Electronically-smooth '3-D graphene': A bright future for trisodium bismuthide

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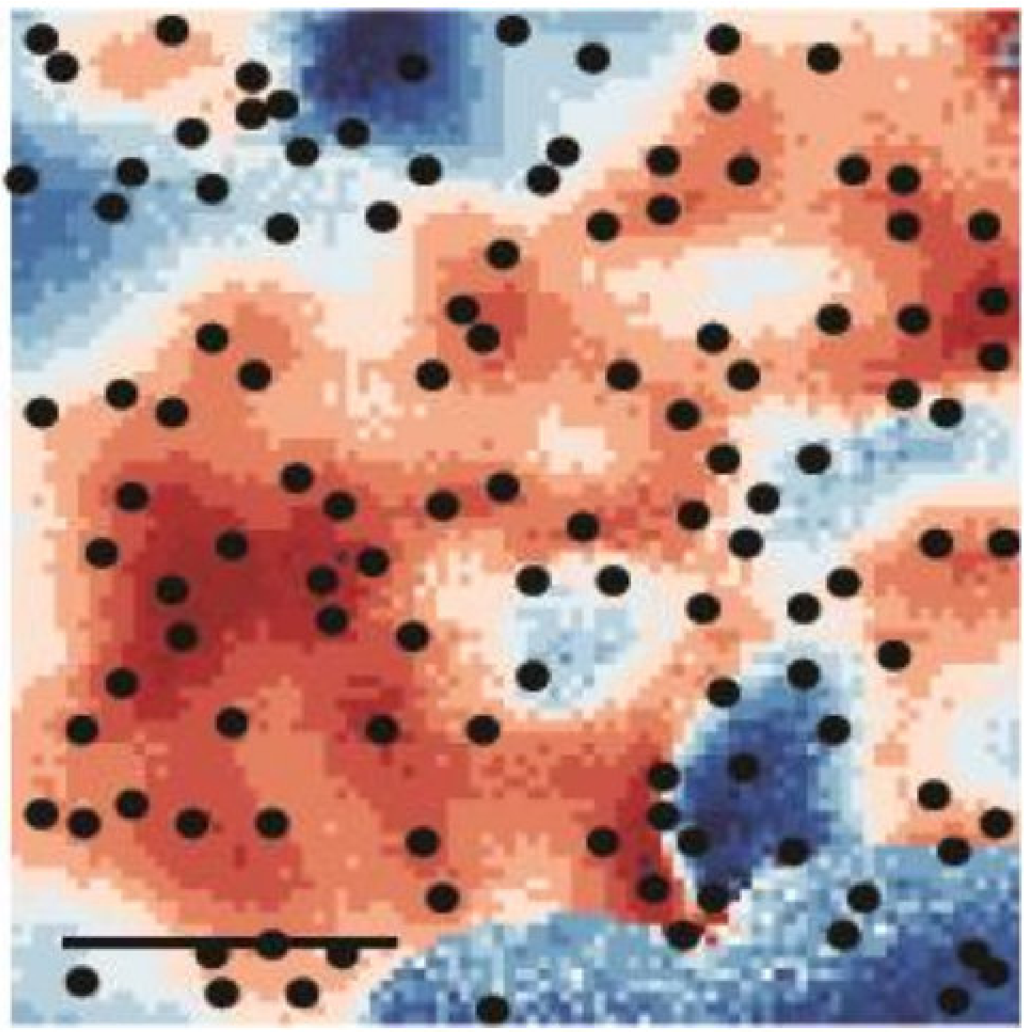


Map of charge inhomogeneities, known as ‘charge puddles’. Credit: ARC Centre of Excellence in Future Low-Energy Electronics Technologies

Researchers have found that the topological material trisodium bismuthide (Na_3Bi) can be manufactured to be as 'electronically smooth' as the highest-quality graphene-based alternative, while maintaining graphene's high electron mobility.

Na_3Bi is a Topological Dirac Semimetal (TDS), considered a 3D equivalent of graphene in that it shows the same extraordinarily high electron mobility.

In graphene, as in a TDS, electrons move at constant velocity, independent of their energy.

This high electron mobility is highly desirable in materials investigated for fast-switching electronics. The flow of electrons in graphene can be, theoretically, 100 times as fast as in silicon.

However in practice there are limitations to graphene's remarkable electron mobility, driven by the material's two-dimensional nature.

Although graphene itself can be extremely pure, it is far too flimsy to use as a standalone material, and must be bound with another material. And because graphene is atomically thin, impurities in that substrate are able to cause electronic disorder within the graphene.

Such microscopic inhomogeneities, known as 'charge puddles', limit the mobility of charge carriers.

In practice, this means that graphene-based devices must be painstakingly constructed with a graphene sheet laid upon a substrate material that minimises such electronic disorder. Hexagonal boron-nitride (h-BN) is commonly used for this purpose.

But now, researchers at Australia's FLEET research centre have found that trisodium bismuthide (Na_3Bi) grown in their labs at Monash University are as electronically smooth as the highest-quality graphene/h-BN.

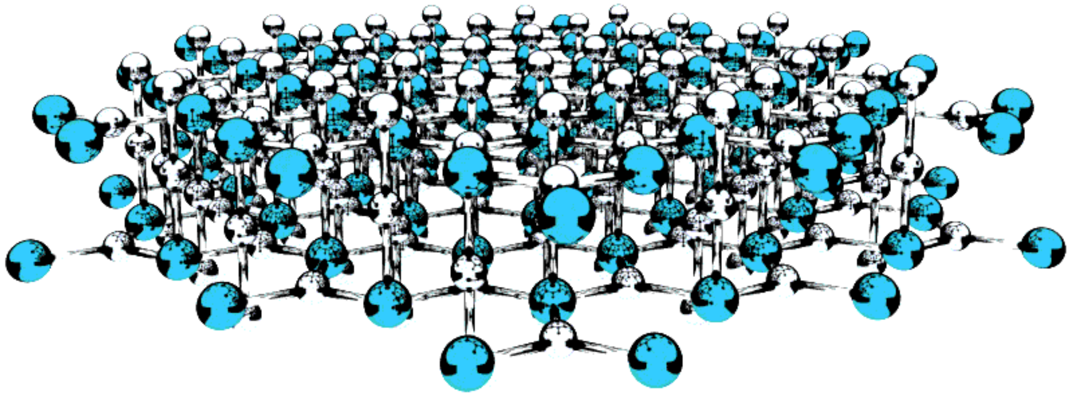
It's a significant achievement, says lead researcher Dr Mark Edmonds. "This is the first time a 3D Dirac material has been measured in such a way," Dr Edmonds says. "And we are excited to have found such a high degree of electronic smoothness in this material."

The discovery will be critical for advancement of the study of this new topological material, which could have wide applications in electronics. "It's impossible to know how many fields of research this could open," says Dr Edmonds. "The same finding in graphene/h-BN sparked considerable supplementary studies in 2011."

With electronic-smoothness of Na3Bi now demonstrated, an array of other research possibilities open up. There have been many studies into the relativistic (high mobility) flow of electrons in graphene since it was discovered in 2004. With this latest study, similar studies into Na3Bi can be expected.

Na_3Bi offers a number of interesting advantages over graphene.

As well as avoiding the difficult construction methods involved in bi-layer graphene/h-BN devices, Na_3Bi can be grown on a millimetre scale or larger. Currently, graphene-h-BN is limited to only a few micrometres.



Trisodium bismuthide structure shown with sodium atoms white and bismuth atoms teal. Credit: ARC Centre of Excellence in Future Low-Energy Electronics Technologies

Another significant advantage is the potential to use Na_3Bi as the conducting channel in a new generation of transistors - one built upon the science of topological insulators. The study was published in *Science Advances* in December 2017.

Next steps & topological transistors

"The discovery of electronically-smooth, thin films of TDS are an important step towards switchable topological transistors," says FLEET Director Prof Michael Fuhrer.

"Graphene is a fantastic conductor, but it can't be 'switched off', or controlled," says Prof Fuhrer. "Topological materials, such as Na_3Bi, can be switched from conventional insulator to topological insulator by the application of voltage or magnetic field."

Topological insulators are novel materials that behave as electrical insulators in their interior, but can carry a current along their edges. Unlike a conventional electrical path, such topological edge paths can carry electrical current with near-zero dissipation of energy, meaning that topological transistors can switch without burning energy.

Topological materials were recognised in last year's Nobel Prize in Physics.

Topological transistors would 'switch', just as a traditional transistor. The application of a gate potential would switch the edge paths in a Na_3Bi channel between being a topological insulator ('on') and a conventional insulator ('off').

The bigger picture: energy use in computation

The overarching challenge is the growing amount of energy used in computation and information technology (IT).

Each time a transistor switches, a tiny amount of energy is burnt, and with trillions of transistors switching billions of times per second, this energy adds up. Already, the energy burnt in computation accounts for 5 per cent of global electricity use, and it's doubling every decade.

For many years, the energy demands of an exponentially growing number of computations was kept in check by ever-more efficient, and ever-more compact computer chips - an effect related to Moore's Law. But as fundamental physics limits are approached, Moore's Law is ending, and there are limited future efficiencies to be found.

"For computation to continue to grow, to keep up with changing demands, we need more-efficient electronics," says Prof Michael Fuhrer. "We need a new type of transistor that burns less energy when it switches."

"This discovery could be a step in the direction of topological transistors that transform the world of computation."

The study is published in *Science Advances*.

More information: "Spatial charge inhomogeneity and defect states in topological Dirac semimetal thin films of Na3Bi" *Science Advances*, advances.sciencemag.org/content/3/12/eaao6661

Provided by ARC Centre of Excellence in Future Low-Energy Electronics Technologies

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