3Sn film and capping layers with relatively uniform thicknesses. Atomic-resolution HAADF-STEM images obtained from (111) oriented (bottom-left) and (002) oriented (bottom-right) grains demonstrate their crystalline orientations. Fast Fourier transforms (FFTs) from the (111) and (002) oriented grains are also displayed (bottom-middle). **d** Atomic-resolution HAADF-STEM image and EDX elemental maps of the $Pt_3Sn_xFe_{1-x}$. Schematic of the atomic structure is illustrated along with elemental line profiles, extracted from the region in the yellow-dashed line on the HAADF-STEM image. Credit: *Nature Communications* (2023). DOI: 10.1038/s41467-023-39408-2

A University of Minnesota Twin Cities team has, for the first time, synthesized a thin film of a unique topological semimetal material that has the potential to generate more computing power and memory storage while using significantly less energy. The researchers were also able to closely study the material, leading to some important findings about the physics behind its unique properties.

The study is published in *Nature Communications*.

As evidenced by the United States' recent CHIPS and Science Act, there is a growing need to increase semiconductor manufacturing and support research that goes into developing the materials that power electronic devices everywhere. While traditional semiconductors are the technology behind most of today's computer chips, scientists and engineers are always looking for new materials that can generate more power with less energy to make electronics better, smaller, and more efficient.

One such candidate for these new and improved computer chips is a class of quantum materials called topological semimetals. The electrons in these materials behave in different ways, giving the materials unique properties that typical insulators and metals used in electronic devices do not have. For this reason, they are being explored for use in spintronic devices, an alternative to traditional semiconductor devices that leverage the spin of electrons rather than the electrical charge to store data and process information.

In this new study, an interdisciplinary team of University of Minnesota researchers were able to successfully synthesize such a material as a thin film—and prove that it has the potential for high performance with low energy consumption.

"This research shows for the first time that you can transition from a weak topological insulator to a topological semimetal using a magnetic doping strategy," said Jian-Ping Wang, a senior author of the paper and a Distinguished McKnight University Professor and Robert F. Hartmann Chair in the University of Minnesota Department of Electrical and Computer Engineering.

"We're looking for ways to extend the lifetimes for our electrical devices and at the same time lower the energy consumption, and we're trying to do that in non-traditional, out-of-the-box ways."

Researchers have been working on topological materials for years, but the University of Minnesota team is the first to use a patented, industry-compatible sputtering process to create this semimetal in a thin film format. Because their process is industry compatible, Wang said, the technology can be more easily adopted and used for manufacturing real-world devices.

"Every day in our lives, we use electronic devices, from our cell phones to dishwashers to microwaves. They all use chips. Everything consumes energy," said Andre Mkhoyan, a senior author of the paper and Ray D. and Mary T. Johnson Chair and Professor in the University of Minnesota Department of Chemical Engineering and Materials Science.

"The question is, how do we minimize that energy consumption? This research is a step in that direction. We are coming up with a new class of materials with similar or often better performance, but using much less energy."

Because the researchers fabricated such a high-quality material, they were also able to closely analyze its properties and what makes it so unique.

"One of the main contributions of this work from a physics point of view is that we were able to study some of this material's most fundamental properties," said Tony Low, a senior author of the paper and the Paul Palmberg Associate Professor in the University of Minnesota Department of Electrical and Computer Engineering.

"Normally, when you apply a magnetic field, the longitudinal resistance of a material will increase, but in this particular topological material, we have predicted that it would decrease. We were able to corroborate our theory to the measured transport data and confirm that there is indeed a negative resistance."

Low, Mkhoyan, and Wang have been working together for more than a decade on topological materials for next generation electronic devices and systems—this research wouldn't have been possible without combining their respective expertise in theory and computation, material growth and characterization, and device fabrication.

"It not only takes an inspiring vision but also great patience across the four disciplines and a dedicated group of team members to work on such an important but challenging topic, which will potentially enable the transition of the technology from lab to industry," Wang said.

More information: Delin Zhang et al, Robust negative longitudinal

magnetoresistance and spin–orbit torque in sputtered Pt_3Sn and $Pt_3Sn_xFe_{1-x}$ topological semimetal, *Nature Communications* (2023). DOI: 10.1038/s41467-023-39408-2

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