Tailoring Hard Magnetic Properties in Magnetic Films and Microstructures: Electrodeposition of Co-Pt Alloys

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The availability of an integrated fabrication process for the synthesis of hard magnetic microstructures, compatible with the Complementary MOS technology for the fabrication of microelectronic circuits and capable to synthesize magnets in a wide range of sizes, would enable the practical and low cost integration of permanent micromagnets with micro-electro-mechanical systems, opening numerous possibilities for the implementation of novel on-chip actuation or sensing functions, or the improvement of existing ones.

Electrodeposition from aqueous solutions distinguishes itself as the most favorite growth technique for the implementation of such process, due to its versatility, low capital cost and the possibility to fabricate microstructures with high aspect ratio by purely additive processes [1]. A significant drawback of this technique is however the limited set of hard magnetic materials that can be plated. Materials of interest in this respect include Pt–TM alloys (TM = Fe, Co, Ni), where high coercivity can be achieved through the synthesis of the equiatomic, high anisotropy $L1_0$ phase, or Co alloys, where alloying can increase the intrinsic anisotropy of Co by deformation of the hexagonal unit cell. We focus on the latter approach, since the synthesis of the $L1_0$ phase is likely to require post-annealing under conditions most probably incompatible with C-MOS processing.

Co-rich Co-Pt alloys with a Pt content of 20 at% – approximately the solubility limit of Pt in the hexagonal phase of Co – were grown from an amino-nitrate electrolyte with pH 8, at a temperature of 65°C. Various seed layers were used to control the crystalline phase and crystallographic orientation of the Co-Pt films. It was found that a Cu(111) underlayer and high current density favor the growth of single phase hexagonal films (Fig. 1) with the c-axis perpendicular to the film plane. These films exhibit a saturation magnetization of about 830 kA/m (830 emu/cm^3), a net perpendicular anisotropy of about 1 MJ/m^3 (10^7 erg/cm^3) – more than two times the anisotropy of Co, and a perpendicular coercivity of up to 486 kA/m (6.1 kOe) [2]. Typical hysteresis loops of these films are shown in Fig. 2. Temperature-dependent measurements of the anisotropy support the hypothesis that the high magnetic anisotropy is originated by the crystalline anisotropy of the alloy, and thus is intrinsic to the material obtained.

Arrays of permanent micro-magnets with diameter between 2 and 10 microns and thickness from 55 to 2000 nm were grown using electrodeposition through a resist mask. The process could be optimized to achieve energy products of up to 52 kJ/m^3 (6.52 MGOe), comparable with the values obtained in bulk ferrites and much higher than values obtained using other electrodeposited materials. These results demonstrate the great potential of electrodeposited Co-Pt alloys for the practical production of integrated micromagnets in various applications, in particular in magnetic micro-electromechanical systems.

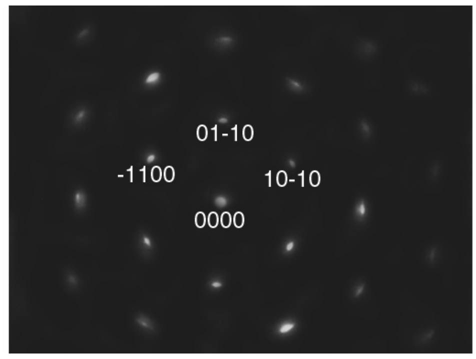

Figure 1 - Electron diffraction pattern from a Co-Pt film grown on Cu(111) showing only hcp spots, indicating an epitaxial growth according to hcp Co-Pt(0002)//Cu(111)

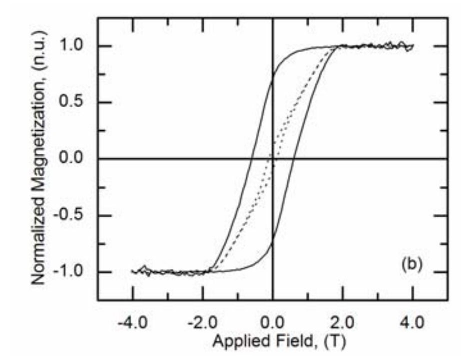

Figure 2 – In-plane (dotted line) and perpendicular (continuous line) hysteresis loops for Co-Pt films grown on Cu(111) at high current density.

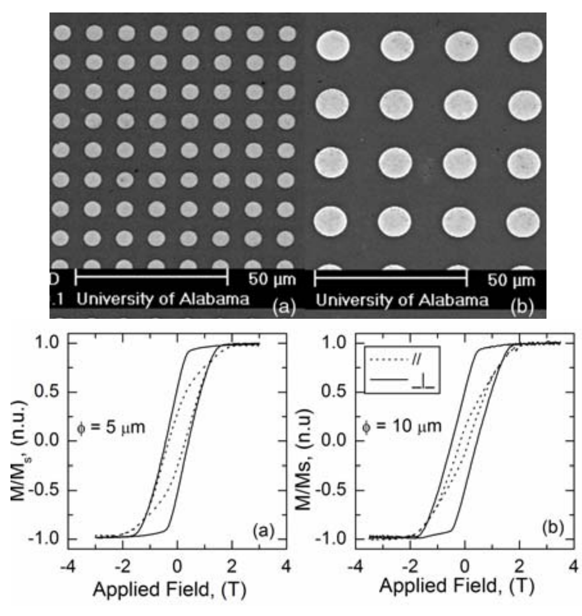

Figure 3 – Morphology (top) and magnetic properties (bottom) of a micromagnet array with 5 and 10 µm diameter and 2 µm thickness.

References

[1] L.T. Romankiw, *Electrochim. Acta* **42** (1997) 2985.

[2] I. Zana, and G. Zangari, *Electrochem. Solid St. Lett.* **6**, C153 (2003).