Experimental Signature of Majorana Fermions

April 25, 2012 (HP47). The *Science* journal pre-published in *Sciencexpress* of April 12, 2012, a paper on "Signatures of Majorana Fermions in Hybrid Superconductor-Semiconductor Nanowire devices" by V. Mourik *et al*. (group of Leo Kouvenhoven) of the Kavli Institute on Nanoscience, Delft University, The Netherlands,. This is the first reasonably convincing experiment supporting the existence of hypothetical Majorana fermions in semiconductor nanowires coupled to superconductors. Majorana fermions are particles identical to their own antiparticles, theoretically postulated by Ettore Majorana in 1930s and recently predicted to exist under certain conditions in topological superconductors [1, 2]. Majorana states in such superconductors do not require the presence of a vortex in the system, in contrast to the theoretical proposal we highlighted in HP41.

The spectroscopic demonstration of bound Majorana fermions signature by the Delft group appears to be a significant fundamental physics event which may eventually have important consequences for quantum computing. The expected although unproven statistical property of the Majorana zero-energy bound states would be the ability to process quantum information free from local sources of decoherence.

The authors report electrical spectroscopic measurements on the density of states in InSb nanowires contacted with one normal (Au) and one *s*-wave superconducting (NbTiN) electrode held at mK temperature. Such In Sb nanowires are known to have strong spin-orbit interaction and a large *g* factor. Gate voltages vary electron density and define a tunnel barrier between normal and superconducting contacts. In the presence of magnetic fields on the order of 100 mT, the authors observed bound, mid-gap states at zero bias voltage, *i.e*., zero energy. These bound states remain fixed to zero bias even when magnetic fields and gate voltages vary over considerable ranges. The s-wave superconductor induces in InSb a proximity superconducting gap of $\Delta = 250\ \mu\text{eV}$.

In the presence of magnetic field orthogonal to the nanowire and exceeding about B_{so} =0.15 T the authors expected to enter the topological phase with an energy gap of a few Kelvin and to observe Majorana zero-energy states, assuming a ballistic regime. Their observation of the zero-energy peak (zero-bias peak, ZBP) in the dI/dV *versus* V spectra of Figure 1A at $1 > B_{so} > 0.07$ T is interpreted as a signature of Majorana fermions. The experimenters varied all the essential experimental parameters (the intensity of magnetic field and its angle with the nanowire, the gate voltage, replaced the superconductor by a normal conductor, *etc*., and observed the ZBP only in conditions conforming to the theoretical prediction for Majorana states.

The reported work doesn't address the topological properties of Majorana fermions and the ways to any future qubit implementation will remain long and arduous. Nevertheless, it is an important step forward.

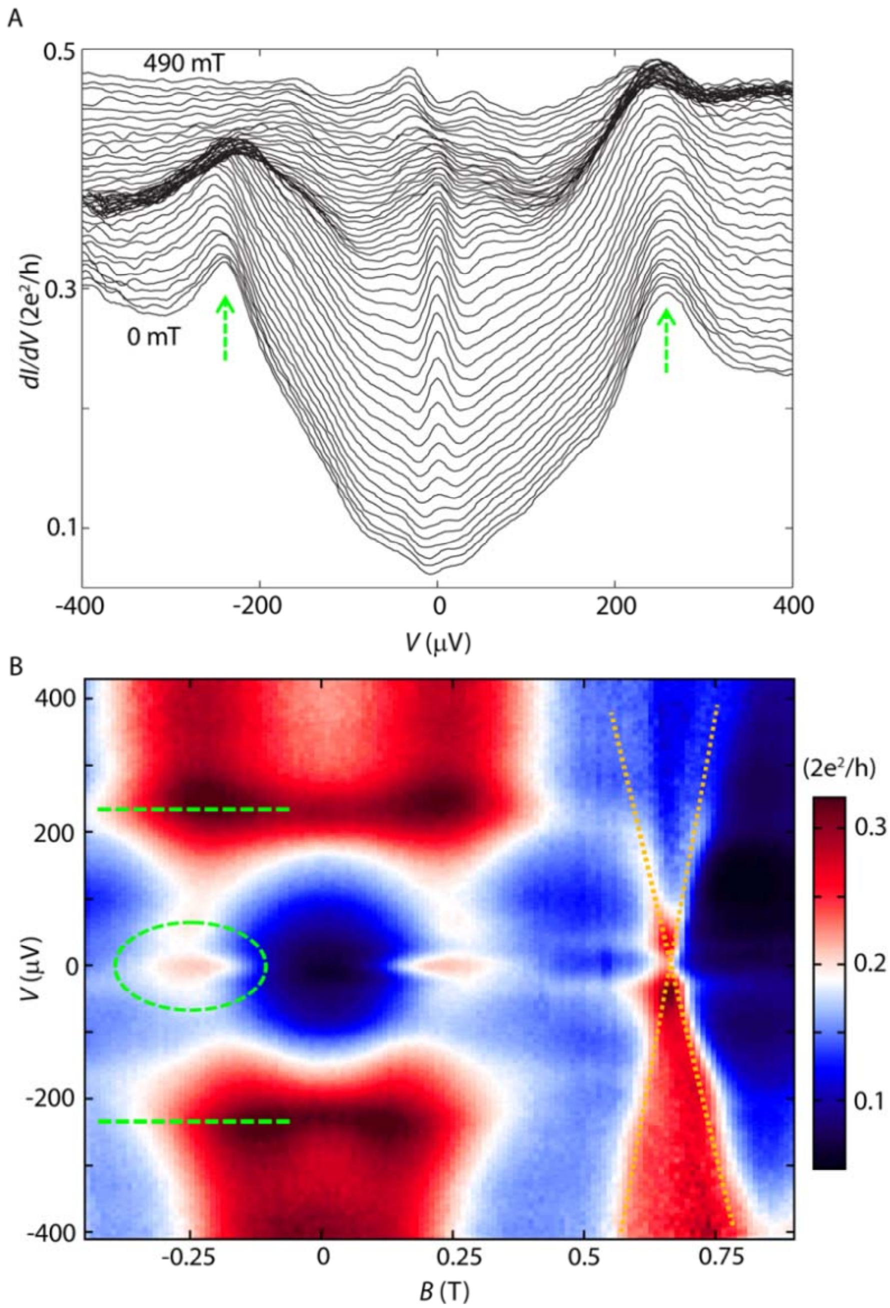

Fig. 1 (Fig. 2 of the paper). Magnetic field-dependent spectroscopy at 70 mK taken at different *B* field intensities (0 – 490 mT). The ZPB is highlighted by the dashed oval. Green arrows in Fig. 1A point to the energy gap induced in NbTiN. All other features and markings are discussed in the paper.

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[1] R. M. Lutchyn, J. D. Sau, S. Das Sarma, Majorana fermions and a topological phase transition in semiconductor-superconductor heterostructures. *Phys. Rev. Lett.* **105**, 077001 (2010).

[2] Y. Oreg, G. Refael, F. von Oppen, Helical liquids and Majorana bound states in quantum wires. *Phys. Rev. Lett.* **105**, 177002 (2010).