A new, positive approach could be the key to next-generation, transparent electronics

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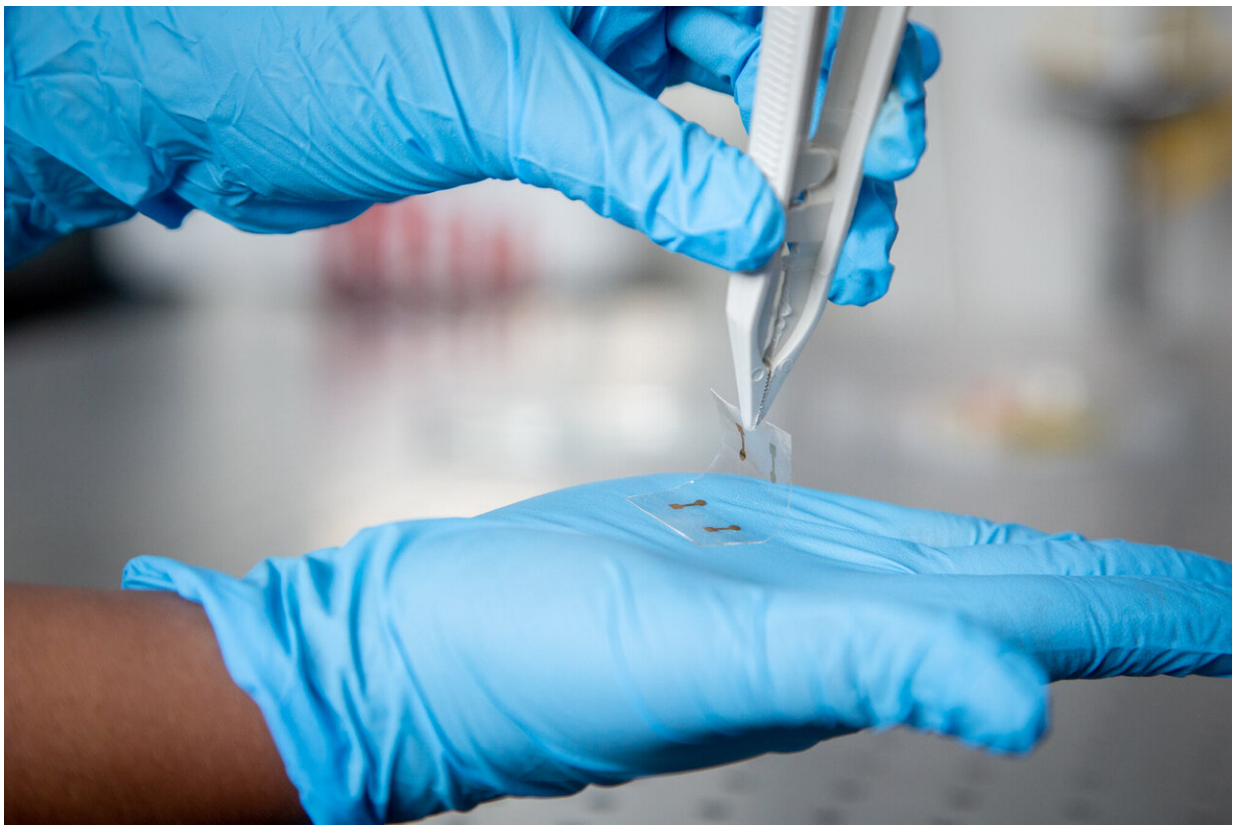


The optical transparency of the new materials could enable futuristic, flexible, transparent electronics. Credit: RMIT University

A new study published this week could pave the way to revolutionary, transparent electronics. Such see-through devices could potentially be integrated in glass, in flexible displays, and in smart contact lenses, bringing to life futuristic devices that seem like the product of science fiction.

For several decades, researchers have sought a new class of electronics based on semiconducting oxides, whose optical transparency could enable these fully-transparent electronics.

Oxide-based devices could also find use in power electronics and communication technology, reducing the carbon footprint of our utility networks.

An RMIT-led team has now introduced ultrathin beta-tellurite to the two-dimensional (2D) semiconducting material family, providing an answer to this decades-long search for a high mobility p-type oxide.

"This new, high-mobility p-type oxide fills a crucial gap in the materials spectrum to enable fast, transparent circuits," says team leader Dr. Torben Daeneke, who led the collaboration across three FLEET nodes.

Other key advantages of the long-sought-after oxide-based semiconductors are their stability in air, less-stringent purity requirements, low costs and easy deposition.

"In our advance, the missing link was finding the right, 'positive' approach," says Torben.

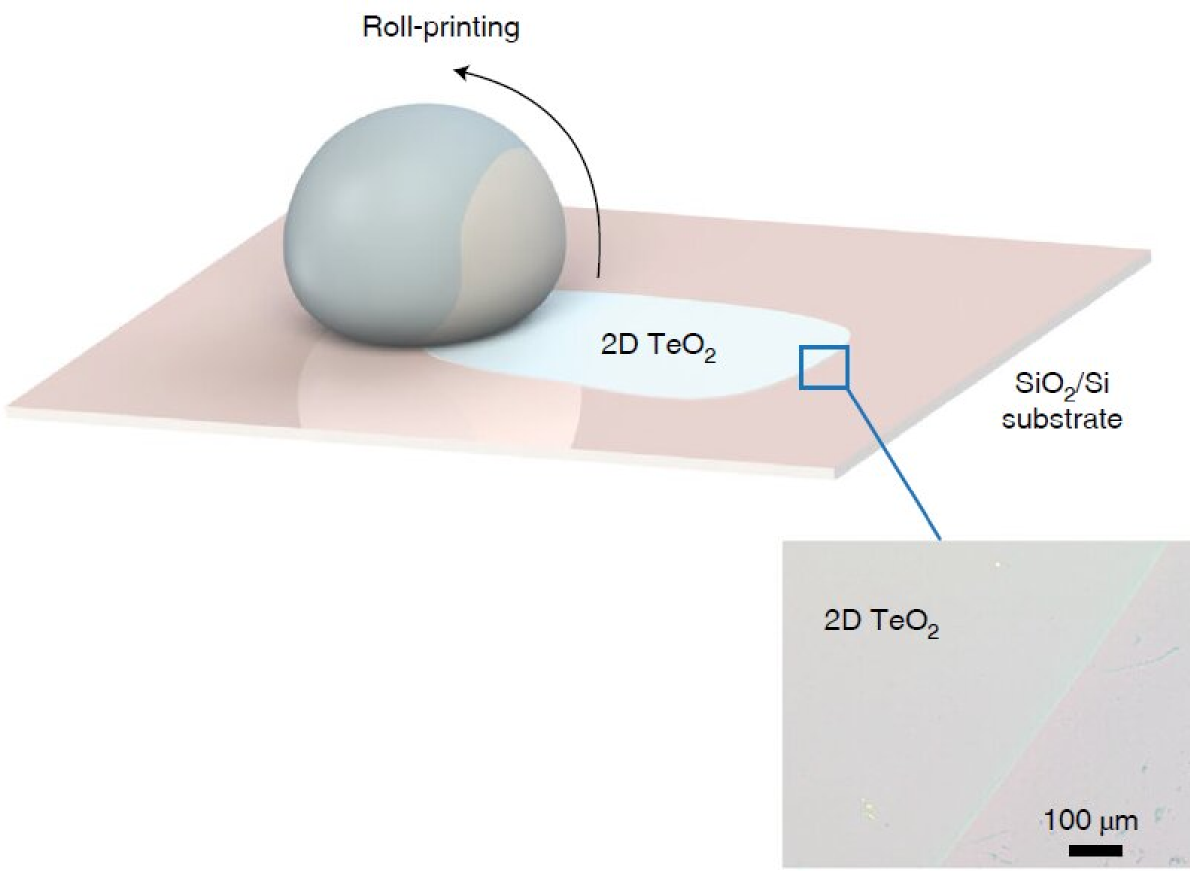
Positivity has been lacking

There are two types of semiconducting materials. 'N-type' materials have abundant negatively-charged electrons, while 'p-type' semiconductors possess plenty of positively-charged holes.

It's the stacking together of complementary n-type and p-type materials that allows electronic devices such as diodes, rectifiers and logic circuits.

Modern life is critically reliant on these materials since they are the building blocks of every computer and smartphone.

A barrier to oxide devices has been that while many high-performance n-type oxides are known, there is a significant lack of high-quality p-type oxides.



A molten mixture of tellurium and selenium rolled over a surface deposits an atomically-thin sheet of beta-tellurite. Credit: FLEET

Theory prompts action

However, in 2018, a computational study revealed that beta-tellurite (β-TeO_2) could be an attractive p-type oxide candidate, with tellurium's peculiar place in the periodic table meaning it can behave as both a metal and a non-metal, providing its oxide with uniquely useful properties.

"This prediction encouraged our group at RMIT University to explore its properties and applications," says Dr. Torben Daeneke, who is a FLEET associate investigator.

Liquid metal—pathway to explore 2D materials

Dr. Daeneke's team demonstrated the isolation of beta-tellurite with a specifically developed synthesis technique that relies on liquid metal chemistry.

"A molten mixture of tellurium (Te) and selenium (Se) is prepared and allowed to roll over a surface," explains co-first author Patjaree Aukarasereenont.

"Thanks to the oxygen in ambient air, the molten droplet naturally forms a thin surface oxide layer of beta-tellurite. As the liquid droplet is rolled over the surface, this oxide layer sticks to it, depositing atomically thin oxide sheets in its way."

"The process is similar to drawing: you use a glass rod as a pen and the liquid metal is your ink," explains Ms Aukarasereenont, who is a FLEET Ph.D. student at RMIT.

While the desirable β-phase of tellurite grows below 300 °C, pure tellurium has a high melting point, above 500 °C. Therefore, selenium was added to design an alloy that has a lower melting point, making the synthesis possible.

"The ultrathin sheets we obtained are just 1.5 nanometres thick—corresponding to only few atoms. The material was highly transparent across the visible spectrum, having a bandgap of 3.7 eV which means that they are essentially invisible to the human eye" explains co-author Dr. Ali Zavabeti.

Assessing beta-tellurite: up to 100 times faster

To assess the electronic properties of the developed materials, field-effect transistors (FETs) were fabricated.

"These devices showed characteristic p-type switching as well as a high hole mobility (roughly 140 $cm^2V^{-1}s^{-1}$), showing that beta-tellurite is ten to one hundred times faster than existing p-type oxide semiconductors. The excellent on/off ratio (over 10^6) also attests the material is suitable for power efficient, fast devices," Ms Patjaree Aukarasereenont said.

The RMIT team from left, Ali Zavabeti, Patjaree Aukarasereenont and Torben Daeneke with transparent electronics. Credit: FLEET

"The findings close a crucial gap in the electronic material library," Dr. Ali Zavabeti said.

"Having a fast, transparent p-type semiconductor at our disposal has the potential to revolutionize transparent electronics, while also enabling better displays and improved energy-efficient devices."

The team plans to further explore the potential of this novel semiconductor. "Our further investigations of this exciting material will explore integration in existing and next-generation consumer electronics," says Dr. Torben Daeneke.

The paper, "High mobility p-type semiconducting two-dimensional β-TeO_2," was published in *Nature Electronics* in April 2021.

More information: High-mobility p-type semiconducting two-dimensional β-TeO_2, *Nature Electronics* DOI: 10.1038/s41928-021-00561-5

Provided by FLEET