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# Nanoscale Magnetic Lithography on FeAl alloys by ion irradiation and nanoindentation

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**Abstract –** Nanoindentation and local ion irradiation (i.e., focused ion beam or broad beam irradiation through shadow masks, such as alumina templates or PMMA masks) are shown to be effective methods to generate periodic arrays of sub-micron ferromagnetic dots at the surface of paramagnetic $Fe_{60}Al_{40}$ alloys (both in the form of sheets and thin films). The fabricated entities exhibit a variety of magnetic properties depending on their size and shape. Remarkably, in some cases, the magnetic anisotropy of the dots is oriented perpendicular to the film plane. Furthermore, the ferromagnetic properties of the patterned structures can be removed by annealing at sufficiently high temperatures, thus evidencing the reversible character of this novel magnetic lithography procedure.

Atomically ordered $Fe_{1-x}Al_x$ (at. %) alloys (with $0.32 < x < 0.5$) are paramagnetic at room temperature. However, these alloys become ferromagnetic when they are atomically disordered [1]. The transformation from the paramagnetic B2-phase to the ferromagnetic A2-phase can be accomplished by either mechanical deformation or by means of ion irradiation procedures. Taking advantage of this effect, nanoindentation has been used to generate periodic arrays of sub-micron ferromagnetic dots at the surface of paramagnetic $Fe_{60}Al_{40}$ sheets and thin films [2]. The induced ferromagnetism is confined into the locally disordered regions, rendering isolated magnetic dots surrounded by a paramagnetic matrix, thus virtually free from the detrimental effects of interdot exchange interactions. Smaller ferromagnetic dots (sub-50 nm) can be fabricated by means of local ion irradiation procedures (i.e., focused ion beam or ion irradiation through masks) [3]. In addition, due to the low fluences used, the latter method does not induce any significant roughening of the surface, thus leading to almost topographically featureless dots. The fabricated entities exhibit a wide range of magnetic properties depending on their size and shape, as revealed by complementary studies using magneto-optical Kerr effect magnetometry and magnetic force microscopy. Under certain conditions, square hysteresis loops with moderate coercivity (around 500 Oe) can be obtained when measuring along the perpendicular-to-film direction. Furthermore, when the patterned sheets or thin films are annealed at sufficiently high temperatures, the ferromagnetic properties are removed due to the annealing-induced atomic reordering. Consequently, contrary to most other patterning techniques, ion irradiation can allow re-patterning the $Fe_{60}Al_{40}$ sheets and thin films indefinitely. Therefore, these methods constitute a novel type of magnetic lithography which could be used to fabricate, in a rapid and rather simple way, new types of patterned recording media free from tribological and exchange coupling effects. Moreover, these approaches have the added value that can be easily extrapolated to a variety of other systems exhibiting either disorder-induced ferromagnetism (CoZr, CoAl, CoGa, CoV, NiSn, FeGe or $FePt_3$) or martensitic phase transformations, like in austenitic stainless steels [4].

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