Structure and magnetic properties of thin permalloy films near the "transcritical" state

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Iron-nickel (permalloy) soft magnetic thin films are of great interest due to their present and potential applications in various magnetic technologies. Usually, softness is associated with in-plane magnetic easy axis of the film. However, under some conditions, an out-of-plane magnetization component, accompanied by the formation of stripe domains and increased coercivity, can appear. This is the so-called "transcritical" state. The perpendicular magnetization component could originate from magnetocrystalline, shape, and/or magnetoelastic anisotropy [1]. In this work we study the microstructure and magnetic properties of a series of thin permalloy films prepared by dc magnetron sputtering at different values of argon pressure (p_{Ar}), in order to get insight on the origin of the perpendicular magnetic anisotropy.

Various series of permalloy thin films were grown on Si (100) and glass substrate at room temperature using a $Fe_{20}Ni_{80}$ target. A constant magnetic field of 250 Oe was applied parallel to the film plane during deposition in order to induce an uniaxial anisotropy. The background pressure was 3×10^{-7} mbar. The argon pressure (p_{Ar}) ranged from 3.8×10^{-3} mbar to 2.4×10^{-2} mbar. The thickness of the thin films was between 20 nm and 300 nm. Their compositions were determined by Energy Dispersive X-ray analysis. X-ray diffraction (XRD) and atomic force microscope (AFM) were used also for characterization. The magnetization loops were recorded by means of the magneto-optic Kerr effect.

The samples of the same thickness deposited at different p_{Ar} have similar XRD patterns, characteristic of a strong (111) texture. However, as p_{Ar} increases, the intensity of the observed peak decreases, indicating a tendency of the grain sizes to decrease while remaining in the 9-12 nm range. Also, with higher p_{Ar} values, the root mean square roughness increases and, for high values of p_{Ar}, the AFM images show island-like features in the surface structure.

The increase of the film thickness leads to an increase of the coercive field. The transition to the "transcritical" state was observed at a critical thickness that decreases from 200 to 50 nm as the argon pressure in the chamber increases. This state was confirmed by the appearance of stripe domains, the characteristic shapes of hysteresis loops, and rotatable magnetic anisotropy (the hysteresis loops are unchanged whatever the orientation of the applied in-plane magnetic field). The increase of p_{Ar} also leads to an decrease of the Fe concentration in the films from 17 at.% to 15 at.%, resulting in a increase of the magnetostriction constant [2]. No significant differences were observed for films grown on glass or Si substrates.

We, therefore, suggest that the origin of the perpendicular magnetic anisotropy in FeNi films with negative magnetostriction and planar tensile stresses is the magnetoelastic coupling. The p_{Ar} increase leads to an increase of the magnetostriction constant, through the change in the film composition, and more imperfections in the films produce larger stresses.

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