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Surface morphology evolution during electrodeposition of amorphous CoP films

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Abstract

We have used atomic force microscopy to measure the roughness of electrodeposited amorphous CoP as a function of length scale and film thickness. In contrast to the power law scaling usually observed for polycrystalline electrodeposited films in the absence of additives, the roughness *decreases* with increasing film thickness. For films grown on Au on glass substrates, the characteristic lateral feature size is ∼250 nm, independent of the CoP thickness. This is consistent with columnar growth. Films of thickness 4 μm have a saturation roughness of only ∼1 nm, which is less than that of the substrates.

Keywords: Kinetic roughening; Electrodeposition; Amorphous films; Soft magnetic properties

Surface roughness can have a major influence on thin film properties ranging from optical reflectivity to magnetic coercivity [1]. During film growth, the surface roughness generally changes with increasing film thickness. Although this process of kinetic roughening has been studied in some detail for single- and poly-crystalline metal films [2,3], there have been considerably fewer quantitative studies of amorphous films. Furthermore, the latter have generally been restricted to films prepared by vacuum methods, in particular evaporation and sputtering [4,5]. Here we present data for a series of CoP films prepared on two types of substrate by electrodeposition. Such films are of interest for their soft magnetic properties [6,7].

We show that for this system the surface roughness $w(l,t)$ decreases with increasing film thickness

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t, for t up to several μm. Here $w(l)$ is the root-mean-square deviation of the surface height h from its mean value:

$$w(l) = \sqrt{\langle (h - \langle h \rangle)^2 \rangle} \qquad (1)$$

where l is the size of the region over which w is measured. The observed decrease in w for electrodeposited CoP is in strong contrast to the large number of systems that exhibit either normal or anomalous scaling [8,9], for which $w(l,t)$ increases with t according to a power law. Similar behaviour was seen for two different substrate materials, although the values of w were substrate dependent. We also show that the lateral correlation length l_c, which is a measure of the feature size, remains approximately constant or increases slowly as t increases, depending on the substrate.

The CoP films were deposited on evaporated Au (280 nm)/Cr (30 nm)/glass substrates from an electrolyte containing 187 ml/l H_3PO_3, 35 ml/l H_3PO_4, 180 g/l $CoCl_2 \cdot 6H_2O$ and 40 g/l $CoCO_3$ in a 3-electrode cell without mechanical agitation [10]. To modify the initial substrate roughness prior to CoP electrodeposition, in some cases an additional ~250 nm Cu was electrodeposited on the Au (280 nm)/Cr (30 nm)/glass substrate from an acid Cu sulphate electrolyte at a current density of 12 mA cm^{-2} [11]. The CoP deposition potential was −1.2 V relative to the saturated calomel reference electrode, and the electrolyte temperature 75 °C. Q, the total charge passed through the electrode, was calculated by integrating the measured deposition current with respect to time. The film thickness t is proportional to Q, with a constant of proportionality that depends on the current efficiency, which was measured as 47% by Rutherford backscattering.

Following growth, the surface topography close to the center of each sample was measured in air using a Molecular Imaging PicoSPM atomic force microscope (AFM). Height data were obtained with a resolution of 512 × 512 pixels. Average values of the surface width $w(l)$ were calculated by applying Eq. (1) to all square regions of side l in a particular image.

The amorphous structure of films prepared by this method was verified by X-ray diffraction (XRD). Fig. 1 shows a typical XRD pattern from a CoP film electrodeposited on a Si substrate that was subsequently removed. Magnetic measurements showed that the magnetic coercivity of the films decreases rapidly with increasing t. Although films grown on the rougher substrates with an additional Cu layer have a higher coercivity for low t, for t greater than ~1 μm the influence of the substrate vanishes and the coercivity remains below 10 Oe.

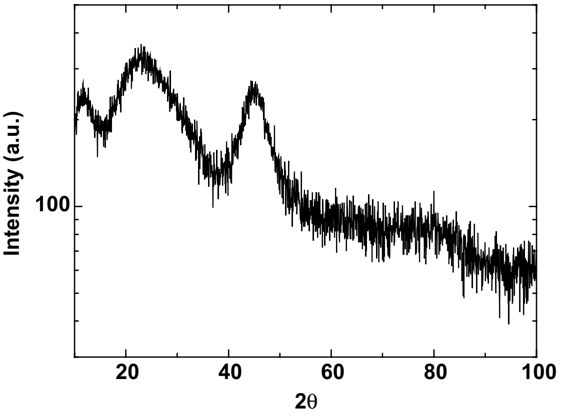

Fig. 1. A typical X-ray diffraction pattern from a CoP film electrodeposited on a Si substrate that was subsequently removed.

Fig. 2(a) shows a typical 5 μm × 5 μm image of a CoP film with $t = 1200$ nm electrodeposited on a Au (280 nm)/Cr (30 nm)/glass substrate, while Fig. 2(b) shows $w(l)$ for the same film. From the latter, for small l, $\log w$ is proportional to $\log l$, i.e. $w \propto l^H$ with $H \approx 0.8$, showing that the film surface is statistically self-affine with l in this range, while for large l, w is constant, and equal to the saturation roughness w_{sat}. The crossover between these behaviours occurs for $l = l_c$.

Fig. 3 shows the variation of w_{sat} and l_c as a function of t for a series of CoP films electrodeposited on Au (280 nm)/Cr (30 nm)/glass substrates. Values of H and w_{sat} for each film were determined by fitting straight lines to the linear parts of the $w(l)$ plot, while l_c was obtained from their intersection. For these substrates $w_{sat} = 3.1 \pm 0.1$ nm and $l_c = 115 \pm 15$ nm. As t increases, w_{sat} decreases from a value significantly greater than for the substrate to only ~1 nm for $t = 4000$ nm, which was