Physicists take a step closer to building a graphene-based topological insulator

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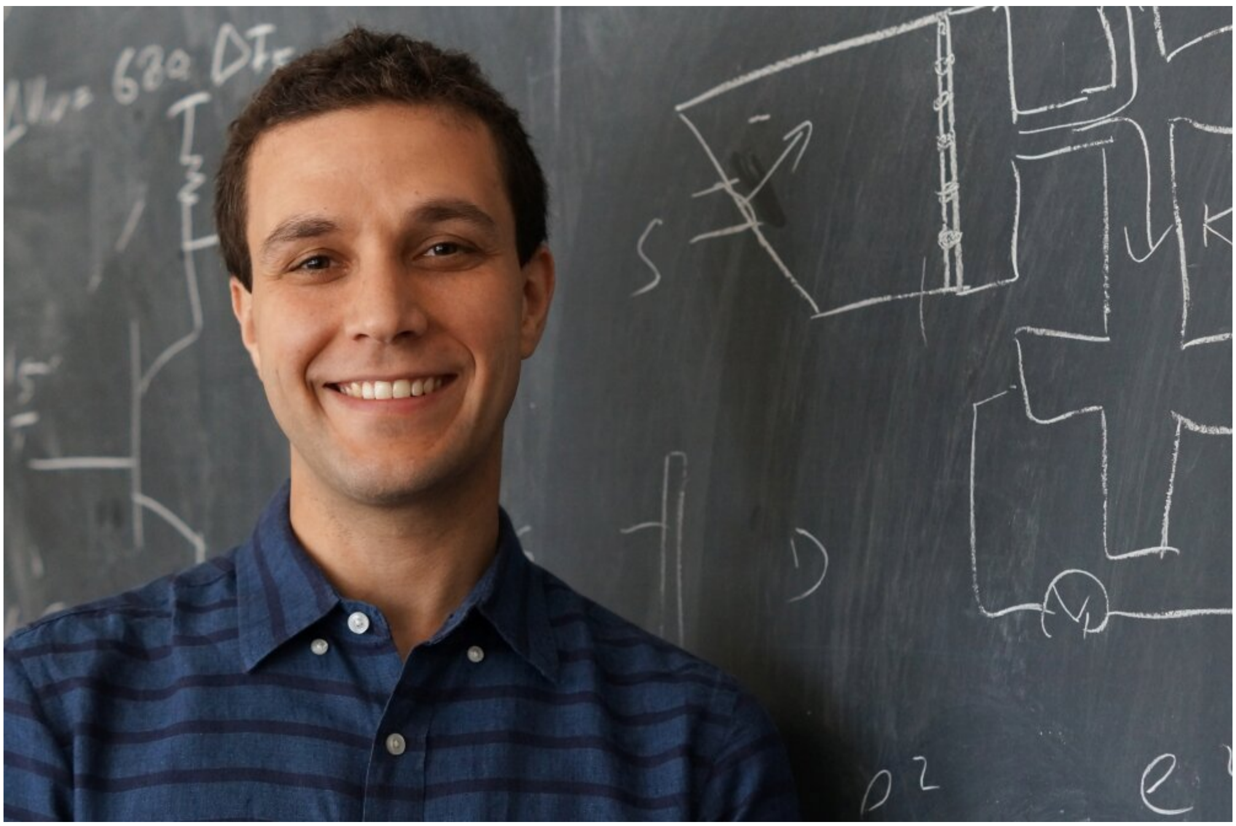

Andrea Young. Credit: SONIA FERNANDEZ

In 2005, condensed matter physicists Charles Kane and Eugene Mele considered the fate of graphene at low temperatures. Their work led to the discovery of a new state of matter dubbed a "topological insulator," which would usher in a new era of materials science.

"A topological insulator is a material that is an insulator in its interior but is highly conducting on its surface," said UC Santa Barbara assistant physics professor Andrea Young. In two-dimensions, an ideal topological insulator would have "ballistic" conductance at its edges, Young explained, meaning that electrons traveling through the region would encounter zero resistance.

Ironically, while Kane and Mele's work would lead to the discovery of topological insulating behavior in a wide variety of materials, their original prediction—of a topological insulator in graphene—has remained unrealized.

At the heart of the trouble is spin-orbit coupling—a weak effect in which the spin of the electron interacts with its orbital motion aroun the nucleus. Critical to all topological insulators, spin-orbit coupling is exceptionally weak in graphene, so that any topological insulating behavior is drowned out by other effects arising from the surface on which the graphene is supported.

"The weak spin-orbit coupling in graphene is a great pity," said postdoctoral researcher Joshua Island, because in practice things haven't really worked out that well for topological insulators in two dimensions. "The two dimensional topological insulators known to date are disordered and not very easy to work with," Island said. The conductance at the edges tends to diminish rapidly with the distance the electrons travel, suggesting it is far from ballistic. Realizing a topological insulator in graphene, an otherwise highly perfect two dimensional material, could provide a basis for low-dissipation ballistic electrical circuits or form the material substrate for topologically protected quantum bits.

Now, in work published in the journal *Nature*, Island, Young and their collaborators have found a way to turn graphene into a topological insulator (TI). "The goal of the project was to increase or enhance the spin-orbit coupling in graphene," lead author Island said, adding that attempts have been made over the years with limited success. "A way to do this is to put a material that has a very large spin-orbit coupling in close proximity with the graphene. The hope was that by doing that your graphene electrons will take on this property of the underlying material," he explained.

The material of choice? After studying several possibilities, the researchers settled on a transition metal dichalcogenide (TMD), consisting of the transition metal tungsten and the chalcogen selenium. Similar to graphene, tungsten diselenide comes in two-dimensional monolayers, bound together by van der Waals forces, which are relatively weak and distance-dependent interactions between atoms or molecules. Unlike graphene, however, the heavier atoms of the TMD lead to stronger spin-orbit coupling. The resulting device feature's graphene's ballistic electron conductance imbued with the strong spin-orbit coupling from the nearby TMD layer.

"We did see a very clear enhancement of that spin-orbit coupling," Island said.

"By adding spin-orbit coupling of just the right type, Joshua was able to find that this in fact leads to a new phase which is almost topologically insulating," Young said. In the original idea, he explained, the topological insulator consisted of a monolayer of graphene with a strong spin-orbit coupling.

"We had to use a trick only available in graphene multilayers to create the right type of spin-orbit coupling," Young explained about their experiment, which used a graphene bilayer. "And so you get something that approximates two topological insulators stacked on top of each other." Functionally, however, Island's device performs as well as other known 2-D topological insulators—the all-important edge states propagate for at least several microns, much longer than in other known TI materials.

Furthermore, according to Young, this work is one step closer to building an actual topological insulator with graphene. "Theoretical work has since shown that a graphene trilayer, fabricated in the same way, would lead to a true topological insulator."

Most importantly, the devices realized by Island and Young can be easily tuned between a topological insulating phase and a regular insulator, which does not have conducting edge states.

"You can route these perfect conductors around wherever you want," he said, "And that's something nobody's been able to do with other materials."

More information: Spin–orbit-driven band inversion in bilayer graphene by the van der Waals proximity effect, *Nature* (2019). DOI: 10.1038/s41586-019-1304-2 , www.nature.com/articles/s41586-019-1304-2

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