Direct imaging of tunable exchange bias domains in model Ni/FeF_2 nanostructures

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Confining the dimensions and geometry of magnetic structures down to critical length scales such as the ferromagnetic (FM) exchange length or the domain wall width results in intriguing new phenomena not observed in the corresponding bulk material. In this regard, a proximity effect such as exchange bias (EB), which refers to the unidirectional anisotropy induced in FM films due to the interfacial exchange interaction with an antiferromagnetic (AF) layer upon cooling through the AF Néel temperature (TN), is of particular interest [1]. The EB effect has become key to numerous applications such as spin valves [2] and the stabilization of the magnetization in nanoparticles against thermal excitations [3]. Recently, FM/AF nanostructures exhibiting both negative [1] and positive EB [4-7], i.e., hysteresis loops shifted either against or along the cooling field direction, respectively, have been proposed as model systems for multistate switching memory units [8, 9]. The sign of EB can be influenced either by the cooling field or by changes in the domain configuration in both the bulk of the AF and at the FM/AF interface [5, 10- 12]. Patterning allows the control of writing fields and the design of the multistate cells [9].

In this work, we show that the spatial confinement of the FM correlation length, either through thickness variation of the FM layer or laterally via patterning, drastically affects the AF domain structure in exchange-biased Ni/FeF_2 nanostructures. Direct observations of the spin configuration at both sides of the FM/AF interface performed by photoemission electron microscopy reveal that the final spin structure is determined by the competing balance between the two dissimilar magnetic length scales. A coexistence of EB domains with opposite directions can be tuned in Ni/FeF_2 bilayers for Ni thicknesses below 10 nm. Patterning of the nanostructures with antidots using focused-ion-beam lithography destabilizes further the FM order. In particular, it promotes the coexistence of opposite exchange-bias domains below a critical antidot interspace in the order of a few FeF_2 crystal domains. Our results suggest that dimensional constrictions in the FM layer might be used to trigger the AF spin structure in spintronic devices or ultra-high density storage media.

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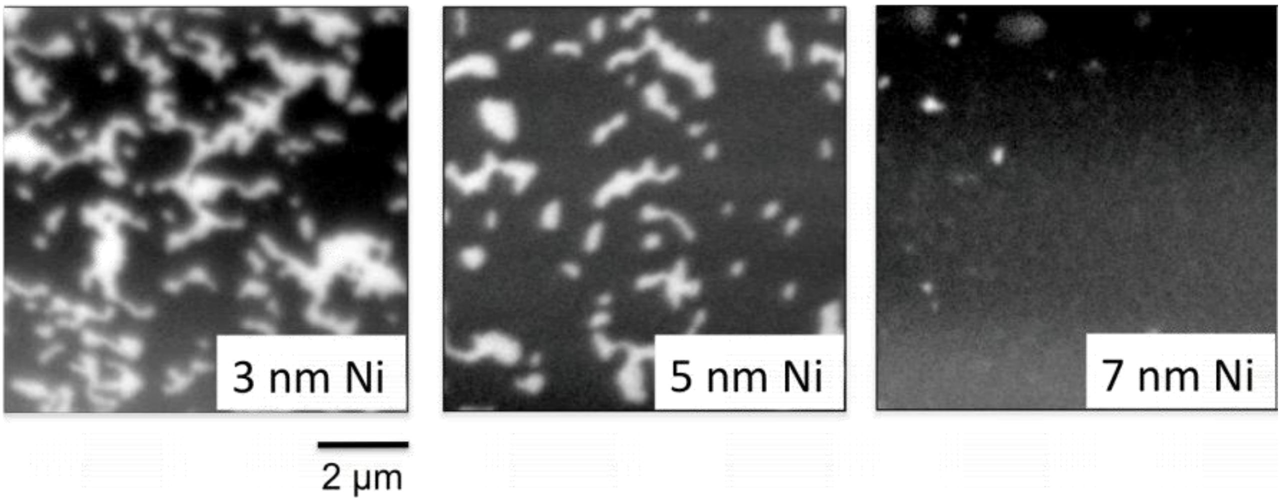

Figure 1. Example of element-specific Ni domain configurations in Ni/FeF_2 (70 nm) bilayers measured at zero magnetic field and 30 K after zero field cool from a saturated state at 296 K. The initial remanent saturated state (dark contrast) splits into a ramified pattern of small, inverted domains with opposite magnetic orientation (bright contrast).