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Interface bias vortex nucleation in magnetic nanoelements

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Abstract – We report a theoretical investigation of vortex nucleation and motion along the hysteresis curves of flat iron and permalloy nanoelements exchange coupled to an antiferromagnetic substrate. We find that interface coupling favors the nucleation of vortex states which suits the opposite trends imposed by the external field and the interface exchange field. For lateral dimensions in the sub-micrometer range vortex nucleation in iron nanoelements require smaller values of the interface field strength. Strong values of the interface field strength leads to double loop hysteresis with the magnetization driven by the vortex motion in both branches of the hysteresis curve.

The interest in the finite size effects in ferromagnetic particles of sub-micron dimensions is motivated from both the potential application of nanoelements in magnetoeletronic devices [1] and from fundamental reasons. Sub-100 nm soft particles have dimensions comparable to the exchange length, and their magnetic states and reversal mechanisms depend on their geometrical shapes and sizes. The remanence and coercivity are key parameters for data storage applications, and control the stray field and the thermal stability. The effects of geometrical confinement on the magnetic states of soft magnetic materials are controlled by the dipolar and exchange fields. The shape of the hysteresis curve is to a large extent controlled by the competing effects of the intrinsic exchange energy, holding neighboring spins in parallel orientation, and the requirement of small surface magnetic charge in order to lower the magnetostatic energy which may lead to nonuniform states.

These issues are of particular interest in the field of exchange bias, where one is aiming at the stabilization of small magnetic particles for use in investigations of systems for high density magnetic recording. The mechanisms of reversal of the interface biased nanoelement have a relevant impact on the effective bias and the coercive field. We have recently shown [2] that magnetization reversal of small area interface flat ferromagnetic dots involves the formation of twisted states that suits the alignment of interface spins with the interface field and free surface spins with the external field. These sates correspond to nearly parallel structure of spins in each atomic layer from the interface plane to the free surface plane. Switching occurs with the gradual increase of the angle between spins in the interface and surface layer.

We show presently that if the lateral dimensions are of the order of a few exchange lengths, then the magnetization reversal of interface biased nanolements may involve the nucleation of vortex states. Due to the larger value of the iron saturation magnetization, vortex nucleation requires smaller values of the interface field strength. In Fig.1 we show the hysteresis curves of iron and permalloy nanoelements for an interface field of 2kOe. The iron hysteresis curve involves reversal by vortex nucleation although the interface field strength is much smaller than the intrinsic exchange field of iron. Double loop hysteresis is found for interface field strength of the order of the intrinsic exchange field. This is shown in Fig.2. The straight line segments in both branches correspond to gradual changes in the magnetic structure (and magnetization) induced by vortex motion.

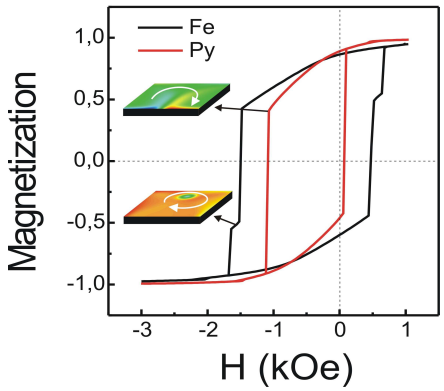

Figure 1: Hysteresis of 90nm x 90nm x 12nm Fe and Py nanoelements for an interface field strength of 2 kOe.

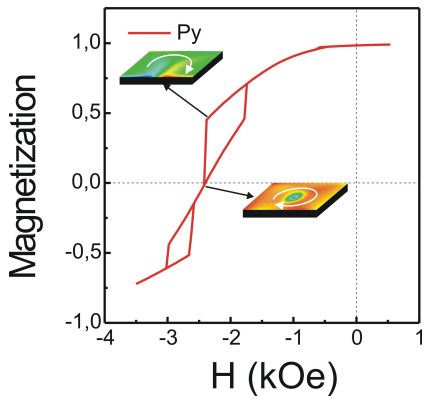

Figure 2: Hysteresis of a 90nm x 90nm x 12nm Py nanoelement for an interface field strength of 10 kOe. Notice that most of the loop consists of vortex motion.

References

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