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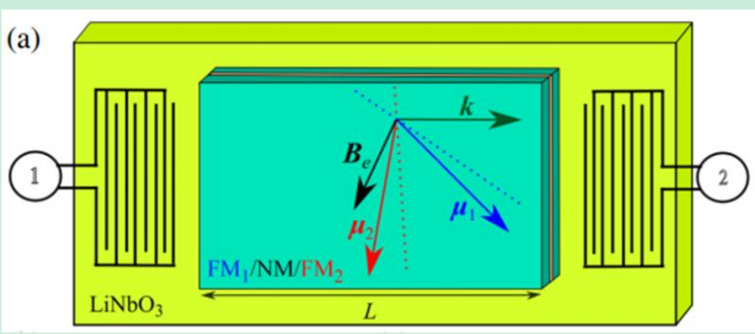
Nonreciprocity of surface magnetoelastic waves in a ferromagnetic bilayer with noncollinear layer magnetizations

Nonreciprocity of surface acoustic waves (SAWs) in a microwave frequency band is a very attractive feature, which would drastically enhance functionality of microwave SAW electronics devices. Due to symmetry of fundamental laws of mechanics, pure acoustic waves in solids are reciprocal, and nonreciprocity of their frequency and/or losses can be induced only by a coupling to excitations of another nature. The most promising way to induce SAW nonreciprocity is the utilization of magnetoelastic interaction of SAW with spin waves (SWs) propagating in hyrbid magnetoelastic heterostructures.



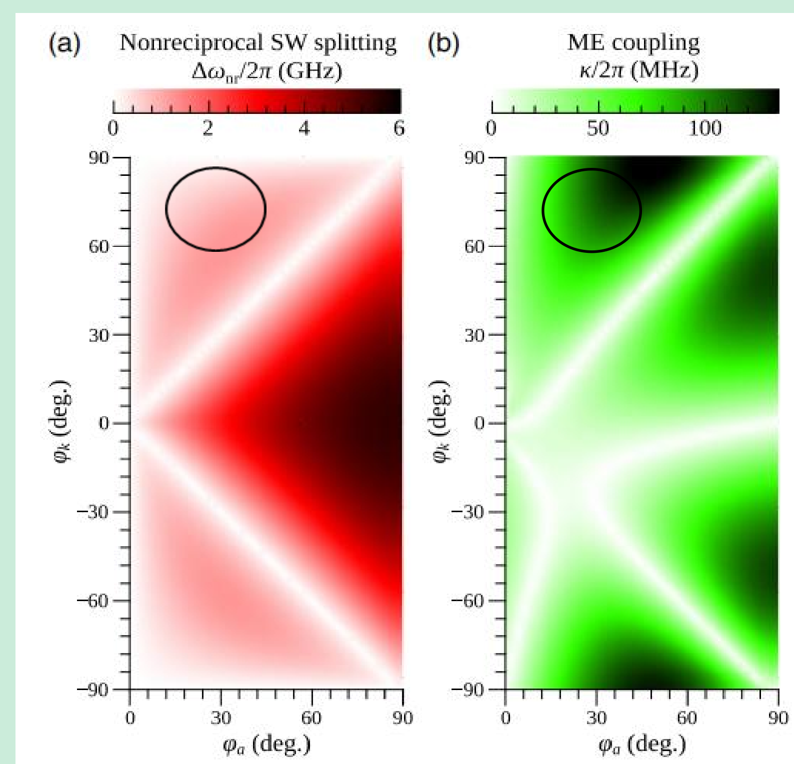
Recent works have shown that ultimate isolation of counter-propagating hybridized SAW/SW is achieved in heterostructures consisting of a synthetic antiferromagnet – ferromagnetic (FM) bilayer with antiferromagnetic RKKY interlayer coupling – placed on top of a piezoelectric acoustic waveguide. In this work, we study in details a more practical and technologically simpler system based on an FM bilayer, where the layers are coupled by only dipole-dipole interaction, placed on a top of piezoelectric crystal.

In contrast to previous works, in which SAW nonreciprocity was observed due to occasionally weakly noncollinear magnetization of the layers, we propose to fabricate FM layers with intentionally noncollinear in-plane anisotropy. A weak in-plane anisotropy of just 1-2 mT magnitude, which can be easily induced by FM layer growth in a magnetic field, is shown to be enough for supporting noncollinear magnetizations of the layers and, thus, SW nonreciprocity.

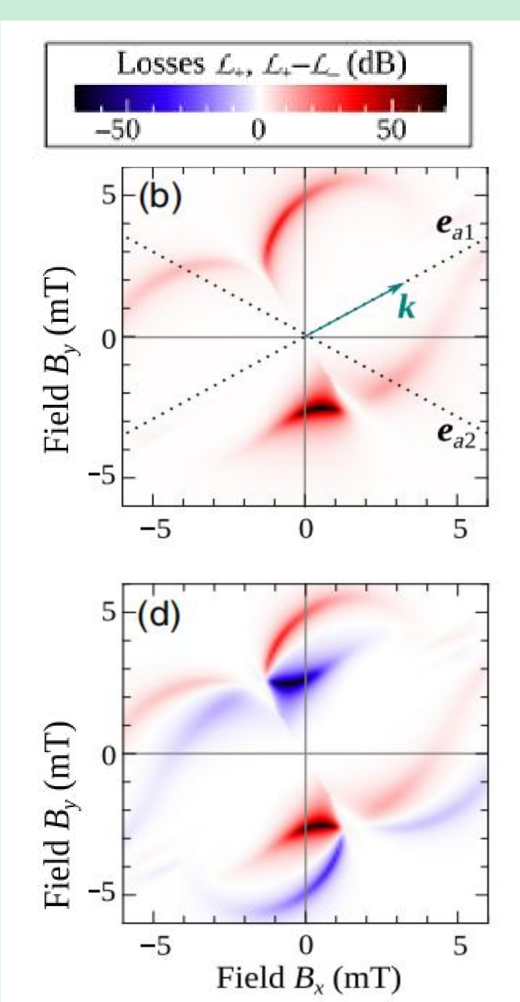
Requirements to realize an efficient SAW microwave isolator:

- a spin-flop static configuration with an angle between the magnetizations of the layers $(\varphi_{M,1} - \varphi_{M,2}) \sim 40^\circ$–$100^\circ$
- wave propagation direction close (but not exactly equal) to the perpendicular to the net static magnetization of the FM bilayer.

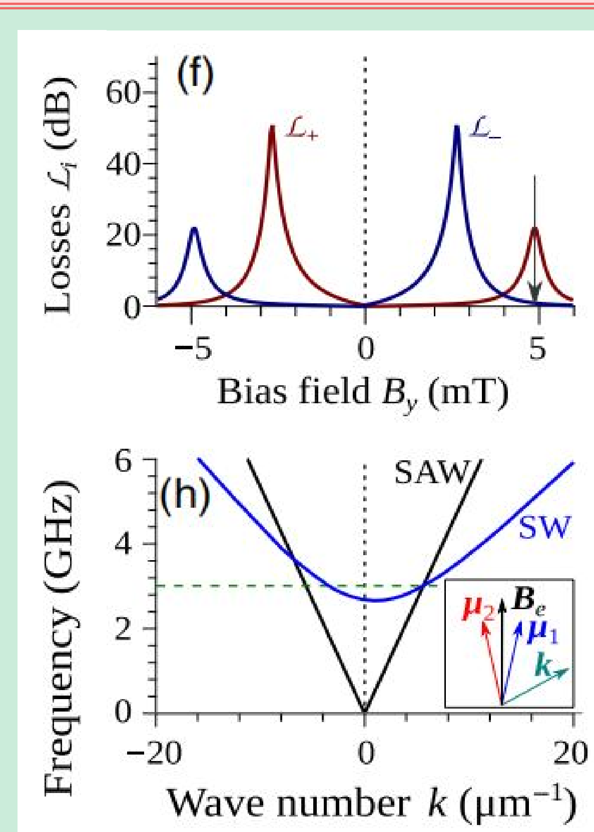
These requirements ensure strong magnetoelastic coupling between SAW and SW and reasonable SW nonreciprocity (see right figure).



Exemplary characteristics of SAW/SW propagating losses and nonreciprocal isolation at 3 GHz



Field dependence of the hybridized SAW/SW direct propagation losses $\mathcal{L}_+$ and (d) the difference of the losses $(\mathcal{L}_+ - \mathcal{L}_-)$ at the operation frequency of 3 GHz and the length of the ferromagnetic bilayer of L=100μm. The dotted lines show the directions of the easy anisotropy axes $\boldsymbol{e}_{a,i}$ of the layers, and the arrows denote the positive wave propagation direction.



(f) A cross-section of 2D losses map (d) for $B_e = B_y$.
(h) The SW and SAW spectra at the point of maximum losses B_y = 4.9 mT in panel (h) (subsidiary maximum of $\mathcal{L}_+$).
The insets show the static magnetization configuration at these field values, while the horizontal green dashed line corresponds to the operation frequency of 3 GHz.

Summary: SAW/SW isolator based the noncollinear anisotropy of the FM bilayer demonstrated the possibility to achieve a high (exceeding 50 dB) isolation for a submillimeter-long FM bilayer with direct insertion losses of just a few decibels larger than those of a pure SAW device.

See details in: L. Ushii, A. Slavin, R. Verba, Nonreciprocity of surface acoustic waves coupled to spin waves in a ferromagnetic bilayer with noncollinear layer magnetizations, PHYS. REV. APPL. 22, 034046 (2024)