Magnetic and Electrical properties of Vitrovac/Au/Vitrovac multilayered obtained by means of magnetron sputtering

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Abstract. We report the effect of the intermediate nonmagnetic layer and the influence of the thickness on the magnetic and electrical properties in Co-based amorphous multilayered, whose composition is VITROVAC-6030/Au/VITROVAC-6030; and these were deposited by DC magnetron sputtering technique. In all samples, the first VITROVAC-6030 layer was deposited on silica glasses substrate, with thickness from 30 to 125 nm, and the middle layer is Au with 5 nm thickness; in top, the VITROVAC-6030 layer was deposited with 30 nm thickness. Additionally, the photolithography process was employed to etch strip patterns on multilayered with length 1 cm and width between 0.1 mm to 1 mm; that it can induce magnetic anisotropy, therefore a change in easy magnetic axis. Finally, we have also made a comparison of magnetic and electrical properties between multilayered and strip patterns on multilayered; where the electrical resistance of multilayered depends on both VITROVAC and Au layer thickness, and electrical measurements show a conductive behavior with high resistance value.

1. Introduction

Recently, the amorphous alloys and metallic nanocrystalline have attracted attention, due to their possible application as magnetic sensors and spintronic devices. [1-7]. Amorphous magnetic alloys have high metallic resistivity, low eddy current, low magnetic losses, high saturation induction, and high permeability. These properties were employed to design devices such as transformers power supplies, magnetic switches, and magnetic field sensor [1,8,9]. It is necessary to mention that VITROVAC-6030 is an amorphous alloy obtained by means of melt-spinning technique, where cooling rates are around 10⁶ °C/s, which prevent the crystalline growth; however, the heat transfer limitation restricts the volume of ribbons and wires with thickness of 100 µm [1,3]. Magnetic and electrical properties in magnetic multilayer system of 3d-transition metals are the more important area of the magnetic phenomena and applied magnetism. The above-mentioned is due to new phenomena as quantum size effects [2], giant magnetoresistance [9,10] and the coupling between ferromagnetic layers through nonmagnetic metallic separators [11,12]; as well as the wide application of these materials in spintronics and (micro-/nano-)electronic devices. On the other hand, a significant improvement in magnetic multilayered systems is through to obtain and to study the magnetic pattern, with the possibility of modulating the magnetic anisotropy field. Moreover, the spintronic technology
requires multilayered, where magnetron sputtering deposition has been useful to control the growth thickness and multilayered deposit [13-16].

In this work, we have researched the structural, magnetic and electrical properties of Co-based amorphous multilayered, VITROVAC-6030/Au/VITROVAC-6030, with different thickness. Additionally, we have also researched the influence of nonmagnetic intermediate Au layer, on the magnetic and electrical properties of thin three-layer systems; as well as the comparison of the magnetic and electrical properties with magnetic multilayered patterns, and its influence in magnetic anisotropy field. Finally, it is necessary to mention that most of the reported multilayered systems are crystalline, and our goal is to present a combination between amorphous and crystalline layers.

2. Experimental details

2.1. Metallic amorphous multilayer deposition

Leica EM MED020 DC Magnetron sputtering deposition was employed to obtain VITROVAC layers with thickness 31.25 nm, 62.5 nm, 125 nm and 250 nm. All deposits were made on silica glass substrate at room temperature, with 3×10^{-2} mbar Argon pressure, and 180-186 voltage between target and substrate with vacuum 1.3×10^{-5} mbar. Structural properties were evaluated by Grazing Incidence X-ray Diffraction (GXRD), and which is equipped with a curved position sensitive detector and CoKα radiation source (λ=1.78901 Å), where the patterns were collected at 0.5° grazing incidence in 2θ interval from 10° to 70°, and acquisition time of 30 min. VITROVAC/Au/VITROVAC are deposited on glass substrates, where the first VITROVAC layer has a different thickness, 31.25 nm, 62.5 nm and 125 nm, the middle Au layer has a thickness of 5 nm, and in the top of multilayered a VITROVAC layer with 30 nm thickness (see figure 1(a)).

![Figure 1](#)

**Figure 1.** (a) VITROVAC/Au/VITROVAC multilayered. (b) Strip patterns of VITROVAC/Au/VITROVAC multilayered.

2.2. Etching patterns of VITROVAC layer and multilayered VITROVAC/Au/VITROVAC

Patterning process was performed by UV photolithography, where we made five strip patterns of 1 cm length, with different wide: 1mm, 0.8 mm, 0.6 mm, 0.4 mm and 0.1 mm (see figure 1(b)). The masks were printed on common transparency film, the transfer process employed AZ 5214-E Ir photo-resin and etching with ferric chloride for 2 seconds.

2.3. Magnetic characterization

Magnetization measurements were carried out in Dyna Cool PPMS Quantum vibrating sample magnetometer (VSM), at room temperature and in the magnetic field range from -5 kOe to 5kOe. Magnetic anisotropy was measured for VITROVAC layer (31.25 nm) and VITROVAC-6030(31.25 nm)/Au(5 nm)/VITROVAC-6030(31.25 nm) multilayer, and in the strip pattern of 0.4 mm width and in the magnetic field range from -8 kOe to 8 kOe.
2.4. Electrical characterization

Electrical resistance measurements were carried out by means of four-point probe method in a Keithley 4200 SCS, in samples with 1 cm² (1 cm x 1 cm) areas, where Kelvin configuration was used with 2 mm separation between probes. Additionally, the electrical resistance measurements of strip patterns were carried out by means of two probe method in Keithley 4200 SCS, with 6 mm separation between probes.

3. Results

3.1. Structural characterization

Figure 2 shows the GXRD spectra of VITROVAC-6030 layers on silica glass as substrate, and which were obtained for 31.25 nm, 62.5 nm, 125 nm and 250 nm thickness. All GXRD spectra have not peaks, indicating that it is an amorphous phase; furthermore, its intensity decreased when diminishes VITROVAC thickness. GXRD spectra confirm that the magnetron-sputtering conditions are appropriate to conserve the amorphous phase of VITROVAC-6030.

![Figure 2. GXRD pattern in VITROVAC-6030 layer with 31.25 nm, 62.5 nm, 125 nm and 250 nm thickness.](image)

3.2. Magnetic characterization

Figure 3(a) shows the magnetization cycles in VITROVAC-6030 layers deposited on silica glass as substrate, with the thickness of 31.25 nm, 62.5 nm, 125 nm and 250 nm; these magnetization cycles show a high saturation magnetization and low coercive field that corresponds to a soft magnetic material. Figure 3(b) shows the coercive field and the saturation magnetization as thickness function, where coercive field has a maximum at 62.5 nm thickness and with a maximum at 125 nm for the saturation magnetization; the changes in coercive field suggest a change in magnetic anisotropy field, due to increase in thickness.
Figure 3. (a) Magnetization cycles of VITROVAC-6030 layers with different thickness. (b) Coercive field (squares) and saturation magnetization (triangles) as thickness function in VITROVAC-6030 layers.

Figure 4(a) shows the magnetization cycles of VITROVAC/Au/VITROVAC multilayered, with the first layer as thickness function (see figure 1(a)); where saturation magnetization increases, due to the increment in volume of the first layer. A similar behavior is observed in saturation magnetization for VITROVAC-6030 layer (figure 3(a)). In the figure 4(b), the coercive field and the saturation magnetization as thickness function, where we observe a decrease in the coercive field and an increase in the saturation magnetization; and this behavior can be associated with the volume increment in the multilayered. When comparing the figures 3(b) and 4(b), the saturation magnetization has increased and the coercive fields have decreased, which suggests a magnetostatic coupling between VITROVAC-6030 layers through Au layer.

Figure 4. (a) Magnetization cycles of VITROVAC/Au/VITROVAC multilayered, with the first layer as thickness function. (b) Coercive field (squares) and saturation magnetization (triangles) with the first layer as thickness function.

We have also measured the multilayered at different orientations, determining the easy magnetization axis; where V0° and H0° orientations corresponds the parallel magnetic field to multilayered plane, and V90° and H90° orientations corresponds the perpendicular magnetic field to multilayered plane. Figure 5(a) shows magnetization cycles of VITROVAC (31.25 nm)/Au
(5nm)/VITROVAC (30 nm) multilayered for different magnetic field orientations, where saturation magnetization has a similar behavior for V0º, H0º and V90º, H90º; respectively. These results suggest that easy magnetic field is V0º and H0º orientations, i.e. the easy magnetic axis is in-plane and its hard axis is out-plane in the multilayered.

Figure 5(b) shows the magnetization cycles for the same multilayered but with pattern strip of 0.4 mm width, and the measurements were made at same orientations. We have observed that the saturation magnetization is conserved for V0º and H0º, then for these orientations the easy magnetic field is conserved, while for V90º and H90º the hard axis is still out-plane; however, the substrate contribution is eliminated, and it can be associated with only one direction in magnetic anisotropy, therefore, the easy magnetic field is along strip pattern. It is necessary to mention that we present only this multilayered, because it has more evident changes. The previous results suggest that it is possible to change the easy magnetization axis, by increment in the shape anisotropy though the strip patterns, while the Au layer induces a low magnetostatic interactions between magnetic layers.

Figure 5. (a) Magnetization cycles of VITROVAC/Au/VITROVAC multilayered with 31.25 nm thickness for the first layer. (b) Magnetization cycles of the same multilayered as strip patterns with 0.4 mm width.

3.3. Electrical characterization

Figure 6(a) shows multilayered resistivity with the first layer as thickness function, where the resistivity increases as thickness function; this change cannot be associated with the volume increment, however, it can be associated with increment of magnetic anisotropy. Figure 6(b) shows the multilayered resistivity as function of strip pattern width, where electrical resistivity decreases with width of strip pattern, confirming that shape anisotropy increases with the conductivity. This result suggests a correlation between electrical conduction and spin behavior.

Figure 6. (a) Electrical resistivity of VITROVAC multilayered as thickness functions at the base. (b) Electrical resistivity VITROVAC multilayered as function of strip pattern width.
4. Conclusions
We have deposited amorphous VITROVAC-6030 layer and we have manufactured a VITROVAC-
6030/Au/VITROVAC-6030 multilayered. The samples have an amorphous state and a magnetic
homogeneity similar to target. The magnetic anisotropy field and magnetostatic coupling were induced
in multilayered by shape modifications with strip patterns, which change the easy magnetic directions
and the electrical conductivity; suggesting a strong correlation between electrical conduction and spin
behavior. As conclusion, magnetic anisotropy should be nearly zero for tuning anisotropy for metallic
systems, and this way to have control on the magnetic behavior and electrical conduction.

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