Third research team close to creating Majorana fermion

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(PhysOrg.com) -- Recently there has been a virtual explosion of research efforts aimed at creating the elusive Majorana fermion with different groups claiming to be near to creating them. First there was news that a team at Stanford was on the precipice, then came reports that another group at Delft University of Technology in The Netherlands was very close as well. Now comes news of yet another team who some think may have the best chance yet of making them, and better yet, using them to help make quantum computing possible. This third group, made up of Chinese and American teams takes the approach, as they describe in their paper published in *Science*, of growing a topical insulator film on top of a superconductor.

A fermion is a particle that adheres to the Fermi-Dirac statistics - as opposed to a boson. A Majorana fermion specifically, is a fermion particle pairing that is its own anti-particle, and was first proposed by Ettore Majorana back in 1937. To make a Majorana fermion, a particle and its anti-particle must be combined into a single new particle.

In similar fashion, as a result of the way some crystals are grown there can exist conducting electrons and so-called mobile holes, which are akin to electron anti-particles. They form when an electron moves out of the lattice structure. If a conducting electron falls into such a hole, it disappears, much the same way particles and anti-particles obliterate one another if they happen to meet. Thus, creating a Majorana fermion has been a significant problem.

To create an environment where electrons and holes could co-exist, researchers have been using superconductors paired with topological insulators, or substances that conduct electricity only on their surfaces. When the topological insulator is made to meet with the superconductor, the electrical field creates a boundary that prevents the electrons from falling into the holes and disappearing. Under such conditions, Majorana fermions should be able to form.

In this latest effort, the research team has coated a superconductor with a topological insulator, creating an ultra smooth juncture between the two. The resulting conditions, the researchers believe, should be optimal for the creation of Majorana fermions. And though they haven't as yet spotted any, they believe they are very close. If they do spot them, they believe that by applying an electrical field they should be able to control them. And if that happens, they just might be able to use them as qubits in a quantum computer.

Using Majorana fermions instead of quantum bits in a quantum computer is considered to be preferable because they are considered to be more robust.

It's still not known at this time if any of the three research efforts will prove fruitful, and if so, which will win out over the others, but it appears clear that the seventy five year search for a way to create Majorana fermions may at long last result in success.

More information: The Coexistence of Superconductivity and Topological Order in the Bi2Se3 Thin Films, *Science* DOI: 10.1126/science.1216466 (ArXiv preprint)

ABSTRACT
Three-dimensional topological insulators (TIs) are characterized by their nontrivial surface states in which electrons have their spin locked at a

right angle to their momentum under the protection of time reversal symmetry. The topologically ordered phase in TIs does not break any symmetry. The interplay between topological order and symmetry breaking such as observed in superconductivity can lead to new quantum phenomena and devices. We fabricate a superconducting TI/Superconductor (SC) heterostructure by growing Bi_2Se_3 thin films on superconductor $NbSe_2$ substrate. Using scanning tunneling microscopy and angle-resolved photoemission spectroscopy, we observed the superconducting gap at Bi_2Se_3 surface in the regime of Bi_2Se_3 film thickness where topological surface states form. This observation lays the groundwork for experimentally realizing Majorana fermions in condensed matter physics.