Integrating micromagnets and hybrid nanowires in heterostructure Majorana fermions experiments

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Introduction and Purpose

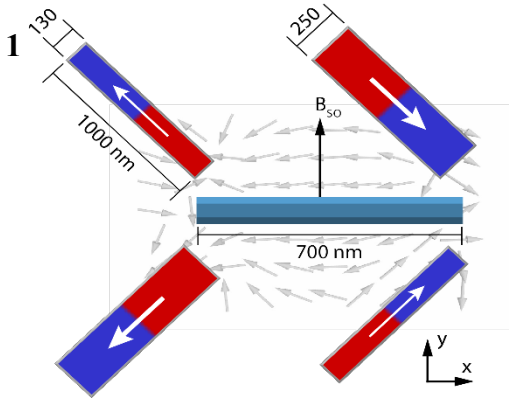
Majorana zero modes are expected to arise in semiconductor-superconductor hybrid systems, with potential topological quantum computing applications. One limitation of this approach is the need for a relatively high external magnetic field that should also change direction at the nanoscale.

This work proposes devices that incorporate micromagnets to address this challenge. We performed numerical simulations of stray magnetic fields from different micromagnet configurations, which were then used to solve for Majorana wavefunctions. Several devices were proposed, starting with a basic four-magnet design to align magnetic field with the nanowire and scaling up to nanowire T-junctions. The experimental feasibility of the approach was assessed by performing magnetic imaging of prototype patterns.

Summary and Conclusions

We consider device concepts in which micromagnets generate stray field patterns suitable for the generation of Majorana zero modes. Our approach assumes micromagnets placed next to semiconductor nanowires that possess strong spin-orbit coupling, and are coated with superconducting shells. The requirements on the stray magnetic fields are that they are of sufficient strength to drive a topological transition, and should be oriented as much as possible along the nanowire. The building block of our magnetic design is a Dragonfly configuration in which four micromagnets are magnetized such that the magnetic field lines flow out of one pair of mircomagnets, along the nanowire, and into the other pair (Figs 1 and 2). By repeating the Dragonfly pattern along the nanowire, we can extend the length of the topological segment with addition of coupling magnets. The approach can also be applied to T-junctions required for Majorana braiding experiments, in which case magnetic field turns into the T-junction leg that is perpendicular to the junction top.

1



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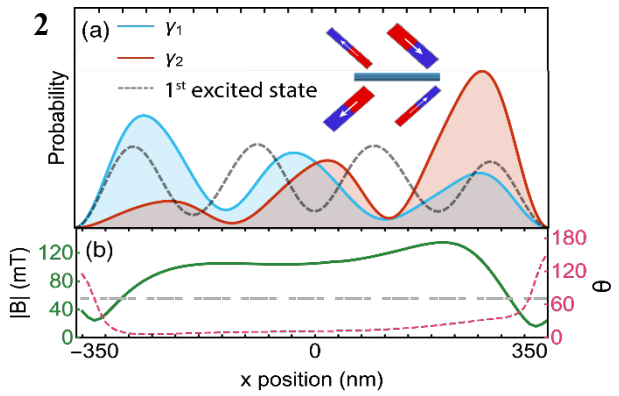

(1) The Dragonfly setup with four micromagnets (blue/red) and an overlay of the magnetic field calculated with MuMax3 (gray arrows). The nanowire runs horizontally with the spin-orbit axis vertical, indicated by $B_{so}. (2) (a) Probability distributions for two Majorana wavefunctions γ_1 and γ_2. The first excited state (dashed line) is a bulk nanowire state.
(b) Magnetic field profile produced from Dragonfly magnet configuration.