Oscillations in Exchange-Coupled Nanomagnets

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Introduction

Spins in ferromagnetic materials undergo precession when subjected to an oscillating magnetic field. This so-called ferromagnetic resonance (FMR) has been a widely-used characterization technique for magnetic materials.

Recently, FMR techniques have been extensively applied to nanostructured magnets, where both shape and magnetostatic interactions play a role in shaping the FMR spectrum [1]. In this paper, we study nanomagnets that are patterned from exchange-coupled layers. In this case, the interlayer exchange coupling will also have a role in determining the resonance behavior of the magnets.

Magnetic oscillations are currently being studied for possible applications in computing devices [2], and the structures studied here may find applications there.

Physical structure and experimental characterization

We used sputtering to fabricate the magnetic multilayers. Top and bottom ferromagnetic layers were 10 nm CoFe and 3 nm CoFe, with a 0.8 nm thin Ru spacer layer sandwiched between them. The resulting stack was measured in a vibrating sample magnetometer (Fig. 1). From the M-H curve, we obtained the exchange field (~ 100 mT), which was used to extract the coupling strength '*J*'. We used this '*J*' in our simulations. The film was subsequently patterned to 200 nm x 100 nm nanomagnets for FMR measurements in the near future.

Numerical method

Micromagnetic simulations were carried out using OOMMF in order to understand the resonance modes of the coupled system. For different external fields (along easy axis), a small oscillating field was applied perpendicular to the external field direction. Frequency of the oscillating field was varied from 1-15 GHz. First, top and bottom CoFe layers were approximated as single-domain magnets in order to understand the basic modes (see Fig. 2). Using a numerical mesh of 5 nm x 5 nm x 3 nm, a full micromagnetic mode reveals the role of the internal oscillation modes (Fig 3).

Results

The single-domain calculations straight-forwardly show the emergence of symmetric and antisymmetric modes, which can be tuned by the exchange-coupling strength and the external field (Fig. 2). Considering the internal degree of freedom for the nanomagnets, it is already known to result in a number of additional resonances. Our simulations clearly show that the number of possible modes multiplies due to interlayer coupling (Fig. 3). The exchange coupling also alters the possible static-domain configurations, resulting in modes that are different from the known center and edge modes [3]. We are currently studying these modes both experimentally and, via further simulation and analytical methods.

Conclusion

We are not aware of any studies on the dynamic behavior of exchange-coupled and patterned films. Besides being an interesting model system, such systems can be engineered to display a wide variety of resonance phenomena, and can have applications in oscillatory computing architectures.

Acknowledgment

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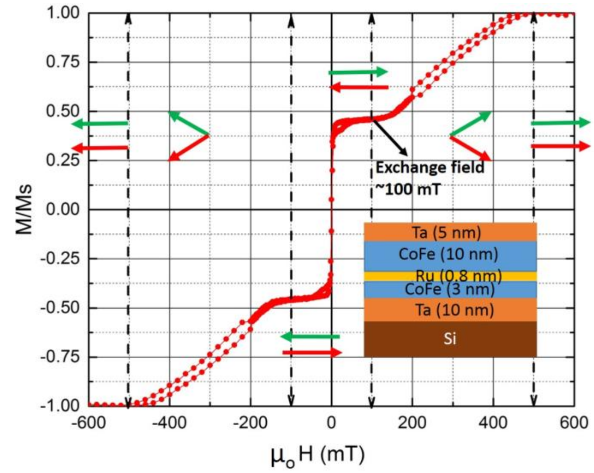

Figure 1: M-H curve for the exchange coupled stack (Green arrow: Magnetization of top layer, Red arrow: Magnetization of bottom layer), stack geometry shown in inset.

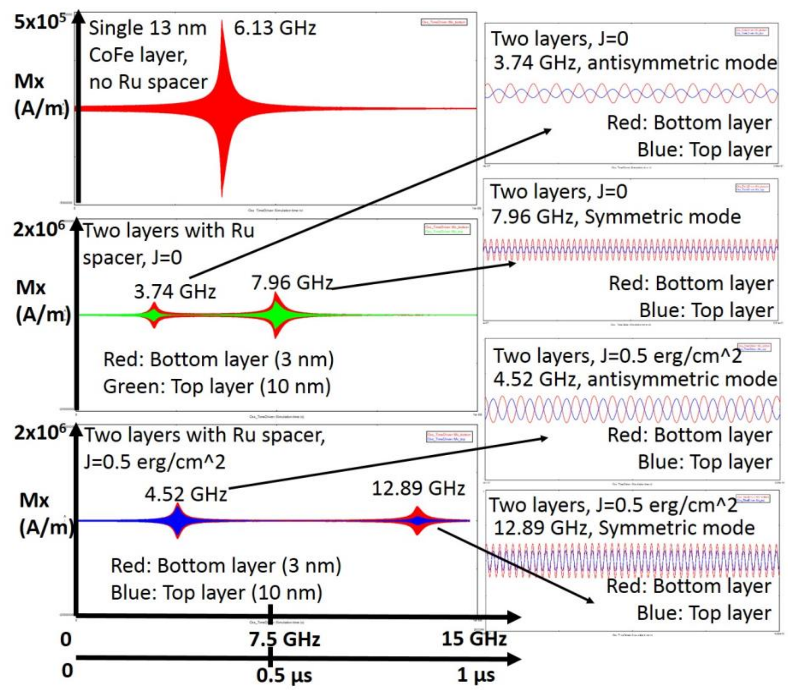

Figure 2: Simulated FMR spectra for three different cases (10 mT external field applied along easy axis); symmetric and antisymmetric modes for J=0 and J= 0.5 erg/cm^2 are zoomed in and shown (single-domain approximation).

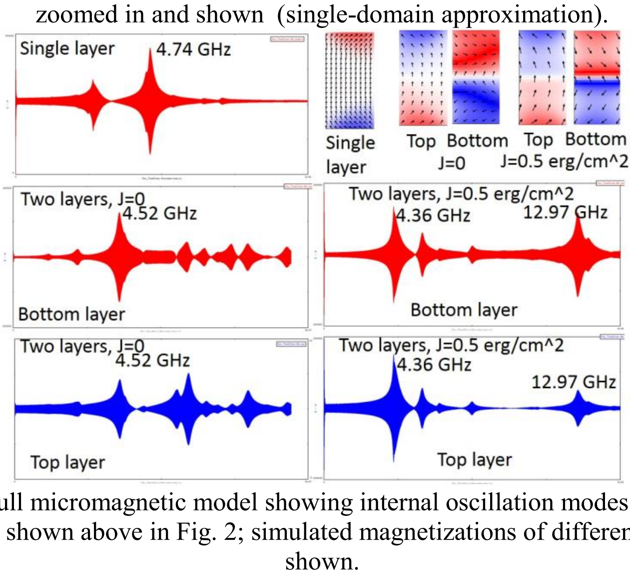

Figure 3: Full micromagnetic model showing internal oscillation modes for the same three cases shown above in Fig. 2; simulated magnetizations of different layers also shown.