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Magnetoresistance behavior in microfabricated trilayer strip pattern

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Abstract

This paper reports a highly sensitive GMR behavior observed in a microstructured $Ni_{78}Fe_{22}/Cu/Co$ trilayer strip pattern deposited by the electron beam evaporation method. The MR ratio of 3.2% for an applied field of 20 Oe was obtained at room temperature. The superior selective switching of the magnetizations in the two magnetic layers has been confirmed by the MR behavior in a rotating magnetic field.

1. Introduction

Metallic multilayers consisting of magnetically soft and hard materials without antiferrimagnetic coupling present giant magnetoresistance (GMR) behavior at relatively low applied fields [1]. Recently, NiFe/Cu/Co trilayer films deposited by UHV electron beam evaporation [2] and ion beam sputtering [3] were reported to present sharp switching of the magnetization direction, which is suitable for practical application to highly sensitive magnetic sensors or recording heads. However, there are only a few studies on GMR behavior in a lithographically patterned sample in this system [4]. This paper reports the GMR behavior in a microstructured $Ni_{78}Fe_{22}/Cu/Co$ trilayer strip pattern deposited by electron beam evaporation.

2. Experimental

Samples were deposited at an ambient temperature on 1×1 cm^2 glass substrate (0.04 cm thickness) at a pressure not exceeding 3×10^{-6} Torr with a base pressure of 3×10^{-7} Torr. Typical deposition rates for NiFe, Cu and Co were 0.7, 0.6 and 0.9 nm/min, respectively. The rates were controlled manually with a crystal oscillator, which was calibrated by measuring the thickness of thick single layer films with a surface profilometer Talistep (Taylor Hobson). The deposition was halted for a few minutes to shift the ingot crucible for the subsequent layer evaporation. Strip patterns, with different pattern widths of 30, 40, 60 and 120 μm, were fabricated on a same substrate by Ar ion milling through a photoresist mask of 1 μm thickness. The thickness of the magnetic layers (t_{mag}) was varied for a fixed Cu layer thickness of 5 nm. The MR hysteresis was measured at room temperature using the dc four terminal method at a current of 1 mA.

3. Results

The MR hysteresis curves for the sample with $t_{mag} = 3$ nm and $w = 120$ μm are shown in Fig. 1. The measurements were performed for the in-plane field H applied orthogonal and parallel to the current direction (pattern length direction). A relatively large MR ratio of 3.1% was obtained for the orthogonal field, and it was markedly degraded to 1.2% for the parallel field. Similar degradation was observed for other patterns with different widths. The anisotropic GMR behaviors can be ascribed to the uniaxial anisotropy induced with the electron beam evaporation. A well defined anti-parallel spin orientation in the two magnetic layers is realized in the case of an orthogonally

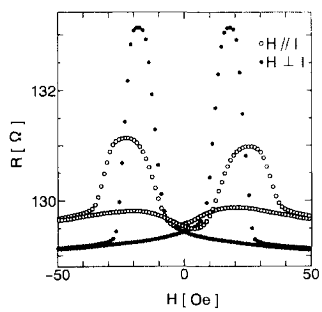

Fig. 1. MR hysteresis of NiFe(3 nm)/Cu(5 nm)/Co(3 nm) trilayer strip pattern for applied field H parallel and orthogonal to current direction.

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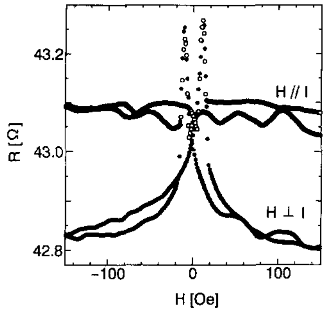

Fig. 2. MR hysteresis of NiFe(15 nm)/Cu(5 nm)/Co(15 nm) trilayer strip pattern.

applied field, that is, along the induced anisotropy direction. The characteristic dependence of the MR ratio on the pattern width was not observed in the range of the designed pattern width w, that is, 3.0, 3.1, 3.2, 3.1% for $w = 30$, 40, 60, 120 μm, respectively. The anisotropic magnetoresistance (AMR) is 0.42%, which is evaluated from the saturation values of the resistance for the two applied field directions. As shown in Fig. 2, the GMR and AMR components become compatible for the sample with $t_{mag} = 15$ nm. The sharp switching behavior would be due to the emphasized local ferromagnetic coupling caused by the increase of the magnetic layer thickness.

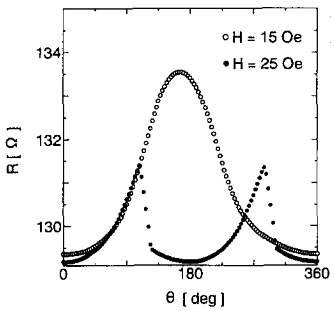

Fig. 3. Angular dependence of MR behavior measured with rotating applied field H.

The MR behavior has been measured in a rotating in-plane field to study the interaction between the two magnetic layers. Fig. 3 shows the angular dependence of the resistance measured for the sample shown in Fig. 1. The abscissa gives the applied field angle θ measured from the pattern length direction. In the measurements, the magnetization was first saturated along the pattern length direction ($\theta = 0°$) with an applied field of 150 Oe. The MR behavior for an applied field of 15 Oe shows angular dependence following a $\cos\theta$ rule, which suggests the selective rotation of the magnetization in the NiFe layer. An asymmetric angular dependence observed in the top ($\theta = 180°$) and the bottom ($\theta = 0°$) region implies a ferromagnetic exchange coupling between the two magnetic layers. The appearance of two peaks for an applied field of 25 Oe suggests that the magnetizations in the NiFe and Co layer rotate chasing each other around. The abrupt decrease of the resistance at $\theta = 90°$ and 270° suggests a flip-like magnetization rotation in the Co layer, which would be caused by the inter-layer ferromagnetic coupling force. It should be noticed that the MR ratio measured in the rotating field is almost the same as that for the orthogonal applied field, as shown in Fig. 1, which confirms that the magnetization switching in the latter case also occurs in the coherent rotation mode.

A relatively large MR ratio of 3.2% (room temperature) has been obtained in a NiFe/Cu/Co microstructured trilayer strip pattern deposited with a simple electron beam evaporation system. The probable cause of the superior GMR properties is the well defined uniaxial anisotropy induced with electron beam evaporation.

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