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Enhancement of giant magnetoresistance sensitivity in a Co/Cu/Co sandwich by using Ni buffer layer

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Abstract. In order to enhance the giant magnetoresistance (GMR) sensitivity in a Co/Cu/Co sandwich, an Ni layer was used as a buffer layer in this paper. It was found that in the Co 55 Å/Cu 35 Å/Co 55 Å sandwich without a buffer layer, the MR ratio was less than 1%, and its coercive force was at about 20 Oe, while in the same structure sandwiches with different thicknesses of Ni buffer layers, MR ratios between 3.5 and 5.6% were obtained, and the coercive forces were found at a value of about 12 Oe. Hence, the best field sensitivity could be improved to about 1% Oe^{-1}. Further investigation indicated that the coercivities of the two Co layers were almost the same in the Co/Cu/Co sandwich without a buffer layer. Due to the usage of the Ni buffer layer, the difference between the coercivities of the Co layers was enlarged. The results from atomic force microscopy also showed improvement of the interfacial flatness in the Ni buffered sandwiches. All these resulted in larger GMR effect and increased sensitivity.

After Baibich *et al* [1] discovered the GMR effect in Fe/Cr multilayers, its attractive applications included magnetoresistive read-back heads and magnetoresistive memory in magnetic storage technology. In recent years, as the usual range of field to be measured is of the order of 0–20 Oe for the currently used storage density, some methods [2–4] were developed to reduce the work field as well as to enhance the sensitivity in multilayers.

From the beginning of the GMR investigation, almost every researcher noticed the important effect of the buffer layer on the GMR effect in multilayers [5–9]. Some researchers [6–8] studied systematically different buffer layers with different crystalline structure, and testified the crystallization inducement of the buffer layer on the structure of the multilayers. Some buffer layers such as Fe, Cr [10] etc were generally considered as a useful way to control the crystalline orientation for the layers in multilayers.

In this paper, thin metal Ni film was investigated as a buffer layer of the Co/Cu/Co sandwiches. After comparing with the sandwich without buffer layer, it was found that the Ni buffer layer can make its neighbouring lower Co layer in the Co/Cu/Co sandwich softer, and the interfaces smoother, which enhances the GMR effect and increases the sensitivity.

The sandwiches were prepared using a Balzers ultra-high vacuum electron beam evaporation system. The base pressure was about 9×10^{-9} mbar. The purity of the materials Ni, Co and Cu were better than 99.9%. The deposition rates were 0.5 Å s^{-1}. Chemically etched Si(100) wafers were used as substrates. To reduce the coupling field between the two ferromagnetic layers, a 35 Å copper layer was chosen. The sandwiches were grown with a structure of NI *t* Å/Co 55 Å/Cu 35 Å/Co 55 Å. The thickness of each layer was controlled by a quartz oscillating thickness monitor and calibrated by high resolution electron microscope.

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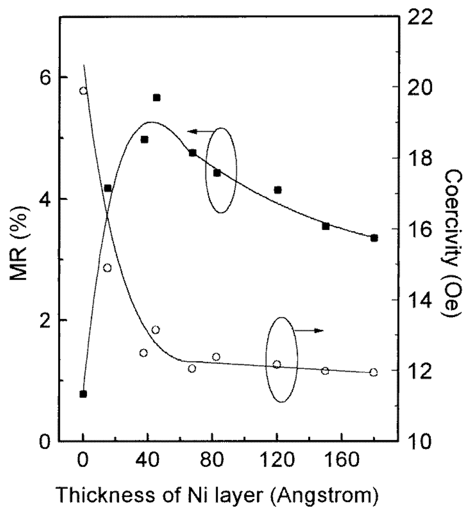

Figure 1. The MR ratio and the coercivity as functions of Ni buffer thickness for different thickness Ni layer buffered Co 55 Å/Cu 35 Å/Co 55 Å sandwiches.

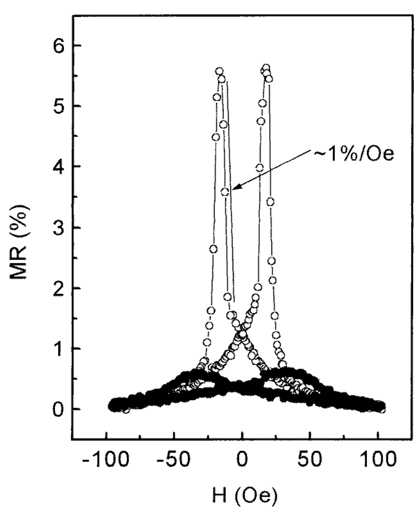

Figure 2. The MR curves for Co 55 Å/Cu 35 Å/Co 55 Å sandwiches without (closed circles) and with (open circles) a 45 Å Ni buffer layer.

The MR ratios and the hysteresis loop curves of the samples were measured at room temperature. The MR ratios were obtained using a four-terminal method in a magnetic field of 100 Oe. The magnetic field was applied in plane and parallel to the current. The MR ratio was defined as the ratio of the total resistivity change to the resistivity at a magnetic field of 100 Oe. A vibrating sample magnetometer (VSM) was used to measure the hysteresis loops. An atomic force microscope (AFM) by Park Scientific Instruments was used to analyse the topography of the samples. To minimize the air-exposure effect, the AFM measurement was performed immediately after the sample fabrication.

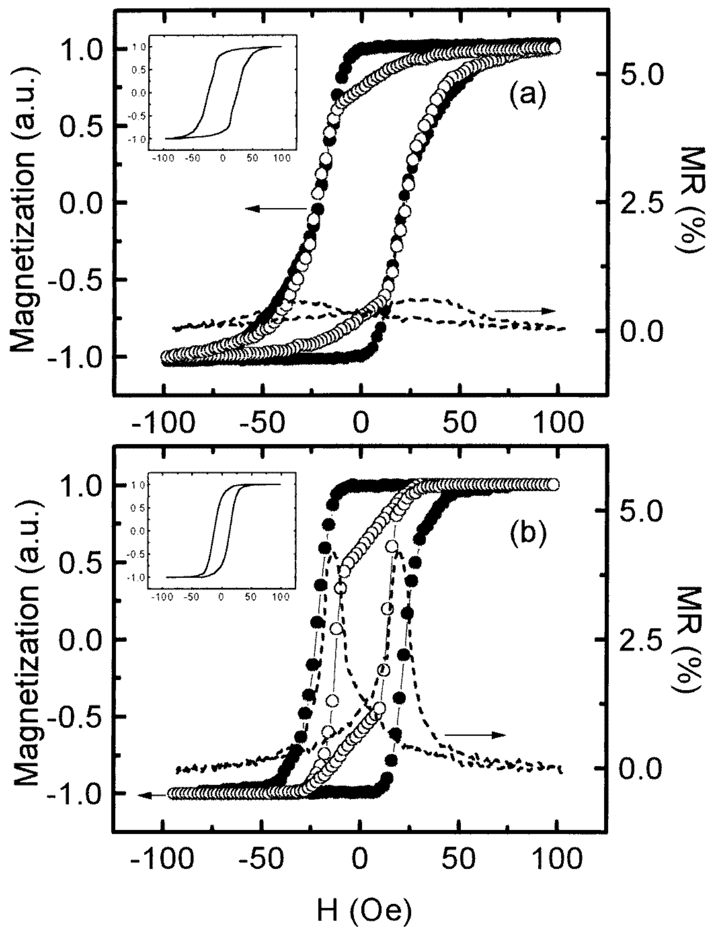

Figure 3. The hysteresis loops of the lower and upper Co layers in each Co 55 Å/Cu 35 Å/Co 55 Å sandwich without a buffer layer (a) and with a 120 ÅNi buffer layer (b) and the corresponding MR curves of the sandwiches (the dashed line). The open circles relate to the lower Co layer, and the solid circles are from the upper Co layer. The top left inset is the related hysteresis loop of each sandwich. It should be noted that all presented hysteresis loops are normalized.

The dependence of the coercivity and the MR ratio of the NI *t* Å/Co 55 Å/Cu 35 Å/Co 55 Å sandwiches on the thickness of the Ni buffer layer is shown in figure 1. Two typical MR curves are shown in figure 2. It can be found that the magnetic and magnetoresistive behaviours of the sandwiches are strongly affected by the existence of the Ni layer. In figure 1, the coercivity decreases monotonically with increasing the thickness of the Ni layer. In the sandwich without a buffer layer, the coercivity is around 20 Oe. When the thickness of the Ni layer grows to 40 Å, the coercivity decreases to about 12 Oe, and then it keeps this value as the thickness of the Ni layer increases. At the same time, the MR ratio increases from 0.78% to 4.17% immediately when a 15 Å Ni layer is inserted into the structure between the substrate and Co/Cu/Co sandwich. As the thickness of the Ni layer increases to 45 Å, the MR ratio reaches its maximum at 5.6%, and then it decreases monotonically due to current shunting in the buffer layer. All these results indicate that the usage of the Ni buffer layer can reduce the coercive

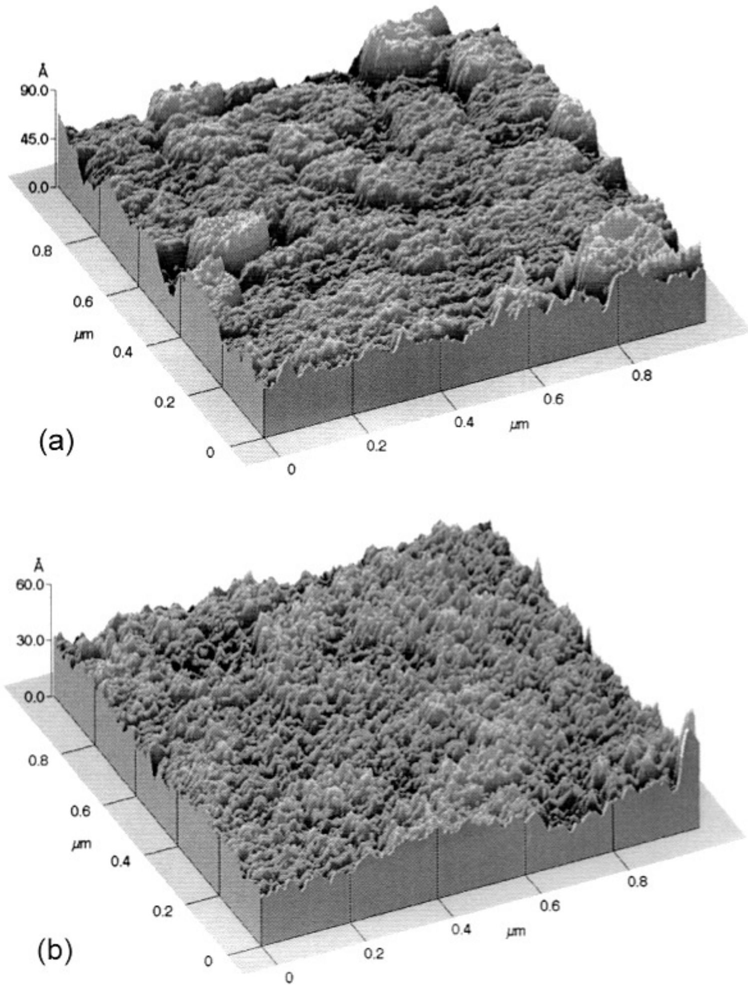

Figure 4. The AFM images of Co 55 Å/Cu 35 Å/Co 55 Å sandwiches without a buffer layer (a) and with a 120 Å Ni buffer layer (b).

forces of the Co/Cu/Co sandwiches and improve the GMR effect. In the Co/Cu/Co sandwich with a 45 Å Ni buffer layer, the MR ratio, as shown in figure 2, is about 5.6%, and its coercive force is only about 12 Oe. It can be found that its best sensitivity can reach about 1% Oe^{-1}. As far as we know, for a single Co/Cu/Co sandwich structure with Cr [10] or other buffer layers [11], although the highest MR ratio can reach 7%, as its coercivity is at 80 Oe or higher, the largest sensitivity can only be about 0.07% Oe^{-1} [11].

Generally, the maximum GMR for a sandwich structure is understood to be the difference between the low resistance state of the sandwich when the two films are fully magnetically aligned, and the high resistance state when the two films are fully magnetically anti-aligned. Although the completely aligned case can always be achieved by the application of a field larger than the saturation field, the completely anti-aligned state relies on the quality of the films [12] and magnetic behaviour of the two magnetic layers [13]. In our sandwiches, as the thickness of the non-ferromagnetic copper layer is 35 Å, the exchange coupling between the ferromagnetic Co layers through the non-magnetic layer should be very weak [12] so that it does not affect the presentation of the anti-alignment much. Therefore, the anti-aligned state in these sandwiches should be achieved from the difference between the magnetic properties of the two Co layers. As the exchange coupling is very weak in these samples, the hysteresis loop of the sandwich can be estimated as a simple addition of those of the two Co layers [13]. Thus, it is not hard to obtain the hysteresis loop of the upper Co layer by subtracting the directly measured hysteresis loop of the lower Co layer from that of the sandwich. The results from the sandwiches with different thickness Ni buffer layers showed that the magnetic property of the upper Co layer is almost the same. Figure 3 represents the hysteresis loops of the lower and upper Co layers in the sandwiches without and with a 120 Å Ni buffer layer. It can be found that in the Co/Cu/Co sandwich without buffer layer the hysteresis loops of the two Co layers shown in figure 3(a) are very similar. Their coercivities are both at about 20 Oe. It is obvious that the difference between these two Co layers' coercivities is too small to achieve a completely anti-aligned state in the Co/Cu/Co sandwich. Therefore, its MR ratio cannot be high. When the Ni layer is used as a buffer layer, the coercivity of the lower Co layer is reduced to about 12 Oe. As the coercivity of the upper Co layer grown on the Cu inter-layer is still 20 Oe, as shown in figure 3(b), the difference between the two Co layers is 8 Oe. When the applied field transforms its direction from negative to positive and makes the magnetization of the soft lower Co layer begin to rotate at about −30 Oe, the resistance changes. As the abrupt change of the magnetization takes place at 10 Oe, the sharp increase of the resistance starts. At the field of about 16 Oe where the direction of the magnetization has just reversed overall, the highest anti-aligned state will be achieved between the two Co layers, and the maximum of resistance is observed here. Therefore, it is obvious that the reduction of the coercivity of the lower Co layer enhances the MR ratio and the sensitivity of the sandwich.

Figure 4 represents the AFM images of the Co/Cu/Co sandwiches without and with a 120 Å Ni buffer layer. It can be found that the topography presents a lot of island-like areas in the sandwich without an Ni buffer layer, while no island-like areas in the sandwich with an Ni buffer layer. This shows that the usage of the Ni buffer layer can flatten the film. The root-mean-square roughness calculated from the images showed the same tendency. It decreases from 6.2 to 4.5 Å as the thickness of the Ni layer grows from zero to 45 Å, and then it keeps this value. As in this case the interface is not too far from the top surface, the surface topography should be related to the interface topography [14], and therefore the surface parameters from AFM should characterize the flatness of the interfaces. Our results imply that the interfaces of the Co/Cu/Co sandwiches were also improved by the usage of the Ni layer, which is also helpful to the enhancement of the MR ratio [12].

In summary, it can be concluded that the usage of the Ni buffer layer for a Co 55 Å/Cu 35 Å/Co 55 Å sandwich enlarged the magnetic difference between the two Co layers and improved the interfacial flatness, resulting in enhanced MR ratio and correspondingly increased field sensitivity of the sandwich.

Acknowledgments

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