VORTEX BEHAVIOR IN PATTERNED MAGNETIC HETEROSTRUCTURES WITH CIRCULAR EXCHANGE BIAS

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INTRODUCTION

Lithographically-patterned magnetic heterostructures have become the object of intense research due to their potential application in ultrahigh density magnetic recording media and spintronic logic devices. The nanoscale confinement of the magnetization leads to the existence of magnetic vortex states and new magnetization reversal mechanisms. Vortices are flux closure states exhibiting two topological parameters, chirality and polarity, each having two possible orientations. Exchange-biasing to an antiferromagnetic (AF) layer can offer a mechanism of controlling the reversal behavior of the ferromagnetic (FM) vortex. Vortex behavior has been investigated by techniques such as magneto-optical Kerr effect, photoemission electron microscopy and more recently by Lorentz microscopy. In this study a comparison has been made between two systems with comparable values of the exchange-bias field, but with high and respectively low magnetocrystalline anisotropy: $Co_{90}Fe_{10}$ and $Ni_{80}Fe_{20}$ wt% exchange-biased to 5 nm IrMn, as 1 μm diameter, 12 nm-thick lithographically-patterned disks. The reversal mechanism and exchange-bias properties of individual dots are investigated by Lorentz microscopy, Quantum Interference Magnetometry (SQUID) and magneto-optical Kerr effect (MOKE). Vortices were swept out of the disks and renucleated by changing the intensity of a magnetic field applied in-situ in the transmission electron microscope (TEM), by tilting the sample around the holder axis and weakly exciting the objective lens. The high spatial resolution of the Lorentz technique (10nm) combined with the large field of view allows investigation of behaviour of individual elements, as well as statistics on arrays of disks.

RESULTS

The exchange-bias field was set in the AF layer by cooling from above the Neél temperature in two distinct magnetic configurations: in a 5 kOe magnetic field producing a saturated state (referred to as field cooling, FC), and in zero-field (zero field cooling, ZFC)[1]. The ZFC treatment used the molecular field from the adjacent FM layer to set exchange bias in a vortex, or circular configuration. MOKE magnetometry confirmed that exchange-bias was indeed set circularly after the ZFC treatment and the strength of the exchange-bias was determined from micromagnetic simulations. LTEM shows that reversal takes place via vortex states only for Py, whereas for CoFe a mixed mechanism involving both domain walls and a vortex state is observed. Exchange-bias stabilizes the vortex over a wider applied field range, and in the case of CoFe/IrMn disks it stabilizes the vortex reversal mechanism against domain walls. The time variation in reversal behavior observed in single FM layer disks, as a result of thermal activation, is suppressed in the exchange-biased (FM/AF) disks, which switch reproducibly. The coercivity of the FM layer in ZFC disks is reduced w/r to the coercivity in FC disks and remains finite for CoFe/IrMn due to the finite magnetocrystalline anistropy of CoFe. In Py/IrMn, circular exchange bias promotes completely reversible behavior (zero coercivity) in a centered range of fields in which the vortex exists in all four quadrants of the hysteresis loop.

In-situ Lorentz magnetization experiments show that for the Py disks the vortex nucleation occurs with alternating chirality, whereas in ZFC Py/IrMn disks the initial chirality in the FM layer is preserved throughout the magnetizing experiments indicating that EB was set in a vortex configuration with well defined chirality. The circular symmetry of EB is confirmed by the fact that the vortex nucleation field (H_n) and annihilation field (H_a) are insensitive to the in-plane applied field direction. H_n and H_a increase for the ZFC disks with respect to the single layer FM disks, indicating that the circular exchange bias increases the stability of the vortex state.

CoFe and CoFe/IrMn disks reverse by a mechanism involving a set of three domain walls at remanence that collapse into a vortex at higher fields. In ZFC CF/IrMn disks the reversal follows a regular pattern with domain walls of the same contrast (i.e. black,white, black) forming after decreasing the saturating field with the same sign, and opposite (i.e. white, black,white) for the other sign of field. Upon decreasing the field to remanence and increasing it in the opposite direction, the central domain wall collapses into a vortex and the domain wall contrast dictates the vortex chirality (i.e. a white wall forms a white vortex). CoFe disks reverse similarly except that reversal is occasionally randomized by thermal effects. By comparison between the experimental data and simulations, we conclude that the value of EB for ZFC CoFe/IrMn disks is larger than that for ZFC Py/IrMn disks (0.3 vs. 0.1 erg/cm^2 from best fitting simulation). In addition, pinning effects originating from nonzero magnetocrystalline anisotropy cause the vortex to move in a zig-zag motion about the ideal trajectory, which would be linear in the absence of pinning.

CONCLUSION

Using LTEM, we demonstrate that the vortex reversal mechanism in Py disks changes from microstructure-governed to exchange-bias governed upon the ZFC treatment and a consequence of this is reversal with fixed vortex chirality. In CoFe disks, although exchange bias has a higher value, the reversal mechanism remains dominated by microstructure upon the ZFC treatment. In both FM systems the thermal effects on switching are removed at room temperature and the switching becomes reproducible over time.

REFERENCES

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