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GMI effect in CuO coated Co-based amorphous ribbons

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ABSTRACT

A Copper oxide (CuO) film has been grown on a surface of Co-based amorphous ribbon using chemical successive ionic layer adsorption and reaction technique, at room temperature and atmosphere pressure. The influence of coating and width of ribbon on giant magneto impedance have been investigated over a frequency range from 0.1 to 3 MHz and under a static magnetic field between −8 and +8 kA/m. The results showed that Co-based amorphous ribbons, which are coated CuO film, have a significant effect on the magnitude and operation frequency for the giant magneto impedance effect as compared to the samples without coating. The highest giant magneto impedance effect was found to be 14.90 on 5 mm width coated ribbon, which is 60% higher than the sample without coating. A surface observation of these samples has been carried out by an atomic force microscope. The AFM images reveal the difference between surfaces of coated and as-cast sample.

1. Introduction

A giant magneto impedance (GMI) effect, discovered some years ago in amorphous samples, has generated growing interest because of their promising applications in magnetic sensors [1]. The GMI effect in a magnetic conductor has been interpreted in terms of the classical theory of the skin effect characterized by a penetration depth [2]. The magnitude of the GMI effect depends not only on the magnetising frequency and intrinsic properties of the material, but also geometrical and surface factors of the sample.

The successive ionic layer adsorption and reaction (SILAR) technique is a suitable method for making uniform coating for amorphous ribbons. The SILAR technique is an aqueous solution technique based on sequential reactions at the substrate–solution interface for the deposition of thin films [3]. This method is mainly based on the adsorption and reaction of the ions from the solution and rinsing between every immersion with deionised water to avoid homogeneous precipitation in the solution [4]. The method has several advantages; it does not require high quality substrates, the deposition rate and the thickness of the film can be easily controlled over a wide range with changing the deposition cycles, there are virtually no restrictions on substrate material, dimensions or its surface profile; moreover, it is convenient for large area deposition [5].

This paper is concentrated on the GMI effect to understand the influence of coating, geometrical factors and surface roughness of Co-based amorphous ribbons.

2. Materials and methods

2.1. Preparation of the samples

The CuO thin films were grown on the surface of Co-based amorphous ribbons using the SILAR technique. A copper(II) sulphate solution was used as a source of Cu caption precursor which was made from alkaline with addition of aqueous ammonia solution making the pH of solution 12. Some distilled water at 80 °C constant temperature was used as an anionic precursor. The SILAR cycle consists of four steps: Firstly, a clean substrate was immersed into the $CuSO_4$ and ammonia solution for 12 s and then the substrate was also put into the distilled water bath, which was maintained at 80 °C for 25 s, thirdly the substrate was kept in air for 25 s, and finally the substrate was dipped into the distilled water bath at room temperature for 8 s; thus the first SILAR growth cycle is finished. A thin film with desired thickness on the sample can be grown with repeating these cycles. Using this method we obtained a CuO film of about 15 nm thickness with repeating this SILAR cycles 30 times. Fig. 1 schematically shows the detailed SILAR procedure for the deposition of CuO nanostructure seed layer thin films. The detailed chemical reactions involved in the SILAR growth process are given as follows:

$$[Cu(NH_3)_4]^{2+} + H_2O \rightarrow Cu^{2+} + NH_4{}^{+} + OH^{-}$$

$$Cu^{2+} + 2OH^{-} \rightarrow Cu(OH)_2$$

$$Cu(OH)_2 \rightarrow CuO(s) + H_2O$$

2.2. GMI measurements

The coated samples with varied widths have been placed along the axis of a solenoid for the GMI measurements. The sample axis is perpendicular to the earth's

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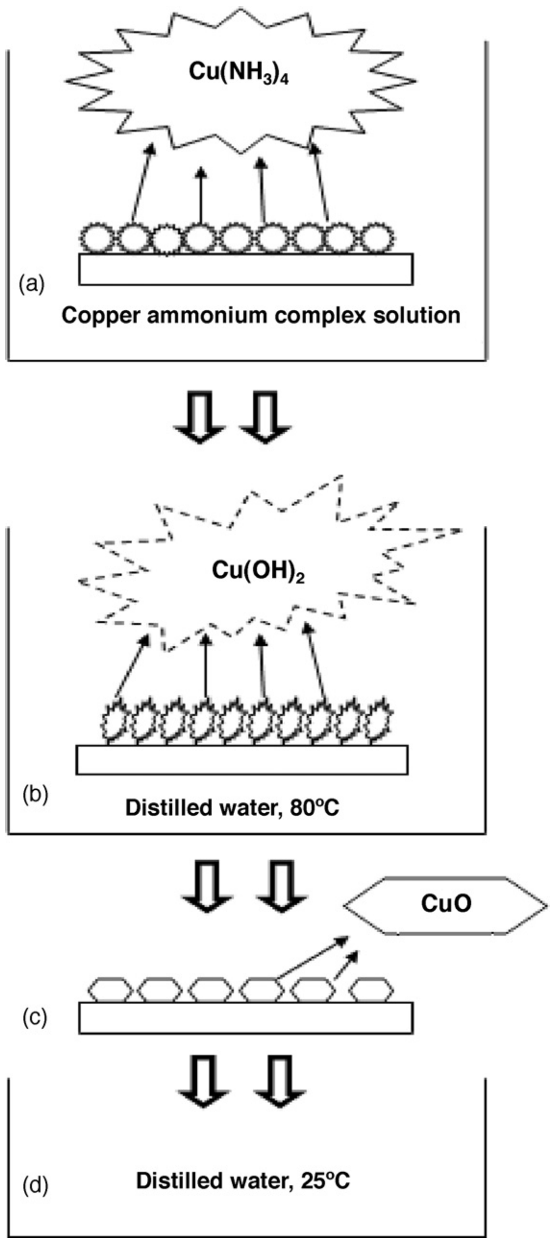

Fig. 1. The SILAR growth mechanism of CuO nanostructure film (a) formation of tetra-amine copper(II) complex $[Cu(NH_3)_4]^{2+}$ (b) formation of $Cu(OH)_2$ (c) formation CuO seed layer (d) cleaning of CuO seed layer.

magnetic field to minimize its effect on the sample [6]. The GMI ratio measurements have been carried out over the frequency range from 0.1 to 3 MHz using a controlled alternating current with a magnitude of 10 mA, which is passing through the ribbon. The GMI ratios have been calculated as [7];

$$\frac{\Delta Z}{Z_{\max}}(\%) = \frac{Z(H) - Z(H_{\max})}{Z(H_{\max})} \times 100 \quad (1)$$

where $\Delta Z/Z_{\max}$, $Z(H)$ and $Z(H_{\max})$ are the GMI ratio, magneto impedance at magnetic field H, and magneto impedance at maximum magnetic field, respectively.

2.3. Atomic force microscopy

Topography of the sample surfaces was imaged by an AFM manufactured by Nanomagnetics Instruments Co. The AFM has been operated in tapping mode at the room temperature. Aluminum coated silicon probes manufactured by Nanosensors have been used for tapping. The technical specifications of the silicon AFM probe have been such as: resistivity, 0.01–0.02 Ωcm; resonance frequency, 204–497 kHz; thickness, 4.0 μm; length, 125 μm; width, 30 μm; force constant, 10–15 μm. The resonance frequency for imaging was 298.4 kHz.

The AFM images are typically quantified by three numbers at the microscopic scale: the mean roughness, RMS value and z scale. The mean roughness, R_a of an AFM image is defined as [8].

$$R_a = \frac{\sum_{i=1}^{N} |h_i - \bar{h}|}{N} \quad (2)$$

where h_i indicates the surface roughness data at the point i, $\bar{h}$ is the mean surface roughness, and N is the number of data points for the image. The simplest and most common method used for the observation of changes in surface topography is called the root mean square (RMS) roughness calculation (R_q). The image RMS, R_q is the root mean square average of the height deviations taken from the mean data plane and is expressed as [8]

$$R_q = \sqrt{\frac{\sum_{i=1}^{N} |h_i - \bar{h}|^2}{N}} \quad (3)$$

The z scale gives the vertical distance between the highest and the lowest point of the image.

3. Results and discussions

3.1. GMI effect

The frequency dependency of GMI effect is shown in Fig. 2. The GMI effect has a maximum at 1 MHz, and a minimum at 0.1 MHz frequency on coated sample, which has a width of 5 mm. The GMI effect of CuO coated sample with 5 mm width is about 28% higher than that of the CuO coated sample with 10 mm width. The smallest GMI value has been calculated on coated sample with a width of 15 mm. Fig. 2 also shows the coating effect on the samples. It is clear that the GMI effect is less pronounced on the samples with a wide width than the samples with a smaller width.

Fig. 3 shows the variation of percentage change of GMI (%), with applied field for the samples coated and without coating. The frequency was kept constant at 1 MHz as the highest GMI ratio was obtained. It is observed that the GMI effect increases on the coated samples and reduces with the sample width.

The coating of the sample surface with CuO film has improved the GMI ratio at 1 MHz frequency. It is believed that coating of the sample surface has caused some stress on the surface and the domain structure. The dielectric thin film layer suppresses the magnetic field passing through the sample and therefore the magnetic field penetrates better inside the sample as compared with the sample without coating.

The geometry dependency of the GMI ratio is also shown in Fig. 3. The GMI ratio increases up to 46%, while the ribbon width decreases from 15 to 5 mm. This can be attributed to the change of electrical resistance with decreasing width and internal structure of these samples.

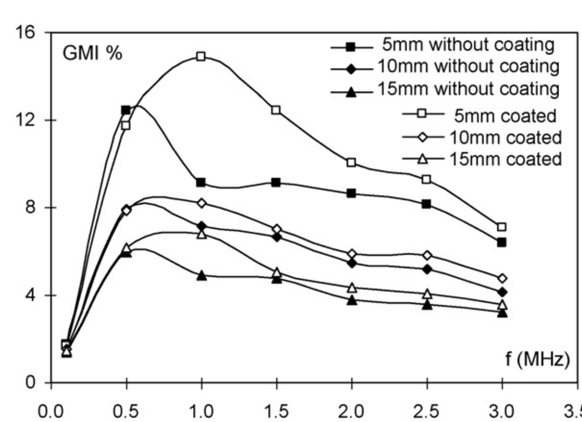

Fig. 2. The frequency dependency of the GMI ratio.

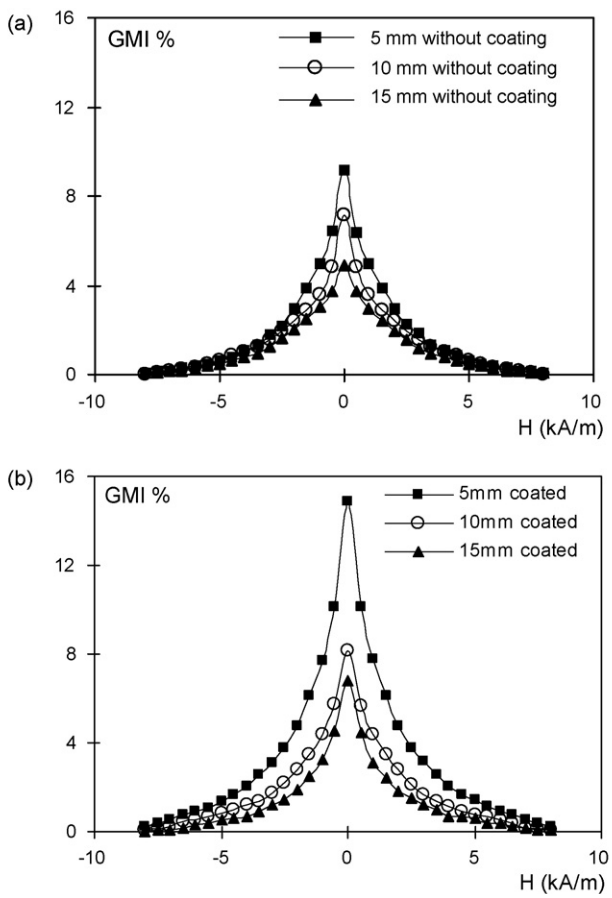

Fig. 3. The variation of the GMI ratio with applied field at constant frequency 1 MHz for the samples (a) coated (b) without coating.

The measured data from different samples has been used to improve a mathematical model over the range of 0–8 kA/m. This model is defined as;

$$GMI\% = ae^{-bH} \tag{4}$$

where a indicates the highest value of the GMI effect and b is the rate of change the GMI. a and b values are shown in Table 1 for the samples CuO coated and without coating.

Fig. 4 indicates the GMI effect for the measured and calculated values in the coated samples and the samples without coating with a width of 5 mm. The results show that the calculated values of these ribbons are in agreement with measured values up to 99%. The model can be improved using extended data obtained from different samples.

3.2. AFM images

The statistics for the samples without coating and copper oxide (CuO) coated samples are summarized in Table 2. The mean roughness and RMS values for the samples without coating are found to be lower than the samples CuO coated. Although the R_a, R_q and z scale were improved on the CuO coated samples, the GMI effect was also increased on these samples. The mean surface roughness has changed 248% after the samples have been coated and then the GMI has improved 60% indicating the coating effect.

Fig. 5 shows 2D surface variations on the samples without coating obtained using the AFM. Some spherical agglomerations, which are large and small, have been observed on the surface of CuO film (Fig. 5). The surface of the sample without coating is smoother than the coated sample. The mean roughness parameters of the sample without coating and coated sample are measured as 183.6, 454.5

Table 1
The parameters of the model given in Eq. (4).

Sample	Width (mm)	a	b
Without coating	5	9.75	0.58
	10	8.21	0.59
	15	5.66	0.53
CuO coated	5	13.23	0.47
	10	8.70	0.54
	15	6.49	0.56

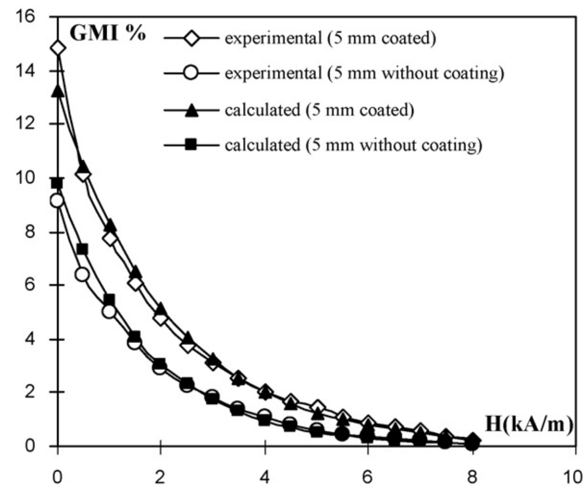

Fig. 4. Measured and calculated GMI values on the amorphous ribbon, which has a width of 5 mm.

Table 2
Surface roughness analysis of the samples.

Sample	Mean roughness (R_a) (nm)	RMS (R_q) (nm)	z Scale (nm)
Without coating	183.6	184.1	448.0
CuO coated	454.5	483.9	1576.0

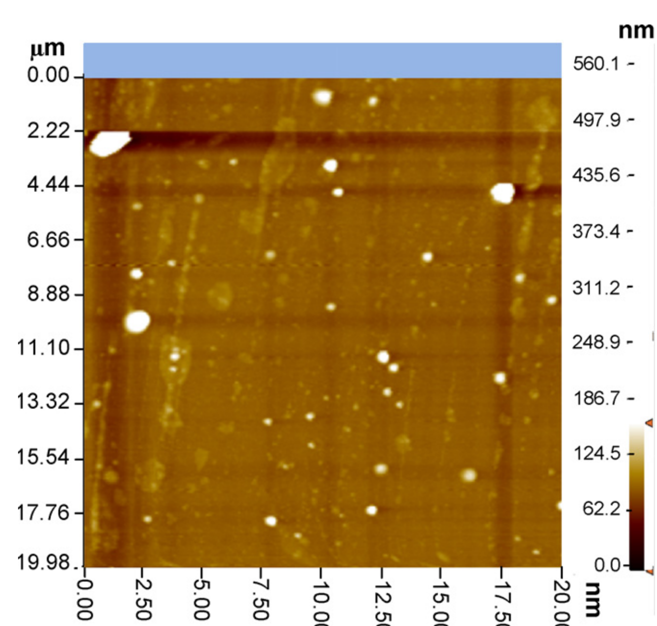

Fig. 5. 2D topography image of Co-based amorphous ribbon without coating. The image size is 20 × 20 μm^2.

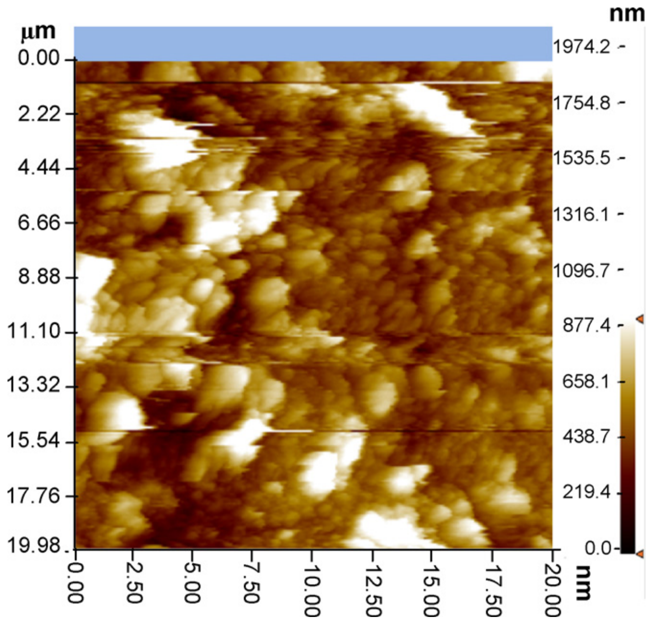

Fig. 6. 2D topography image of CuO coated Co-based amorphous ribbon. The image size is $20 \times 20\,\mu m^2$.

within an area of $20 \times 20\,\mu m^2$, respectively. The RMS and z scale values of these samples have confirmed this (Table 2; Fig. 6).

4. Conclusions

The GMI effect in the samples coated and without coating has been studied as a function of frequency and magnetising field. The highest GMI ratio was found to be 15 at 1 MHz in the CuO coated samples, which have 13 mm long and 5 mm wide.

It was found that the GMI effect has been changed significantly by the geometrical dimensions of samples. GMI effect was nonlinearly varied with increasing ribbon width. A mathematical model was developed using the experimental data and correlation between the calculated and measured values in the model was 99%.

The AFM images reveal the variation of the surface structure between the samples coated and without coating. The interaction between the magnetic field and surface domain structure has an important effect on the GMI ratio of the samples coated and without coating.

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