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Giant magnetoresistance in Co/Cu multilayers sputtered with Kr

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Abstract

This paper presents some results of magnetoresistance measurements on Kr-sputter-deposited Co/Cu multilayers. We find that Co/Cu MLs sputtered with Kr gas show a larger GMR effect than those sputtered with Ar gas.

The critical condition for the giant magnetoresistance (GMR) effect has not yet been fully clarified. Reports on the MR ratio of Co/Cu multilayers (MLs) disagree as to whether the interfacial roughness or crystallinity of the MLs is the cause. The film morphology is significantly affected by sputtering conditions such as sputtering gas and pressure. This paper presents some results of the magnetoresistance, structure and morphology of Co/Cu MLs sputtered with Kr gas. A comparison with Ar-gas-sputtered films is also presented.

Co/Cu MLs have been deposited by a conventional rf sputtering system in which one target position was used to fix two small targets of 4 cm diameter. The substrates, at ambient temperature, were positioned below the targets on a rotating table and the distance between target and substrate was 4 cm. Si(100) wafers were used as substrates. Background pressure prior to deposition was typically 1×10^{-7} mbar. The sputtering gases were high-purity Kr and Ar. The number of bilayers (N) was typically 15 for all samples. Most of the films were deposited on a seed-layer of Fe.

Firstly, the Ar pressure during sputtering was varied between 8.3×10^{-3} and 6.2×10^{-2} mbar. It was confirmed that the Ar pressure was a crucial parameter in obtaining films with a good MR ratio. In the case of Ar, the maximum MR ratio was obtained at 3.1×10^{-2} mbar at a deposition rate of 1 Å/s for Co and 2 Å/s for Cu. In Kr gas sputtering the gas pressure was kept constant at 2.2×10^{-2} mbar in order to achieve a deposition rate equal to that of Ar at 3.1×10^{-2} mbar, because the deposition rate also affects the film morphology.

Fig. 1 shows the MR ratio as a function of Cu layer thickness around the second peak for films sputtered with Kr gas and with Ar gas. Maximum MR ratios of 23.5% and 16.5% were obtained for 2.2×10^{-2} mbar of Kr and 3.1×10^{-2} mbar of Ar, respectively. The maximum MR ratio of Kr-sputtered multilayers is larger than that of Ar-sputtered multilayers. The magnetization curve of the Kr-sputtered sample with a MR ratio of 23.5% showed an M_r/M_s ratio of 0.5 (where M_r and M_s are respectively the remanent and saturation magnetization). This value is smaller than that of the Ar-sputtered sample, which has an MR ratio of 16% ($M_r/M_s = 0.75$), due to stronger antiferromagnetic coupling in the Kr case. To make clear these differences, the layered structures were evaluated by transmission electron microscopy (TEM) and low-angle X-ray diffraction (XRD) (Cu Kα) for the Kr and Ar samples. Typical cross-sectional TEM images indicate almost the same clear layer structure for both MLs. However, at the peak intensity for the first-order and second-order low-an-

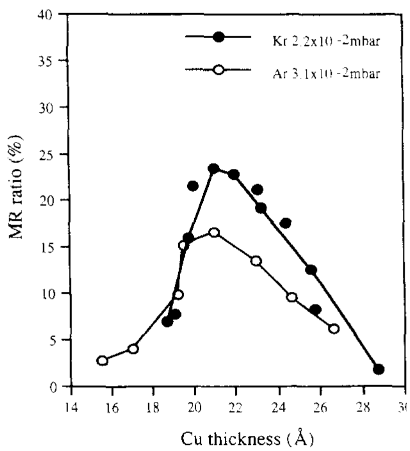

Fig. 1. MR ratio plotted as a function of Cu thickness for films sputtered with Kr and Ar.

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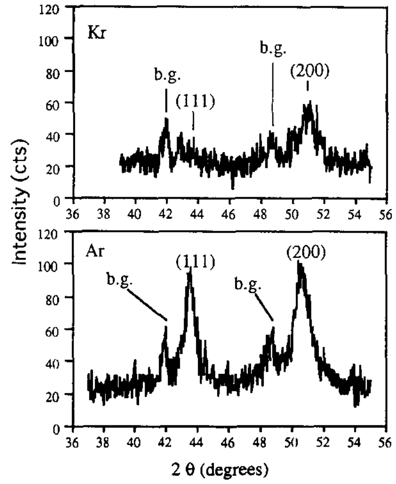

Fig. 2. XRD patterns for samples sputtered with Kr and Ar which showed MR ratios of 23.5% and 16.5% respectively. b.g.: background.

gle maximum, the intensities of Kr-sputtered MLs are slightly larger than those of Ar-sputtered MLs, which means that the interfaces are slightly smoother in the Kr case. High-resolution electron microscopy studies (HREM) in the near future will probably give more information about the interfaces.

Fig. 2 displays some typical high-angle XRD (Cu K α) patterns for samples sputtered with Kr and Ar. Both samples show a (111) and a (200) reflection. The reflections in the Ar case are always stronger than those in the Kr case, as can be seen in Fig. 3. On the other hand, from the TEM plan view, we found that the grains of the Kr-sputtered film had reduced in size slightly to about 15 nm, while the Ar film had an average grain size of about 20 nm. In addition we believe that the grains in Kr become less well defined and parts of the films look more amorphous although the diffraction pattern is still polycrystalline fcc. In the case of Kr, a decrease in crystal size is probably associated with the heavier Kr neutral atoms and more energetic Co/Cu atoms reducing the crystal size and

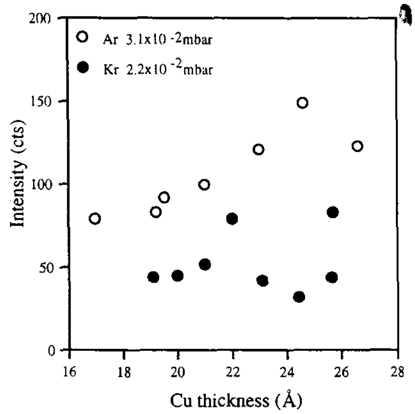

Fig. 3. A plot of (200) peak intensities as a function of Cu thickness for films sputtered with Kr and Ar. (The (111) peak shows similar behavior.)

subsequently flattening the interfaces. These structural results and the data of the MR ratio in our samples tend to support the conclusions of Egelhoff Jr. et al. [1] and of Grundy et al. [2] that textures or orientations other than (111) can be related to the GMR effect.

We find that Co/Cu MLs sputtered with Kr gas show a larger GMR effect than those sputtered with Ar gas and that the sputtering gas does play a role in determining multilayer quality. However, recent investigation on Xe-sputtered MLs suggest that perfectly flat layers often lead to lower GMR values because of the reduced number of scattering centers. These results will be published in the near future. The measurements do not show a clear dependence of the GMR on the (111) or (200) texture.

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