Electrodeposited amorphous CoP multilayers with high permeability

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Abstract

Multilayer films composed of Co_xP_{1-x} ferromagnetic layers with different composition ($0.74<x<0.86$) have been obtained by varying the electrolytic current during the deposition process. These samples exhibit planar anisotropy, high permeability and a very low coercive force (~5 A/m). The magnetic properties of these samples have been compared with the properties of Co_xP_{1-x} multilayers consisting of magnetic and non-magnetic ($x<0.7$) layers.

Keywords: Electrolytic multilayers, Magnetic anisotropy, Coercive force.

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Electrodeposited amorphous Co-P alloys have a magnetic anisotropy with an easy axis perpendicular to their surface [1] and this limits their application as soft magnetic materials. Since the 1970's, some efforts have been made in order to obtain amorphous Co-P alloys with planar anisotropy. Some authors have reported tube-shaped samples with high permeability (>10^5) and very low coercive force (H_c~6 A/m). [2]. However, these kind of tube-shaped samples are not very useful in planar applications. Riveiro et al. have reported amorphous Co-P multilayer films, consisting of alternating magnetic and non-magnetic layers (M/NM samples), with planar anisotropy, high permeability and a low coercive force (10-100 A/m) [3].

In this work we show that it is possible to obtain CoP multilayer samples with planar anisotropy and low coercive force if just ferromagnetic layers are used (M/M samples).

Before obtaining multilayer samples, monolayers were obtained to study the relation between electrolytic current density and composition. The compositions were measured by using a scanning electron microscope with energy dispersive X-ray microanalysis. Figure 1 shows that it is possible to change the composition in a wide range by varying the current density used in the deposition process. In order to produce multilayer samples consisting of layers with different composition (and different magnetic properties) we used a current density pulse with different amplitude and duration to obtain each layer.

Amorphous Co-P multilayer films were electrodeposited onto Cu substrates under the conditions described in Ref. [4]. The thickness of the samples was measured using a surface roughness detector. Due to the non-homogeneity of the surface, it is only possible to estimate an average value of the thickness, despite the high sensibility of the detector.

Hysteresis loops with the applied field in the sample's plane were obtained by using a conventional ac-magnetometer. The anisotropy has been obtained from the magnetization work by numerical integration of the area enclosed by the magnetization curve, the ordinate axis and the line $M = M_S$.

Samples composed of N bilayers $Co_{83}P_{17}/Co_{74}\ P_{26}$ were obtained. All the samples had the same thickness (~30μm) and shape (the same shape anisotropy), but different number of bilayers (and, of course, different thickness of bilayer). Figure 2 shows the variation in the perpendicular anisotropy with the thickness of the bilayer. It is shown that we can continuously vary the anisotropy by only changing the thickness of the layers.

Subsequently, samples with the same number of layers (1000 bilayers) but with different compositions were obtained. Figure 2 also shows the variation in the anisotropy in this case. In the x-axis we show the difference between the M_S of the two layers which form a bilayer. With a smaller than $0.3\mu_B$/at difference in M_S (a smaller than 300 mA/cm^2 difference in current density), perpendicular anisotropy is reduced from 1 to 0.25. It has been observed that, due to planar and shape anisotropy, it is not possible to reduce the anisotropy below 0.15.

As we can see, not only by introducing a non-magnetic layer, but also by modulating the M_S of the layers, can we control the anisotropy and obtain samples with planar anisotropy and very high susceptibility.

The coercive force was measured in a dc-field by using the extraction method. Before the measurement, the sample was saturated in a field of 10^4 A/m. We measured M/M samples and M/NM samples (obtained as reported in [4]) in the same conditions. We obtained H_c~30A/m in M/NM samples, as it had been obtained by Riveiro et al. [3]. In the M/M samples we obtained values between 3A/m and 10A/m.

From these results, we can conclude that it is possible to obtain electrodeposited samples almost as soft as amorphous materials produced by rapid quenching methods.

The domain wall structure of M/NM samples has been widely studied [5]. Those samples show Nèel and Cross-Tie walls, which means that there are no exchange coupling between the ferromagnetic layers. The domain wall structure of the MM samples has been studied using Bitter technique. Figure 3 corresponds to a multilayer sample consisting of 100 bilayers $Co_{83}P_{17}/Co_{78}P_{22.}$ We can see two different magnetic structures: a domain wall (a Bloch wall), which is very easy to move applying a field of a few A/m and other magnetic structure very difficult to move applying a field. This structure changes when the domain wall interacts with it, but does not seem to be capable of pinning the domain wall. This hard structure is associated to the surface single layer, and the domain wall is associated to more than one layer. Moreover, we suggest that this is the cause of the decrease of the coercive force. In the M/NM layers, there is no exchange interaction between layers, so the roughness of the interface between layers pins strongly the domain walls. In the M/M samples, there is exchange interaction between the layers, so the pinning produced by the inhomogeneities between layers is higly reduced and it is easier to move the large domain walls that involve more than one layer.

In conclusion, we present electrodeposited Co-P films with better soft magnetic properties than other electrodeposited films reported before. The coercive force and susceptibility are comparable to the properties of amorphous produced by rapid quenching methods. This fact opens a great field of application of such a material because it can be easily integrated in planar structures such as planar flux-gates [6] or planar transformers and inductors to be used in switching regulators or dc-dc transformers.

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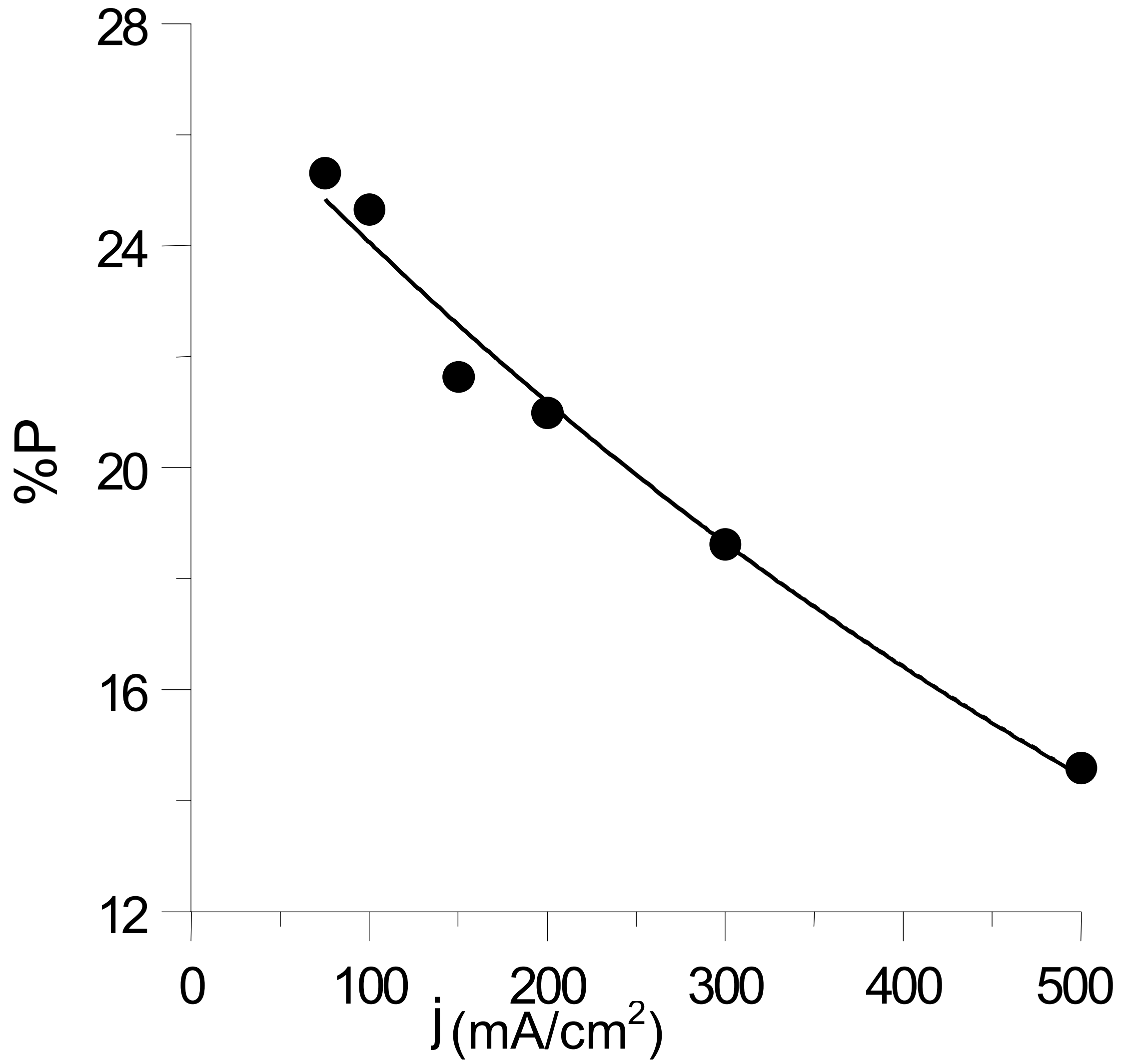
Figure captions

Figure 1. Sample composition as a function of the electrolytic current density.

Figure 2. Anisotropy as a function of the thickness of the bilayers and difference in saturation magnetization. Anisotropy is normalised to the perpendicular anisotropy maximum value.

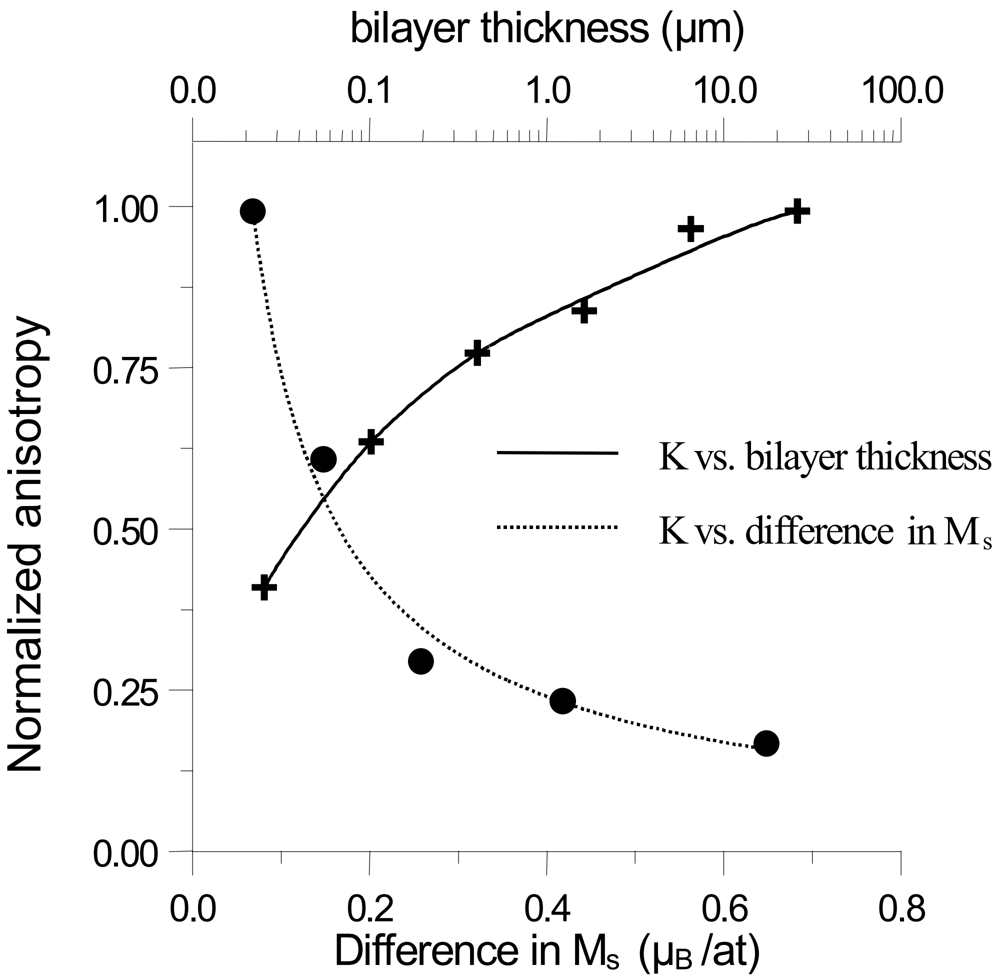
Figure 3. Domain wall structure of a M/M sample obtained by Bitter technique (a) before and (b) after applying a low magnetic field.

Figure 1. L. Pérez et al.



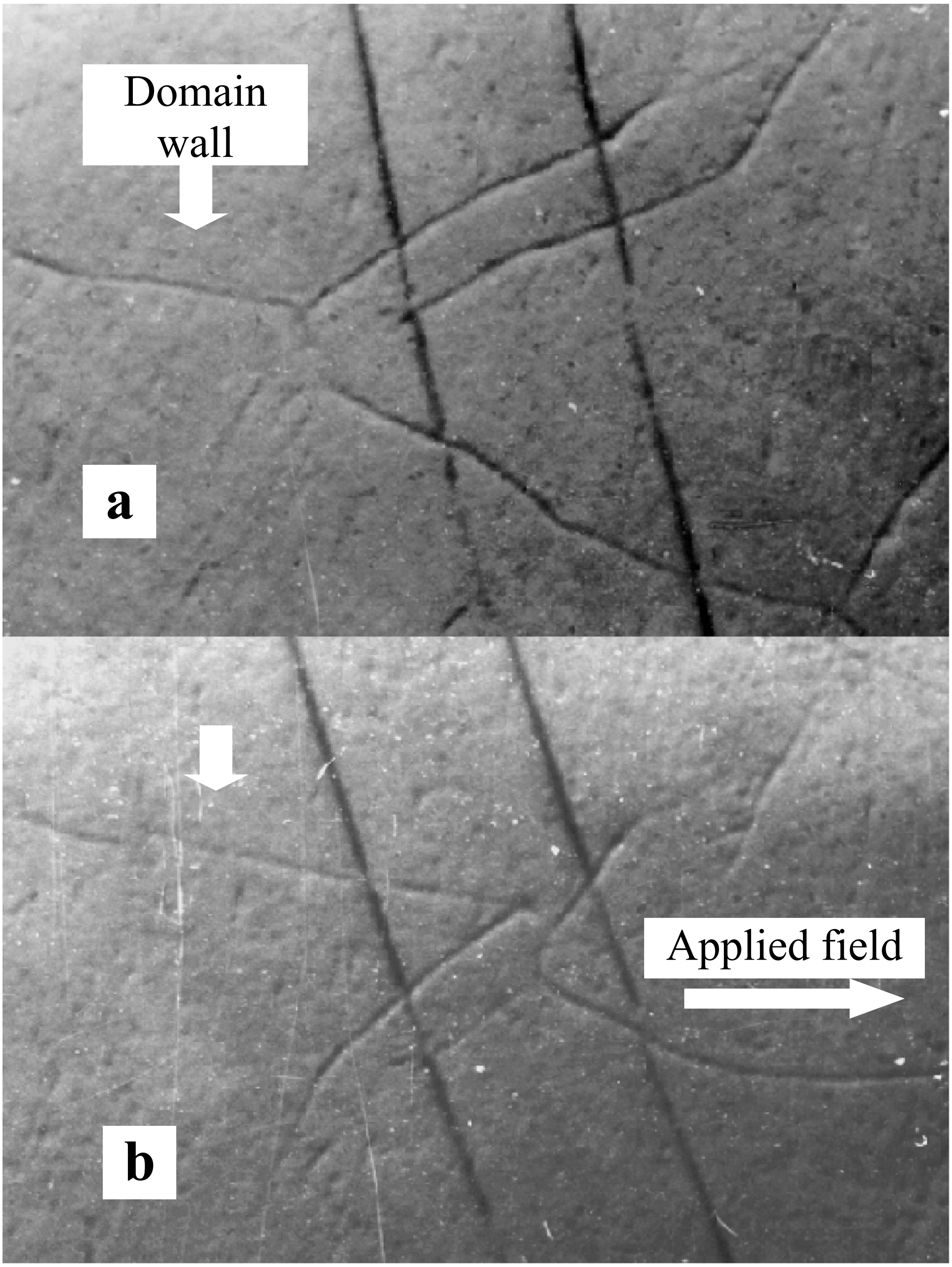
Reduction factor: 1/3

Figure 2. L. Pérez et al.



Reduction factor: 0.5

Figure 3. L. Pérez et al.



Reduction factor: 0.5