

Hybrid Ferromagnet–Superconductor Architectures for Programmable Magnonics

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One of the key challenges in magnonics is achieving local control over both the static magnetization configuration and magnetization dynamics. A promising route toward this goal is the use of hybrid ferromagnetic (FM)–superconducting (SC) nanostructures. Superconductors respond to external magnetic fields by generating screening (eddy) currents, which produce nonuniform magnetic field landscapes that can strongly influence the magnetization configuration and spin-wave dynamics in nearby ferromagnetic elements.

We investigate spin-wave (SW) confinement in a uniform ferromagnetic layer with perpendicular magnetic anisotropy (PMA), induced by the stray field of a superconducting strip positioned above it [1]. The SC strip creates an effective magnetic field well in the FM layer, capable of confining spin waves with frequencies below the ferromagnetic resonance frequency of the pristine FM layer. The depth of this potential well, as well as the number of bound spin-wave states, can be tuned by the uniform external magnetic field. Furthermore, we demonstrate the possibility of inducing a magnonic crystal on demand in an otherwise homogeneous FM layer by applying a periodic array of superconducting strips [2]. The amplitude of the internal field modulation—and consequently the width of the magnonic band gaps—can be controlled by the strength of the uniform applied field.

In addition, we explore the stabilization of skyrmions in a continuous ferromagnetic layer without relying on the Dzyaloshinskii–Moriya interaction (DMI), using the stray field generated by a superconductor. Specifically, we show that a superconducting nanoring [3] can stabilize a skyrmion texture in a PMA layer in the absence of DMI. Importantly, the use of superconducting nanorings enables local control of the magnetic field stabilizing the skyrmion via an electric field pulse. We analyze the conditions required for skyrmion stabilization as a function of the nanoring size and superconducting current, and identify a critical current threshold necessary for stability.

Our analytical results are validated by numerical simulations.

References:

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