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REMANENCE CURVES FOR THE THIN CuNi FILMS

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Abstract: Thin CuNi films with varying thicknesses were fabricated via electrodeposition, and their magnetic properties were investigated using isothermal remanent magnetization (IRM) and direct current demagnetization (DCD) techniques. The coercivity of thin CuNi films can be modeled by a logarithmic normal distribution. We also investigate the effects of thickness above coercivity on thin films of NiCu, FeCu, and FeNi obtained by electrodeposition.
Keywords: Magnetic interactions, ΔM plots.

INTRODUCTION

Conventionally, alloys CuNi are of actual interest due to their high resistivity. Thin CuNi films exhibit a coercivity $H_c \approx 100$ Oe and display the existence of dipolar and exchange coupling interactions. While some potential applications of the thin Ni films in store media, microwave absorption, catalysis, magnetic field sensors [6]. Meanwhile, nanomaterials of Fe/Cu in the form of multilayer nanowires have revealed that an increase in the thickness of the Fe layer increases coercivity [1]. FeCu nanomaterials exhibit ferromagnetism, spin glass-like behavior, and antiferromagnetism, which is attributed to the presence of α-Fe particles enclosed in a nanometric surface layer [3]. It has been observed that $Fe_{50}Cu_{50}$ alloys exhibit ferromagnetic behavior, whereas films of Fe deposited in Cu present antiferromagnetic behavior, which may be due to the presence of Fe fcc ferromagnetic with a dilated lattice [8]. Additionally, for thin films of NiCu an increase in the thickness of nonmagnetic Cu layers results in variations in the magnetic and magneto -transport properties of these thin films [10]. An important application of thin films occurs a conducting spacer such as Cu are present, as these thin films exhibit an effect known as exchange bias during cooling [4]. It is also noteworthy that the thickness of thin films affects magnetic properties such as coercivity and the onset of dipolar magnetic interactions. A study of these magnetic interactions is vital due their effects above the magnetic reversal modes [14]. The study of the demagnetizing field in thin films is important because the sensitivity of MR also depends on the demagnetizing field as well as the anisotropy field [15]. Therefore, this work aims to study the determination of the dipolar interaction field of remanence curves and the effects of magnetic properties in CuNi thin films obtained by electrodeposition.

GENERAL CONSIDERATIONS

The Ni, FeCu and NiCu thin films are three-dimensional arrangements, too recognized as granular GMR films. The thin films such as NiCu are of attention owing to their likely applications as spin valve read heads. It is also chief to letter that the thin films display magnetic interactions, and each particle has a rectangular hysteresis loop. Here, it is considered for the thin films of NiCu that the easy axes magnetization is perpendicular to the plane to the film. Here, the thin films of Ni and NiCu, are studied via isothermal remanent magnetization (IRM) and direct current demagnetization (DCD) methods, which show that the exchange coupling magnetic interactions. In the material with cubic structure as the Ni and/or NiCu, the contribution of the effective field calculations to total field is defined as follows:

$$\vec{H} = h_o \hat{z} - EM_Z \hat{z} + JM\hat{m} \quad (1)$$

Where h_o is defined as the applied magnetic field perpendicular to the plane to the film, EM_Z is well-defined as the demagnetizing field and *JM* is the magnetic field related with the exchange interaction. Then, in the molecular field calculations, the hamiltonian is well-defined as follows:

$$\mathcal{H} = \frac{1}{2} JM^2 - \frac{1}{2} EM^2 - (h_o \hat{z} - EM_Z \hat{z} + JM\hat{m}) \cdot \vec{S} \quad (2)$$

Where the first term denotes the exchange energy, the second term denotes the demagnetizing energy and $h_o \hat{z}$ denotes the external magnetic field, while that EM_Z is associated with exchange interaction and M denotes the total magnetization.

EFFECTIVE ANISOTROPY ENERGY

Also, it is vital to contemplate the effective anisotropy energy to comprehend the magnetic properties of thin films containing an assemblage of magnetic particles. The effective anisotropy energy is well-defined as follows:

$$K^{eff} = \frac{1}{d}\int_0^d \left(K^v + K^s \delta(z)\right) dz \quad (3)$$

Where K^v denotes the bulk anisotropy energy density, while that K^s signifies the energy per unit area localized at the surface and, δ(z) denotes the Dirac function. The effective anisotropy energy density is defined as follows:

$$K^{eff} = K^v + \frac{K^s}{d} \quad (4)$$

Where the volume anisotropy includes the magnetocrystalline anisotropy, magnetostatic energy, and the magnetoelastic anisotropy. Then, H_{Demag} can be well-defined as the effective demagnetizing field $H_{Demag} = H_{Self} + H_{dip}$ where H_{Self} represents the demagnetizing field and H_{dip} signifies the dipolar interaction field. Here, the correction due to the effective demagnetizing field expressed as $H_{Demag} = -(N - N_i)M$ where N=1 for the applied magnetic field perpendicular to the plane to the film and $N_i = \frac{1}{3}$. While, that the influence of dipolar interaction field to thin films was found from the IRM and DCD remanence curves as:

$$\alpha_{dip} = 3\Delta H_{dip} \quad (5)$$

where α_{dip} signifies the dipolar interaction coefficient, ΔH_{dip} can be found by the next equation:

$$\Delta H_{dip} = H_r - H_d \quad (6)$$

where H_r represents the magnetic field whit magnetic interactions (continue line), representing the thin CuNi films. The H_d represents the magnitude of the magnetic field without magnetic interactions (dashed line) as shown in the Fig. 4.

EXPERIMENTAL

Electrodeposition techniques are unique due to their low cost and rapid deposition, making them important to produce amorphous and nanostructured materials. Ni, Cu, and Fe foils were used as anodes, and the films were deposited onto a metallic substrate (cathode). After deposition, the thin films were not cleaned with HCl to avoid changes in their magnetic properties. Subsequently, the films were coated with epoxy resin to prevent corrosion and maintain their magnetic properties, and their magnetic properties were measured with an applied magnetic field perpendicular to the film plane. Magnetization curves were obtained using the IRM and DCD methods, as shown in Fig. 1.

RESULTS

Figure 1 displays the remanence curve for the thin Ni films. Now m_r signifies normalized remanent magnetization later applying a magnetic field to the thin film in a demagnetized statestate; m_d denotes the normalized remanent magnetization subsequently application of a reverse magnetic field in a thin film previously magnetized with a maximum magnetic field of 225 Oe.

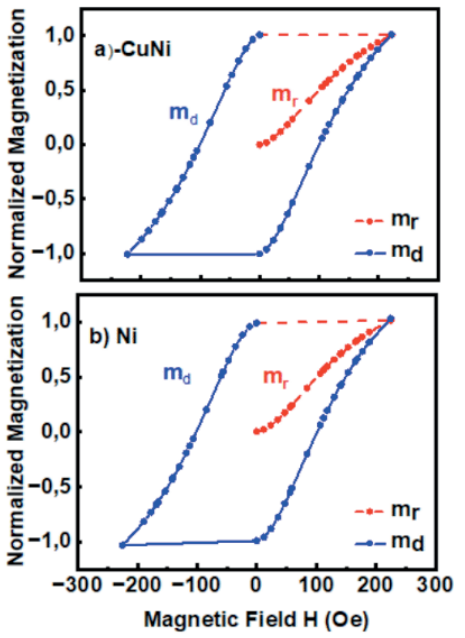

Figure 1. Isothermal remanent magnetization curve (m_r) and direct current demagnetization (m_d) for a Ni and CuNi thin film obtained via electrodeposition.

Fig. 2 shows that the coercivity data can be modeled by a logarithmic normal distribution, which is a modification of the normal distribution. In this distribution, g(h) represents the distribution function, and the measured coercivity (H_c) is normalized to the value of H_o, representing the median distribution coercivity. The dispersion width parameter is represented by s.

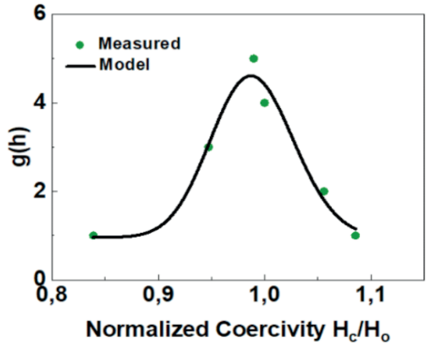

Figure 2.- Normalized coercivity H_C/H_o for thin films of NiCu, Ni, FeCu, and FeNi obtained by electrodeposition.

Here, we investigated the values that change the coercivity, and it is true that the parameters that can contribute to a change in coercivity are crystal size, crystallinity, crystal structure, the texture of grains, surface roughness. However, in this study, we investigate the effects of thickness above coercivity on thin films of NiCu, FeCu, and FeNi obtained by electrodeposition, as demonstrated in Fig. 3. shows a plot of log t versus log Hc for the thin films of NiCu, FeCu and FeNi obtained by electrodeposition. The data presented in Fig. 3 for the thin films of NiCu, FeCu, and FeNi can be modeled using a behavior straight-line type.

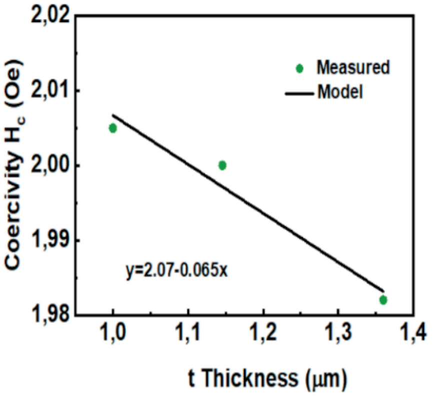

Figure 3.-Thicknees vs coercivity for thin films of NiCu, FeCu and FeNi obtained by electrodeposition.

Figure 4 also shows the IRM and DCD remanence curves (m_r and m_d) of the CuNi thin films obtained via electrodeposition. When magnetic interactions exist in the thin films, their IRM and DCD remanence curves are sheared by the interaction field. Also, the results after the correction of H_{Demag} are shown in Figure 4, where the H_{demag} denotes the effective demagnetizing field expressed as $H_{demag}=-(N-N_i)M$ where $N=1$ for the applied magnetic field perpendicular to the plane to the film and $N_i = \frac{1}{3}$. The results of the correction of H_{demag} is shown in Fig. 4. A remanent coercivity of 17 Oe was observed for thin CuNi films respectively.

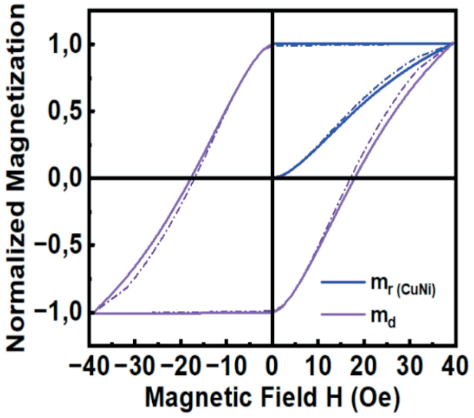

Figure 4. Isothermal remanent magnetization curve (m_r) and direct current demagnetization (m_d) normalized for the CuNi thin films obtained by electrodeposition.

Figure 5 shows the magnetic field-dependent variation of the ΔM curve for the Ni, and CuNi thin films as measured fabricated by electrodeposition. The ΔM plots were employed to inspect the interactions in the Ni and CuNi thin films. Conventionally, ΔM plots are used to study noninteracting systems of single-domain uniaxial particles. We defined the ΔM plots as $\Delta M = m_d - [1-2 m_r]$ where m_d represents the normalized remanent magnetization and use the mean field approach trough of next equation $H_{ext}=H+H_{MF}$ where external field is denoted by H_{ext} and the mean field is considered by $H_{MF.}$ A horizontal line signifies an arrangement with no magnetic interactions. If the ΔM values are positive, it signifies the presence of exchange coupling interactions yielding a magnetizing effect while negative ΔM values indicate dipolar interactions yielding a demagnetizing effect [9,2].

Figure 5a and 5b shows positive and negative values in the ΔM curve for the CuNi and Ni thin film typical of an arrangement where exchange coupling and dipolar interactions exist as is shown previously by other authors [15,9].

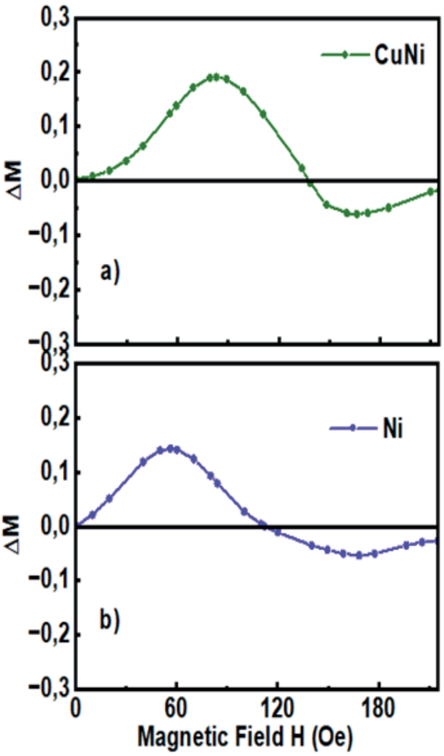

Figure 5. ΔM versus magnetic field plot of different thin films: (a) CuNi, and (b) Ni thin films obtained via electrodeposition.

Figure 6 displays the hysteresis loop and the effect of the dipolar field on the shape of the loop for the CuNi thin films. The Fig. shows that the magnetic interactions field does not cause a change in coercivity; instead, it is associated with shear of the hysteresis loop, resulting in a square-shaped loop [7].

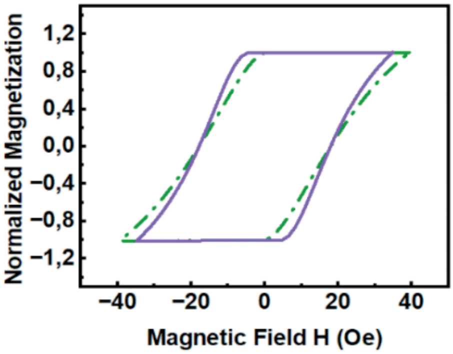

Figure 6. Effect of dipolar interaction field on loop shape for the CuNi thin films obtained by electrodeposition.

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DISCUSSION

In the section of plots ΔM shows ferromagnetic and antiferromagnetic interactions for the thin films of Ni and CuNi. Here, it is important to understand that the ferromagnetic and antiferromagnetic interactions are actual in the technology of thin films due to that the basis exchange bias effect is accompanied with the existence of ferromagnetic and antiferromagnetic interactions. Also, are vital remarks that the exchange bias effect is very important in the spintronic [12]. Moreover, the exchange magnetic interactions are important in the Nickel nanometric pillars (NPs) by create variations in the magnetic anisotropy [5]. In the thin films CuNi the antiferromagnetic interactions can be associated with the presence of nonmagnetic thin films of Cu, while ferromagnetic interactions can be associated with the thin films of Ni. However, it is vital to consider that in the thin films of Ni the behavior is selfsame comparable. Also, the dipolar interactions are more prominent in the thin films of NiCu that are accompanied with the change of the thickness of the thin films as previously shown [16]. Nevertheless, it is also exciting to see that the peaks associated with the ferromagnetic interactions shift positions for the thin films of Ni and NiCu that could be due to the change of the thickness of thin films.

CONCLUSIONS

Thin films of CuNi, FeCu and Ni obtained by electrodeposition. Remanent magnetization properties were measured with the IRM and DCD curves perpendicular to the film plane. The coercivity of thin Films of NiCu were modeled by a logarithmic normal distribution. ΔM curve for the CuNi and Ni thin film typical of an arrangement where exchange coupling and dipolar interactions exist. The hysteresis loop and the effect of the dipolar field on the shape of the loop for the CuNi thin films were established.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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