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Electric-Field Coupling to Spin Waves in a Centrosymmetric Ferrite

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A systematic control of spin waves via external electric fields has been a long standing issue for the design of magnonic devices, and is of fundamental interest. One way to attain such control is to use multiferroics [1], whose electric and magnetic polarizations are inherently coupled. The lack of electric polarization in a centrosymmetric ferrite, however, makes direct coupling of its magnetization to external electric fields a challenge. Indirect electric control of spin waves has been accomplished by hybridizing yttrium iron garnet (YIG), a centrosymmetric ferrite, with a piezoelectric material [2]. Here, we predict direct control of spin waves in YIG by *a flexoelectric interaction*, which couples an electric field to the spatial gradient of the magnetization, and thus the spin waves [3]. Based on a superexchange model, which describes the antiferromagnetic coupling between two nearest neighbor iron ions through an oxygen ion, including spin-orbit coupling, we estimate the coupling constant and predict a phase shift linear in the applied electric fields [4]. The theory is then confirmed by experimental measurement of the electric-field-induced phase shift in a YIG waveguide [5]. In addition to the flexoelectric effect, another electric effect is observed, which couples the electric field directly with the magnetization of YIG. We call this a magnetoelectric effect. By adjusting the direction of the electric field, the two effects can be well separated. Experimental results agree quantitatively with the theoretical prediction. A phenomenological coupling constant for the magnetoelectric effect is also obtained. Our findings point to an important avenue for manipulating spin waves and developing electrically tunable magnonic devices. [1] P. Rovillain *et al.*, Nat. Mater. **9**, 975 (2010). [2] M. Bao *et al.*, Appl. Phys. Lett. **101**, 022409 (2012). [3] T. Liu and G. Vignale, J. Appl. Phys. **111**, 083907 (2012). [4] T. Liu and G. Vignale, Phys. Rev. Lett. **106**, 247203 (2011). [5] X. Zhang *et al.*, Phys. Rev. Lett. **113**, 037202 (2014). [6]The author gratefully acknowledges collaborations with G. Vignale, M.E. Flatte', X. Zhang and H. X. Tang. This work is supported by DARPA MESO and an ARO MURI.