Spin wave confinement in hybrid superconductor-ferromagnet nanostructure

(complete result)

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Eddy currents in a superconductor (SC) shield the magnetic field in its interior and are responsible for the formation of a magnetic stray field outside of the SC structure. The stray field can be controlled by the external magnetic field and affect the magnetization dynamics in the magnetic system located in the vicinity of SC. In our work, we investigate theoretically and numerically the spin-wave (SW) confinement induced in a uniform magnetic layer by the stray field of a SC strip.

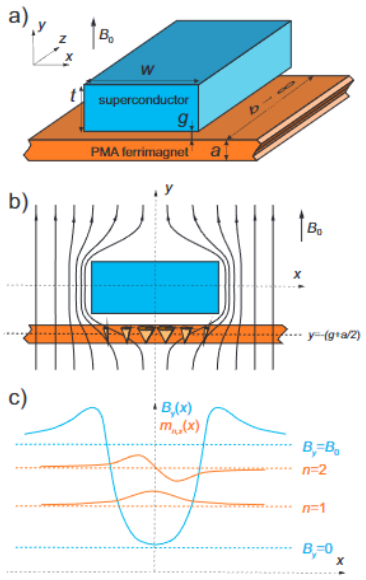

Fig.1. (a) A thin FM film (a = 20 nm) is exposed to the stray field of a rectangular SC strip (w = 800 nm, t = 100 nm). The FM and the SC are separated by a small gap (g = 10 nm). (b) The static internal magnetic field is lowered in the region of the FM, underneath the SC strip. This leads to the confinement of SW modes, (c) which are quantized in the well.

The investigated hybrid system consists of Ga:YIG ferrimagnetic (FM) thin film and Nb SC stripe, which are placed in an external magnetic field perpendicular to the FM layer (Fig. 1). The eddy currents in SC create a non-uniform distribution of the magnetic field in the FM film. In Ga:YIG, the shape anisotropy is overcame by the out-of-plane anisotropy, leading to the magnetization being directed out of plane. Then, the stray field of SC induces the well of static effective field in the FM layer, which can confine the SWs of the frequencies lower than the FMR frequency of FM layer in the absence of SC stripe. For considered geometry, there is no need to take into account the impact of FM layer on the SC stripe.

Fig.2 The frequencies of the localized SW modes *versus* the external magnetic field. The solid lines and square dots correspond to the semi-analytical theory and micromagnetic simulations, respectively. Dashed line shows the FMR frequency of homogeneous film.

Our studies were carried out in two stages. We first calculated the static stray field generated by the SC strip. It was determined from the distribution of SC currents, which was found by semi-analytical solution of the London equation [1]. The static field generated by SC stripe was then included as a component of effective field to Landau-Lifshitz (LL) equation, which was used to find the confined SW modes. The solutions of LL equation were found both semi-analytically [2] and numerically. We have shown that the applied field can tune the depth of the stray field well, and thus we can control the number and frequencies of the SW modes confined in the well (Fig.2).

[1] E.H. Brandt, *Superconductors of finite thickness in a perpendicular magnetic field: Strips and slabs*, Phys. Rev. B **54**, 4246 (1996).

[2] E. V. Tartakovskaya, et al, *Spin-wave localization in tangentially magnetized films*, Phys. Rev. B **93**, 214436 (2016).

The authors acknowledge the support from the grant of the National Science Center – Poland, No. 2021/43/I/ST3/00550.