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Thickness Dependent Structural, Magnetic and Transport Properties of of Cu / Co Thin Film and Multilayer Structures

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Structural, magnetic and transport properties of electron beam evaporated Co / Cu thin film and multilayer structures (MLS) having different layer thicknesses have been characterized using XRD, MOKE and resistivity techniques. The structural studies show different crystal structures for different sub-layer thicknesses. The Co (300 Å) single layer film is amorphous, while Cu (300 Å) film is microcrystalline in nature. The particle size is found to decrease as the number of interfaces increase. The corresponding magnetic and resistivity measurements show an increase in saturation field and resistivity. However, coercivity decreases with decrease in particle size. The results conclude that these properties are greatly influenced by various micro structural parameters such as layer thickness, number of bilayers and the quality of interfaces formed under different growth conditions.

Keywords: Co and Cu film, Magnetization, XRD, interface.

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1. INTRODUCTION

With the ever-rising demands of thin film technology, understanding and controlling thin film development is critical, particularly in case of giant magnetoresistive (GMR) sensors. The strength of the antiferromagnetic coupling depends on the interfacial structure, which in turn depends on the growth of the material. Recently, in the growth of sensor and other magnetoelectronic applications the immiscible system Co / Cu has an appropriate giant magnetoresistance (GMR) effect, continues to be of special interest [1, 2]. Later on the inaugural report of antiferromagnetic (AF) coupling between Fe films spaced by Cr in Fe-Cr-Fe sandwiches [3], a number of studies demonstrated that long range coupling between two ferromagnets separated by nonmagnetic transition metals or noble metals was a fairly universal phenomenon with oscillatory character and short and long periods [4-7]. Nevertheless, in many cases interdiffusion and reaction phenomena at the interfaces occur during deposition, critically alters the physical and chemical attributes. Under such situation one need a careful characterization of these structures in order to understand the role of micro structural parameters in interpreting the various properties exhibited by them. Thus, in the present paper, we systematically took out the structural and magnetic characterization of single, bilayers and MLS using x-ray diffraction and magneto optical Kerr effect technique, in order to get out a clear correlation between the structural parameters and the observed magnetic behaviour in Co / Cu thin film multilayer samples. For the present study, we have prepared following samples, [Co(300 Å) / Cu(300 Å)] bilayer, [Co(60 Å) / Cu(60 Å)]$_{X5}$ and [Co(30 Å) / Cu(30 Å)]$_{X10}$ MLS, keeping the total layer thickness same along with Co (300 Å) and Cu (300 Å) single layer films) under the UHV conditions using the electron beam evaporation system.

2. EXPERIMENTAL DETAILS

The samples Co (300 Å), Cu (300 Å) single layers as well as [Co(300 Å) / Cu(300 Å)] bilayer, [Co(60 Å) / Cu(60 Å)]$_{X5}$ and [Co(30 Å) / Cu(30 Å)]$_{X10}$ multilayer samples used in the present study were synthesized using the electron beam evaporation method under the UHV conditions. The x-ray diffraction measurements were done using Rikagu RINT-2000 diffractometer equipped with a rotating Cu anode as the source of x-rays at $\lambda = 1.542$ Å. The associated changes in magnetic properties were characterized by means of magneto optical Kerr effect (MOKE) technique with a laser source (He-Ne) of wavelength 632.8 nm and transport properties with the help of four-probe method. All the measurements reported were carried out at room temperature. From here in the whole paper for ease we have denoted the sample Co (300 Å) as sample A, Cu (300 Å) as sample B, [Co(300 Å) / Cu(300 Å)] bilayer as sample C, [Co(60 Å) / Cu(60 Å)]$_{X5}$ MLS as sample D and [Co(30 Å) / Cu(30 Å)]$_{X10}$ as sample E.

3. RESULT AND DISCUSSION

3.1 XRD Measurement

Fig. 1 shows the XRD patterns of single, bi-layer and multilayer films. The XRD pattern of Co (300 Å) shows a broad hump at around $2\theta = 44.56°$ due to the reflection from hcp (002) planes, indicating an amorphous nature of the deposited Co thin film as presented in fig. 1a. The broad hump clearly indicates the formation of nanosize crystallites in this instance. The particle size obtained from Scherrer formalism is found to be ~ 39 Å. However, the layer structure for Cu (300 Å) film is crystalline in nature. The XRD pattern corresponding to Cu (300 Å) in fig. 1b, shows a sharp crystalline peak due to reflection from Cu (111) planes at $2\theta = 43.38°$, matches well with the reported value. In this case the particle size is found to be ~ 152 Å (see Table 1). Table 1 shows the values of particle size, saturation field and coercivity for different samples obtained from XRD and MOKE measurements. Likewise, the XRD pattern of Co(300 Å) / Cu(300 Å) bilayer film also presents a single crystalline peak at a 2θ value of 43.52° and is due to the

combine force of both Co and Cu layers. However, the peak is shifted towards higher 2θ value as compared to the above case. We interpret that shift in the peak position is caused by the elongation of the (111) inter-planer distance '*d*' due to internal stress in Cu layer induced by an adjacent Co layer because of different lattice constants of Co and Cu. Since 2θ values of both Co and Cu elements are closely overlapping so they cannot be resolved in the present measurement. But as it is clear from the above XRD patterns the layer structure of Cu (300 Å) film is crystalline, whereas, Co (300 Å) film is amorphous in nature. Thus, we conclude that the crystalline nature of the peak is primarily ascrabible due to the reflection from Cu (111) planes. The particle size in this case decreases to ~ 112 Å (see Table 1). The peak becomes further broader and shifted towards higher 2θ values as the number of bilayers increases to 5 and 10 (i.e. for multilayer cases) as shown in fig. 1d and 1e. The observed broadness and reduction in peak strength is due to the reduction of particle size and increase in intermixing of Co and Co layer at the interfaces produces dis-orders in the crystal structure induced by increasing the number of interfaces.

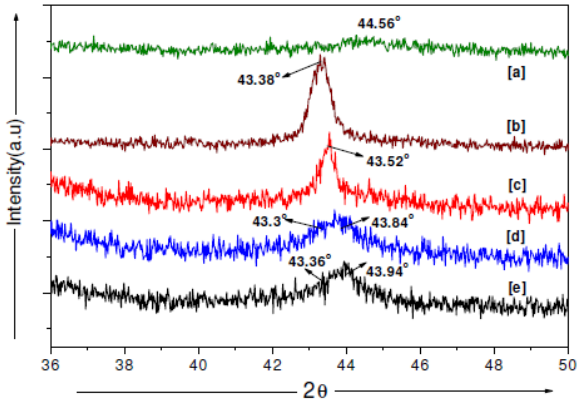

Fig. 1 – XRD patterns of (a) Co (300 Å); (b) Cu (300 Å) thin films; (c) [Co(300 Å) / Cu(300 Å)]; (d) [Co(60 Å) / Cu(60 Å)]x_5; (e) [Co(30 Å) / Cu(30 Å)]$_{X10}$ multilayer samples.

3.2 MOKE Measurement

The MOKE measurements carried out on the corresponding single, bi-layer and multilayer films are shown in fig. 2. For all the measurements magnetic field was applied parallel to the surface of the films and the hysteresis loops were recorded up to saturation magnetization. It can be seen that M-H loop corresponding to the as-deposited Co (300 Å) film is square in shape indicating that distribution of anisotropy is rather sharp, which makes the domain magnetization switching beyond certain applied magnetic field. This can come from 180° type domain walls having uniaxial anisotropy [8]. In the recorded M–H loop, it is also observed that the magnetization reversal from saturation in one direction to saturation in the other direction occurs almost entirely by motion of these walls in the form of large Barkhausen jump occurring at a field equal to the coercive field (H_c). The magnetization corresponding to H_c depends on the extent to which sample imperfections impede the wall motion.The large vertical jumps with retentivity almost equal to the saturation magnetization and lower coercivity value indicating the soft magnetic

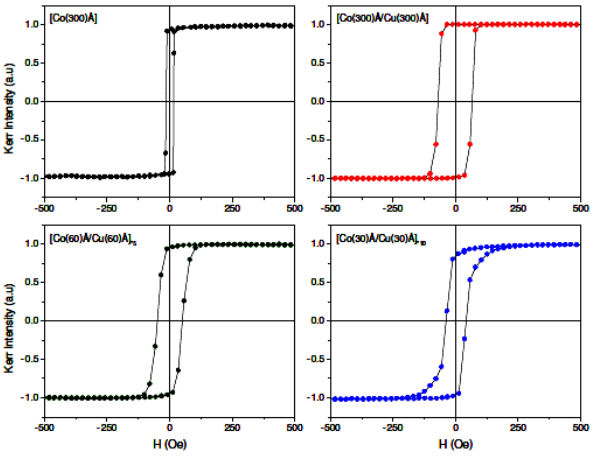

Fig. 2 – Hysteresis loops of (a) Co (300 Å), (b) [Co(300 Å) / Cu(300 Å)], (c) [Co(60 Å) / Cu(60 Å)]x_5; (d) [Co(30 Å) / Cu(30 Å)]x_{10} multilayer samples

nature of the deposited sample with strong anisotropy leading to in plane easy direction of the magnetization. However, we observed drastic changes in the hysteresis loop of sample-C i.e. in [Co(300 Å) / Cu(300 Å)] bilayer sample. One can see that the shape of the square loop (as in case of as-deposited Co (300 Å) film) changes to smoother one indicating the different type of interaction of domains and their wall motion with respect to applied magnetic field. Large increase in saturation (126 Oe) and coercive field (67 Oe) has been observed in this case as shown in Table 1. The observed increase in coercivity and saturation field value is mainly due to the introduction of adjacent Cu layer causing the different type of interaction with domain and their wall motion with respect to applied magnetic field. Similar, M-H loop behaviour but with further increase in saturation field (146 Oe) and reduction in coercivity (49 Oe) value is obtained for sample-D as shown in fig. 2c. These changes in the M-H loop behaviour are due to increase in number of interfaces which may alter the response of applied magnetic field showing gradual variation of domains with increase H_s and decrease H_c values and also due to subsequent reduction in particle size. Similar is the case for sample-E. Moreover, our XRD measurement in this case also shows modifications in the layer structure after the formation of MLS.

Table 1 – Particle size, Saturation field and Coercivity values obtained from XRD and MOKE measurements

	Particle Size (Å)	Saturation Field (Oe)	Coercivity (Oe)
Sample-A	~ 39	19	16
Sample-B	~ 152	-	-
Sample-C	~ 110	126	67
Sample-D	~ 69	146	49
Sample-E	~ 52	260	38

3.3 Resistivity Measurement

The electrical resistivity measurement of the corresponding single, bilayers and multilayer samples is shown in fig. 3. The resistivity value of as-deposited Co (300 Å) and Cu (300 Å) thin film is 14.81 and 6.12

μΩcm, which are much higher than of both its elements. The reported resistivity values for pure bulk Co and Cu are 5.81 μΩcm and 1.68 μΩcm, respectively. The higher resistivity values obtained in each case is because of various factors such as, point defects and structural disorders generally present in the as-deposited layers. From fig. 3, further one can see that resistivity increases linearly with number of bilayers and show a maximum (84.93 μΩcm) for sample-E. The obtained resistivity behaviour can be understood as follows (a) in case of single layers due to different growth morphology in each case, whereas (b) in case of bilayer and multilayer samples (i) initial formation of thin intermixed Co-Cu layer at the interface (ii) thickness of this intermixed layer increases as the number of bilayers increases and individual layer thickness decreases and (iii) subsequent reduction in grain size are the responsible reasons for the observed resistivity behaviour.

4. CONCLUSIONS

The properties of electron beam evaporated Co/Cu thin film and MLS having a different bilayer thickness (keeping the total layer thickness same) have been characterised. The structural studies show modification in the crystal structures for different sub-layer thicknesses. The intensity of the peak as well as particle size decreases due to increase in intermixing of Co and Cu layer at the interfaces and its further growth as the number of interfaces increases. The corresponding magnetic and transport properties additionally vary with transmutation in interface parameters. The results conclude that these properties are greatly depends on various micro structural ML parameters such as layer thickness, number of bilayers and the quality of interfaces formed under different growth conditions.

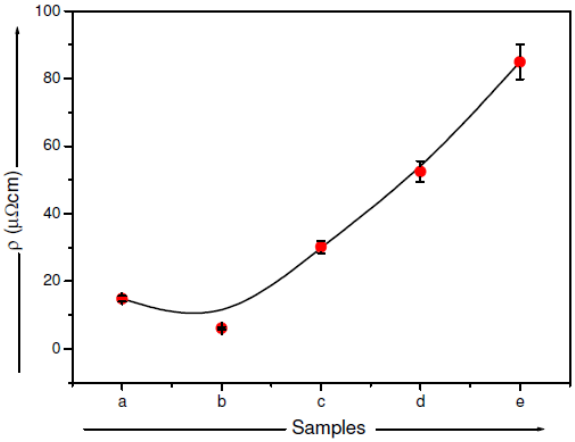

Fig. 3 – Resistivity behaviour of (a) Co (300 Å) (b) Cu (300 Å) single layer thin films along with (c) ([Co(300 Å) / Cu(300 Å)] bilayer sample, (d) $[Co(60 Å) / Cu(60 Å)]_{X5}$ MLS, and (e) $[Co(30 Å) / Cu(30 Å)]_{X10}$ MLS

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