METROLOGY OF MICROSTRUCTURED WAVEGUIDES FOR SPINTRONIC APPLICATIONS

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Abstract

Patterned permalloy films embedded in a coplanar waveguide (CPW) were fabricated, and the magnetization dynamics of such structures were investigated. Anisotropic magneto-resistance (AMR) effect was utilized as the detection mechanism to study the dynamics of such device structures. The introduced approach is suitable for investigation of magnetization dynamics in small magnetic devices and other candidate systems for spintronic applications.

Introduction

The control and manipulation of magnetization dynamics in patterned magnetic structures is of great interest for the fundamental understanding of spin-related physics in micro/nanoscale magnetic devices for spintronic applications. Such small scale magnetic structures display rich magnetization dynamics. One of the dynamic modes in such structures is vortex motion. Although the magnetic vortex in the flux-closure ferromagnetic domain was believed to exist for a while [1], it has been recently confirmed in micro/nanoscale magnetic structures with implementation of new measurement techniques [2-5]. The small volume of the samples makes broadband measurements challenging, and the dynamics were investigated mostly through cavity-based resonant techniques. The difficulty of broadband detection was partially resolved by introducing arrays of magnetic patterned devices positioned on stripline or coplanar waveguides.

In this manuscript, we report a simple experimental approach that has the sensitivity to measure the response of a single patterned magnetic element. Here the patterned element is an integral part of CPW and its dynamics are monitored through the AMR effect. The approach is demonstrated on the example of vortex pair dynamics.

Experiments

The samples were prepared by standard optical lithography and lift-off technique. A rectangular 2 μm × 8 μm × 50 nm thick permalloy ($Ni_{0.8}Fe_{0.2}$) film was deposited by dc sputtering, on a 5 nm thick Ta layer, to increase the adhesion to the quartz substrate. The film was then lithographically patterned with a lift-off process. A CPW with an overlap of 2 μm × 2 μm at each end of the permalloy strip was formed by depositing 20 nm of Ti and 200 nm of Au layers by e-beam evaporation in high vacuum. Figure 1 shows a schematic of the measurement system that contains a broadband diode detector and a DC bias arm. Such a configuration allows for simultaneous measurements of the microstructured magnetic film under test either for the magnetoresistive response or broadband transmission detection for ferromagnetic resonance or time domain magnetization dynamics detection. The magnetoresistance response was recorded by the lock-in technique with 300 averages and 300 ms integration period. The permalloy film was either in the demagnetized state, or in its initial static state was prepared by magnetizing the device in the plane of the film along the waveguide in the positive or negative directions. The RF field for this configuration was perpendicular to the current and the static bias field directions.

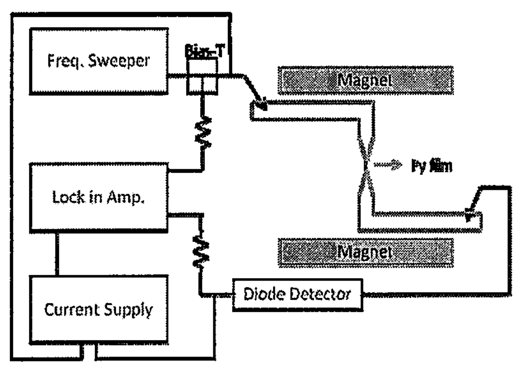

Figure 1. Schematic of the measurement setup with microstructured magnetic patterned films incorporated in the CPW [5].

Results

Magnetoresistance Measurements: Figure 2 shows the as-measured response of the 2 μm × 8 μm, 50 nm thick rectangular permalloy film. The hysteretic curves were obtained by measuring dV/dI while sweeping the magnetic field. Figure 2 shows a gradual increase of differential resistance, indicating the alignment of the magnetization into the field direction with increasing magnetic field. When the

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magnetic field is swept in the opposite direction starting from the positive saturation state, it shows an abrupt reduction of resistance with a following increase back to maximum value as the field approaches the opposite saturation value. The saturated resistance states are obtained at ±2860 A/m. Clearly, the magnetic state of the device is well characterized through the AMR effect. The abrupt change in the resistance can be associated with the nucleation of a vortex pair, while the gradual change in magnetization reflects the dislocation of the vortices and ultimately the annihilation of the vortex pair. The nucleation and annihilation of the vortex states was confirmed by OOMMF [6] based micro-magnetic simulations. The simulated magnetization distribution is in excellent agreement with the observed change in the magnetoresistance and confirms the existence of two vortices in the sample.

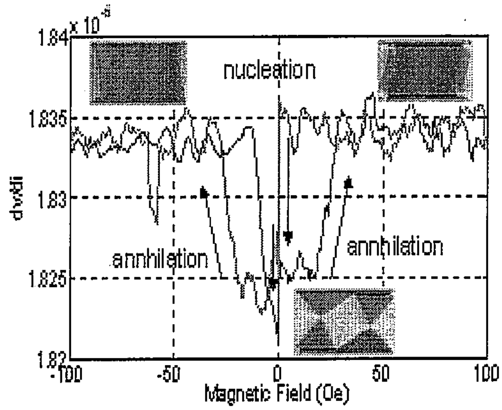

Figure 2. Magnetoresistance curves of the single patterned permalloy thin film as obtained with modulated dc current, showing the nucleation of the vortex states.

Vortex Resonant Excitation: In this section we demonstrate the sensitivity of the technique to the dynamical response of the device. The variation of differential magnetoresistance as a function of frequency is shown in figure 3. Typical ferromagnetic resonance (FMR) responses for the identical rectangular permalloy strip would be in the few GHz range or above; however, the observed signal in Figure 3 is substantially far away from the resonance frequency one would expect in permalloy film for an external magnetic field of 1440 A/m . The observed resonance is due to vortex core precession, which has generally been observed in the sub-GHz frequency range [3]. In this particular device, the vortex resonant frequency is observed at ~60 MHz. The geometry and the dimensions of the permalloy device are responsible for such a low vortex motion frequency, which can be distinguished from FMR.

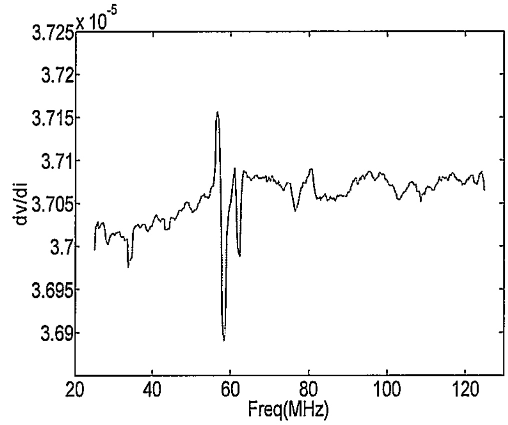

Figure 3. Experimental detection of vortex resonant excitation in patterned permalloy films with CPW.

Conclusions

Single microstructured rectangular permalloy thin films incorporated with CPW over quartz have been fabricated and measured. We introduced a simple experimental technique sufficient to allow the electrical characterization of magnetic micro-structured devices. The approach allows us to identify vortex excitation. The static and dynamic state of the patterned film can be clearly identified through dynamic influences of its magnetization states. We demonstrated the applicability of the technique on the example of vortex excitation, but the technique is suitable for the investigation of the dynamics of a wide variety of spinwave excitations and can contribute to the understanding of the dynamics in the patterned magnetic structures that is important for the development of the new generation of spintronics devices.

References

[1] A. Hubert and R. Schafer, “Magnetic Domains”, *Springer*, Berlin, 1998.

[2] L. Giovannini, F. Montoncello et al., “Spin excitations of nanometric cylindrical dots in vortex and saturated magnetic states,” *Phys. Rev. B*, vol. 70, 172404, 2004.

[3] V. Novosad, FY. Fradin, et al., “Magnetic vortex resonance in patterned ferromagnetic dots,” *Phys. Rev. B*, vol. *72, 024455,* 2005.

[4] Van Waeyenberge, B; Puzic, et al., “Magnetic vortex core reversal by excitation with short bursts of an alternating field,” *Nature*, vol. 444, 23,2006

[5] S. Kasai, Y. Nakatani et al.,”Current-driven resonant excitation of magnetic vortices,” *Phys. Rev. Lett*, vol 97, 107204, 2006.

[6] http://math.nist.gov/oommf

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