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(1) Majorana fermions in pinned vortices; (2) Manipulating and probing Majorana fermions using superconducting circuits; and (3) Controlling a nanowire spin-orbit qubit via electric-dipole spin resonance[1]

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We study [1,2] a heterostructure which consists of a topological insulator and a superconductor with a hole. This system supports a robust Majorana fermion state bound to the vortex core. We study the possibility of using scanning tunneling spectroscopy (i) to detect the Majorana fermion in this setup and (ii) to study excited states bound to the vortex core. The Majorana fermion manifests itself as an H-dependent zero-bias anomaly of the tunneling conductance. The excited states spectrum differs from the spectrum of a typical Abrikosov vortex, providing additional indirect confirmation of the Majorana state observation. We also study [3] how to manipulate and probe Majorana fermions using super-conducting circuits. In [4] we consider a semiconductor nanowire quantum dot with strong spin-orbit coupling (SOC), which can be used to achieve a spin-orbit qubit. In contrast to a spin qubit, the spin-orbit qubit can respond to an external ac electric field, i.e., electric-dipole spin resonance. We develop a theory [4] that can apply in the strong SOC regime. We find that there is an optimal SOC strength $\eta_{\rm opt} = \sqrt{2}/2$, where the Rabi frequency induced by the ac electric field becomes maximal. Also, we show that both the level spacing and the Rabi frequency of the spin-orbit qubit have periodic responses to the direction of the external static magnetic field. These responses can be used to determine the SOC in the nanowire.

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[4] R. Li, J.Q. You, C.P. Sun, F. Nori, *Controlling a Nanowire Spin-Orbit Qubit via Electric-Dipole Spin Resonance*, Phys. Rev. Lett. **111**, 086805 (2013).

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