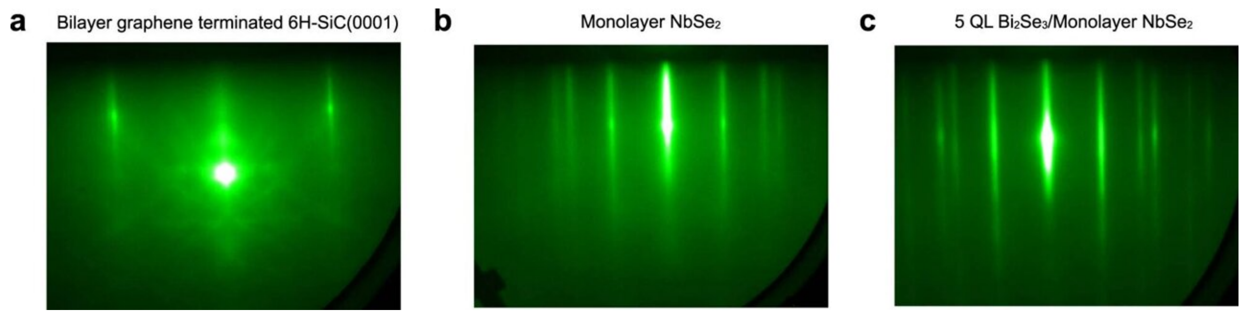
New hybrid structures could pave the way to more stable quantum computers

October 27 2022, by Gail McCormick



RHEED patterns during MBE growth. **(a)** Bilayer graphene terminated 6H-SiC(0001) substrate. **(b)** Monolayer $NbSe_2$ film grown on bilayer graphene. **(c)** 5 QL Bi_2Se_3/monolayer $NbSe_2$ heterostructure grown on bilayer graphene. Credit: *Nature Materials* (2022). DOI: 10.1038/s41563-022-01386-z

A new way to combine two materials with special electrical properties—a monolayer superconductor and a topological insulator—provides the best platform to date to explore an unusual form of superconductivity called topological superconductivity. The combination could provide the basis for topological quantum computers that are more stable than their traditional counterparts.

Superconductors—used in powerful magnets, digital circuits, and imaging devices—allow the electric current to pass without resistance, while topological insulators are thin films only a few atoms thick that restrict the movement of electrons to their edges, which can result in unique properties. A team led by researchers at Penn State describe how they have paired the two materials in a paper appearing Oct. 27 in the journal *Nature Materials*.

"The future of quantum computing depends on a kind of material that we call a topological superconductor, which can be formed by combining a topological insulator with a superconductor, but the actual process of combining these two materials is challenging," said Cui-Zu Chang, Henry W. Knerr Early Career Professor and Associate Professor of Physics at Penn State and leader of the research team.

"In this study, we used a technique called molecular beam epitaxy to synthesize both topological insulator and superconductor films and create a two-dimensional heterostructure that is an excellent platform to explore the phenomenon of topological superconductivity."

In previous experiments to combine the two materials, the superconductivity in thin films usually disappears once a topological insulator layer is grown on top. Physicists have been able to add a topological insulator film onto a three-dimensional "bulk" superconductor and retain the properties of both materials.

However, applications for topological superconductors, such as chips with low power consumption inside quantum computers or smartphones, would need to be two-dimensional.

In this paper, the research team stacked a topological insulator film made of bismuth selenide (Bi_2Se_3) with different thicknesses on a superconductor film made of monolayer niobium diselenide ($NbSe_2$), resulting in a two-dimensional end-product. By synthesizing the heterostructures at very lower temperature, the team was able to retain both the topological and superconducting properties.

"In superconductors, electrons form 'Cooper pairs' and can flow with zero resistance, but a strong magnetic field can break those pairs," said Hemian Yi, a postdoctoral scholar in the Chang Research Group at Penn State and the first author of the paper.

"The monolayer superconductor film we used is known for its 'Ising-type superconductivity,' which means that the Cooper pairs are very robust against the in-plane magnetic fields. We would also expect the topological superconducting phase formed in our heterostructures to be robust in this way."

By subtly adjusting the thickness of the topological insulator, the researchers found that the heterostructure shifted from Ising-type superconductivity—where the electron spin is perpendicular to the film—to another kind of superconductivity called "Rashba-type superconductivity"—where the electron spin is parallel to the film.

This phenomenon is also observed in the researchers' theoretical calculations and simulations.

This heterostructure could also be a good platform for the exploration of Majorana fermions, an elusive particle that would be a major contributor to making a topological quantum computer more stable than its predecessors.

"This is an excellent platform for the exploration of topological superconductors, and we are hopeful that we will find evidence of topological superconductivity in our continuing work," said Chang. "Once we have solid evidence of topological superconductivity and demonstrate Majorana physics, then this type of system could be adapted for quantum computing and other applications."

More information: Cui-Zu Chang, Crossover from Ising- to Rashba-

type superconductivity in epitaxial Bi_2Se_3/monolayer $NbSe_2$ heterostructures, *Nature Materials* (2022). DOI: 10.1038/s41563-022-01386-z

Provided by Pennsylvania State University