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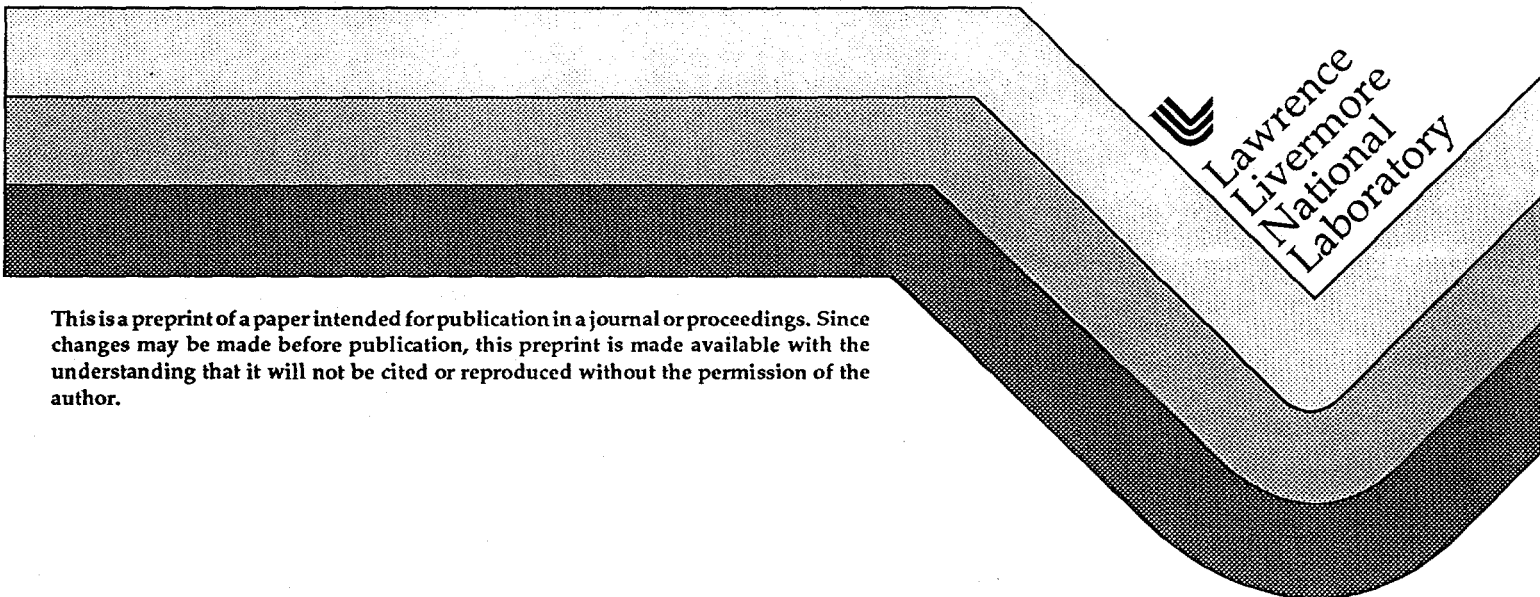
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LARGE GMR VALUES OF SPUTTERED Co/Cu MULTILAYER STRUCTURES WITH Co-Cu BUFFER LAYERS

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Abstract-We demonstrate large giant magnetoresistance (GMR) values of Co/Cu multilayers (MLs) sputtered on combined Co18Å/Cu48Å buffer layer. GMR values at room temperature reach 62% at the first antiferromagnetically (AF) coupling peak and 33% at the 2nd AF coupled peak, which are very close to those found in Co/Cu multilayers sputtered on a Fe buffer layer. The large GMR effect is attributed to the superior superlattice structure of these samples, as evidenced by the x-ray reflectivity data as well as the micrographs of transmission electron microscopy (TEM). In particular, the role of the thin Co initial layer deposited beneath the Cu buffer layer on improved ML structure has been clarified from cross-sectional micrographs of high-resolution TEM.

I. INTRODUCTION

The Co/Cu multilayer (ML) system exhibits the largest giant-magnetoresistance (GMR) values at room temperature (RT). It is important both for fundamental understanding of the GMR effect as well as for its potential application to MR heads [1,2]. The measured GMR in Co/Cu MLs was found to be highly sensitive to the multilayer quality of the films [2,3,4]. GMR values above 50% at RT have been found in Co/Cu multilayers sputtered on an Fe buffer layer (~50Å) [2,3,4]. In this work, we first describe a magnetron sputtering system which is capable of producing Co/Cu multilayers on 4 inch Si wafers with thickness uniformity better than 1% and GMR variation <3% across these wafers. Then we present the structure and GMR results for Co/Cu multilayers deposited on single Cu and combined Co-Cu buffer layers. GMR values at RT for samples deposited on a Co18Å/Cu48Å buffer reach up to 62% at the first antiferromagnetically (AF) coupling peak and 33% at the 2nd AF coupling peak, which are very close to those found in Co/Cu multilayers sputtered on Fe buffers [2]. Structural and magnetic characterizations have been performed on these samples in order to clarify the correlation of GMR values with the microstructure of these films.

II. EXPERIMENTAL

The $[\text{Co}12\text{\AA}/\text{Cu}t\text{\AA}]_N$ MLs with $t_a = 9-40$ \AA were DC magnetron sputtered on 4" [100] Si wafers having a native oxide layer (SiO_2) of ~ 15 \AA at an Ar pressure of 1.5 mTorr. The deposition system consisted of two $5 \times 10''$ magnetron sources mounted 180° apart in the bottom of a large vacuum chamber with a base pressure $\sim 1 \times 10^{-7}$ Torr. The Si substrates were attached to a spinner assembly which was mounted onto a circular platter suspended 5 cm above the targets. The individual layer thickness (t) was precisely adjusted by computer control of the platter rotation speed (v) above the sputtering sources [5]. t vs. v calibrations were performed by x-ray reflectivity measurement of single films.

The structural characterization of the samples were performed by low- and high-angle x-ray diffraction using $\text{Cu-K}\alpha$ ($\lambda = 1.542$ \AA) radiation and high-resolution transmission electron microscopy (HRTEM). The MR measurements were carried out using a four-terminal geometry at room temperature (RT). The current (i) and the magnetic field (H) were applied in the film plane with H perpendicular to i . Magnetization data were obtained using a vibrating-sample magnetometer (VSM).

III. RESULTS AND DISCUSSION

The low-angle x-ray reflectivity spectra reveal superlattice peaks for all samples studied down to a bilayer thickness $\Lambda = 20$ \AA, indicating a well-defined composition modulation along the film growth direction. The bilayer thickness, Λ , was determined by comparing the data to the simulated spectra using an optical model [6]. The uniformity of Λ was better than 1% over the 4" Si wafers, as determined by measurements of the x-ray reflectivity of samples sliced from different locations on the wafer. Fig.1 shows x-ray reflectivity data for two samples at the first AF peak (a) silicon wafer $[\text{Cu}48\text{\AA}/[\text{Co}12\text{\AA}/\text{Cu}9\text{\AA}]_{80}\text{Cu}20\text{\AA}]$ and (b) silicon wafer $[\text{Co}18\text{\AA}/\text{Cu}48\text{\AA}/[\text{Co}12\text{\AA}/\text{Cu}9\text{\AA}]_{80}\text{Cu}20\text{\AA}]$. The first-order superlattice peaks were observed for these two samples. As can be clearly seen, the sample (a) having an Co underlayer of 18 \AA deposited beneath the Cu buffer layer exhibits much higher peak intensity along with well-defined finite-size interference fringes, suggesting a significant superior ML structure with reduced interface roughness [6] of this sample.

The high-angle x-ray diffraction and electron diffraction for the samples studied here show that Co and Cu layers are both fcc with strong $\langle 111 \rangle$ texture out-of-plane, and have coherent interfaces. Fig.2 presents the x-ray diffraction data for the samples (a) and (b). As indicated by the relative intensity of the fcc (111) and (200) peaks, the sample (a) demonstrates a higher degree of $\langle 111 \rangle$ oriented texture. The

width of the rocking curve through the fcc Co/Cu (111) peak was found to be larger in the sample (a) than in the sample (b). Similar results have been also observed in low- and high-angle x-ray diffraction data for two samples at 2nd AF peak (c) silicon wafer/Cu48Å/[Co12Å/Cu19.5Å]₄₀Cu10Å and (d) silicon wafer/Co18Å/Cu48Å/[Co12Å/Cu19.5Å]₄₀Cu10Å. In summary, the AF Co/Cu MLs having Co18Å as first buffer layer exhibit a superior ML structure with smaller interfacial roughness and a higher crystalline <111> out-of-plane texture compared with the samples with the same ML structures deposited on a single Cu48Å buffer layer.

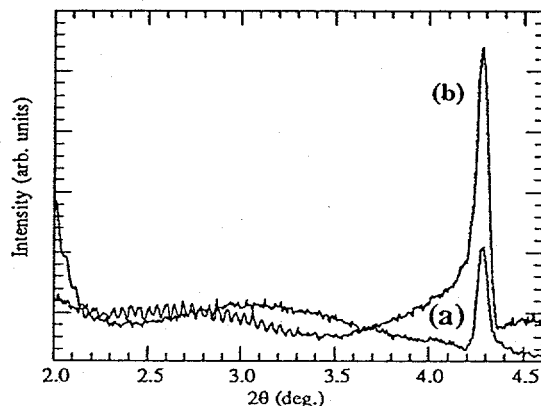


Fig. 1: Low-angle x-ray reflectivity data for the samples (a) Silicon wafer/Cu48Å/[Co12Å/Cu9Å]₈₀Cu20Å and (b) Silicon wafer/Co18Å/Cu48Å/[Co12Å/Cu9Å]₈₀Cu20Å.

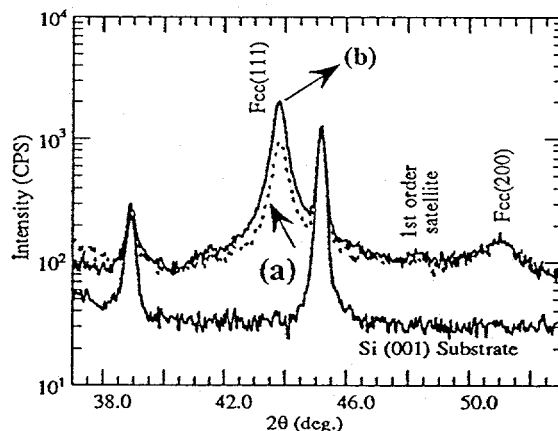


Fig. 2: High-angle x-ray diffraction data for the samples (a) Silicon wafer/Cu48Å/[Co12Å/Cu9Å]₈₀Cu20Å and (b) Silicon wafer/Co18Å/Cu48Å/[Co12Å/Cu9Å]₈₀Cu20Å.

Magnetic characterization on the [Co12Å/Cu t_{Cu} Å]_N MLs with t_{Cu} = 9-40 Å showed oscillatory MR and interlayer magnetic coupling as a function of the Cu thickness t_{Cu} . Three oscillation peaks are identified at t_{Cu} = 9.0, 19.5, 31.2 Å with a period ($\approx$ 11 Å) and a phase similar to values reported in other Co/Cu studies [1-4]. The GMR values, defined as $\Delta R/R = [R(H) - R_s]/R_s$ (R_s is the resistance at the saturation field) and magnetization data are shown in the Fig.3. The most important magnetotransport results were that the samples deposited on a combined Co18Å/Cu48Å buffer

layers exhibit RT GMR as large as 62% at the first AF coupling peak and 33% at the second AF coupling peak, as shown in Fig.3. Corresponding GMR values for samples with the same ML structure deposited on a single Cu buffer layer of 48 Å were 41% and 25 % at the first and second AF peaks, respectively. The largest GMR values at RT found here are very close to those observed in the Co/Cu samples sputtered on an Fe buffer layer (e.g. ~67% at the first AF peak and ~34% at the 2nd AF peak [2]). Finally, it should be noticed that the GMR values (~13%) at the third AF peak ($t_{\text{Cu}}=31.2$ Å) were independent of the buffer layers. This is probably because the roughness introduced during growth of the thick Cu spacers is considerably larger than that resulted from the buffer layer.

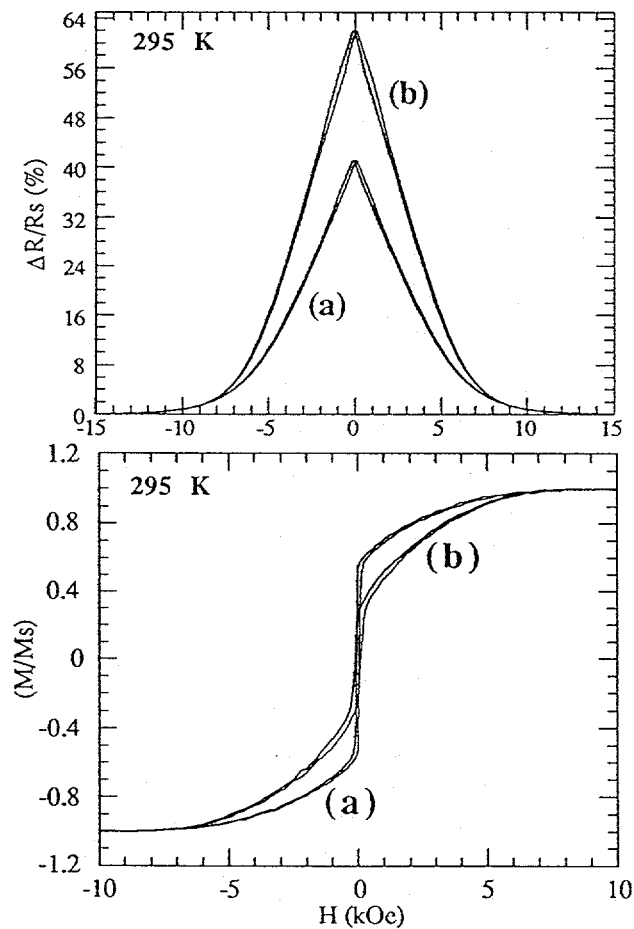


Fig.3: RT GMR and magnetization vs. the applied magnetic field for the same samples (a) and (b) in Fig.1

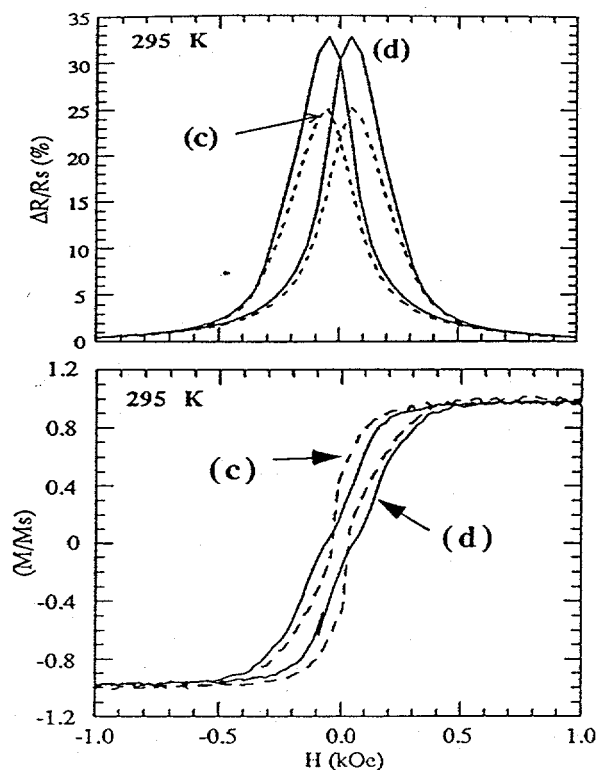


Fig. 4: RT GMR and magnetization vs. the applied magnetic field for the samples (c) Si/Cu48Å/[Co12Å/Cu19.5Å]₄₀Cu10Å and (d) Si/Co18Å/Cu48Å/[Co12Å/Cu19.5Å]₄₀Cu10Å.

The GMR effect was recently found to be insensitive to the crystalline orientation of Co/Cu MLs [7] and the degree of the out-of-plane texture [7,8]. Therefore, the larger GMR effect observed in the AF samples deposited on the combined Co18Å/Cu48Å buffers is mainly attributed to the superior ML structures with low interfacial roughness, as evidenced by the low-angle x-ray reflectivity data, as shown in Fig.1. In the samples deposited on a single Cu48Å buffer, the reduced ML regularity and rougher Co/Cu interfaces could result in large volume fraction of Co coupled ferro-magnetically, either through pinholes (more likely at first AF peak) or due to Cu layer thickness fluctuation. As a result, the smaller GMR effect were observed in these samples. The fraction F_{AF} of the Co which is AF coupled can be estimated using the quantity $1 - M_r/M_s$, where M_r and M_s are the measured remnant and the saturation magnetization of the sample (which can be obtained from VSM magnetization curve) [3]. For sample (a) and (b), this leads to a $F_{AF} = 72\%$ and 45% , respectively. GMR values were found to be increased linearly with $1 - M_r/M_s$ [3].

In order to understand the role of this initial Co layer of 18 Å deposited beneath the Cu buffer layer of 48Å. The samples (a) - (d) were viewed in TEM cross-section. The samples with a Co underlayer of 18 Å exhibit a significantly superior ML structure [9]. Specifically, the chemical layering of the Co and Cu buffer layers and the subsequent Co/Cu ML are flat and continuous even though there are numerous grain

boundaries corresponding to columnar growth. In contrast, MLs which have Cu deposited first characteristically exhibit a markedly poorer layered structure. There is evidence of chemical reaction between the Cu buffer layer and the Si substrate which effectively roughens the "ML-substrate" interface and degrades the subsequent ML structure [9]. This late finding leads one to question the role of the Fe buffer layer in obtaining high GMR in Co/Cu MLs [1-4].

IV. CONCLUSIONS

In conclusion, GMR values as large as 62% at the first AF coupling peak and 33% at the 2nd AF coupling peak have been observed in Co/Cu MLs sputtered on a combined Co18Å/Cu48Å buffer layer. The larger GMR effect is primarily attributed to the superior ML structure of Co/Cu ML specimens having Co as a first buffer layer, which is confirmed by HRTEM images. In order to achieve a high GMR effect, the buffer layer should serve as both a barrier to chemical reaction between MLs and substrates and a smooth seed layer for growing superior ML structures.

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