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Exchange Biased Magnetic Vortices

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The hysteresis loop of a ferromagnet can be modified via coupling to an antiferromagnet giving rise to exchange bias or via patterning, which may stabilize vortices in order to minimize magnetostatic energies. The interplay between exchange bias and vortex formation in patterned ferro-/antiferromagnetic coupled dots gives rise to a rich variety of unusual behavior [1]. When the exchange bias is established in saturation, the magnetization reversal becomes angular dependent due to the new unidirectional anisotropy. As a result hysteresis loops due to either coherent rotation or reversal via a vortex state can be observed for different field directions [2,3]. The angular range for reversal via a vortex state can be tailored either by the dot geometry or by using different field cooling procedures [3]. In addition, field cooling in a vortex state imprints the vortex configuration of the ferromagnet into the antiferromagnet resulting in an interfacial exchange bias field with circular symmetry, which enhances the vortex stability [3,4]. Using additional small magnetic fields for imprinting shifted vortices results in a new asymmetry in the reversible part of the hysteresis loops [4]. Furthermore, the interfacial nature of exchange bias allows modifying the vortex magnetization state along the ferromagnet thickness. As a consequence, for thick enough ferromagnetic layers the vortex core may tilt away from the surface normal resulting in new asymmetries for the vortex critical fields [5,6].

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Recent Advances in Understandings of Coercivity of Nd-Fe-B Permanent Magnet Materials

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The development Nd-Fe-B magnets have opened the door to an era of massive consumption of high-performance permanent magnets and created a new concern about the supply of raw materials, especially, the heavy rare earth metals that are used in the high-coercivity grades, specially designed for the automobile applications that demand high coercivity at elevated temperatures. The current redearch activities in the permanent magnet community are strongly focused on solutions for this issue. Recent developments include the grain-boundary diffusion of Dy or Tb in order to locally enhance the magnetocrystalline anisotropy of $Nd_2Fe_{14}B$ grains[1], the low-oxygen processing techniques for both dry and wet processing, and the extraordinary fine-grained sintered magnets[2]. Investigations of the mechanism of coercivity generation involving combinations of studies of well designed model systems, multi-scale structural analyses, microscopic domain observations, and analysis of macroscopic magnetization process are indispensible in order to obtain new directions of research for highi-performance permanent magnets with no rare elements.

The authors will present two cases in which onset of coercivity in Nd-Fe-B-based permanent magnets materials can be clearly discussed in relation to observed changes in the microstructure. In the first case, the onset of coercivity in surface $Nd_2Fe_{14}B$ grains could be related to formation of a metastable Nd oxide at the interface with the $Nd_2Fe_{14}B$ grains and an Nd layer deposited on the grains. In the second case, the onset of coercivity in the final stage of dehydrogenation process of a hydrogenation-disproportionated Nd-Fe-Co-Ga-B alloy could be related to a relatively sudden redistribution of Nd atoms released by the final decomposition of remnant Nd hydrides. These investigations suggest that the coercivity-inducement mechanisms in these two cases are completely different, and provide an expectation that the coercivity in the latter case may be improved if one can controle the grain boundary compositions.

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