Topological superconductivity and Majorana fermions in a superconducting-ferromagnetic hybrid system

Tristan Cren*†[1], Gerbold Ménard[1], Sébastien Guissart[2], Christophe Brun[1], Raphaël Leriche[1], François Debontridder[1], Mircea Triff[2], Dimitri Roditchev[3], and Pascal Simon[2]

[1]Institut des NanoSciences de Paris – Sorbonne Universités, UPMC, CNRS – France
[2]Laboratoire de Physique des Solides – Université Paris-Saclay – France
[3]LPEM – CNRS, UPMC, ESPCI – France

Abstract

Majorana fermions are very peculiar quasiparticles that are their own antiparticle. They obey non-abelian statistics: upon exchange, they behave differently from fermions (antisymmetric) and bosons (symmetric). Their unique properties could be used to develop new kind of quantum computing schemes. Majorana states are predicted to appear as edge states of topological superconductors, in a similar way as Dirac surface states appears at the edge of topological insulators. Spectroscopic signatures of Majorana bound states were first observed in one-dimensional (1D) InAs nanowires proximity-coupled to a bulk superconductor. Then Nadj-Perge et al. [1] have realized a chain of Fe adatoms on a Pb(110) that induce locally a 1D topological p-wave superconductivity as demonstrated by the appearance of Majorana bound states at the extremity of the Fe chain. The Majorana states are strongly localized; they appear only on a few atoms at the end of the magnetic chains which inhibits their manipulation.

A different strategy, using sizeable magnetic disks made of Cobalt buried under a superconducting monolayer of Pb/Si(111), allows to generate topological superconductivity in 2D. In this case dispersive edge states crossing the gap appears around the magnetic domains [2]. These spectroscopic features are the signature of a locally induced topological superconductivity in 2D Pb/Co/Si(111). This is at odds with the Fe chains whose edge states are intrinsically 0D and are thus characterized by non-propagative bound states. Indeed, in 2D systems one expects to get some propagative Majorana edge states around the topological domains since the edges have a 1D character. The edge states in 2D topological superconductors are analogous to the edge states in Quantum Spin Hall systems. However, there is a very fundamental difference here as the superconducting topological edge states have the specificity of being Majorana excitations. We will show that superconducting vortices can be generated in topological domains; they support localized Majorana bound states in their core. Such Majorana vortex states have been the focus of numerous theoretical proposals for quantum computing schemes due to their non-Abelian anyonic nature. The manipulation of vortices in such 2D architecture may thus be an efficient way to do braiding experiments with Majorana bound states.

*Speaker
†Corresponding author: tristan.cren@upmc.fr

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