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GMR effect in a single trilayer wire with submicron width

K. Shigeto[a,*], T. Ono[b], H. Miyajima[b], T. Shinjo[a]

[a]*Institute for Chemical Research, Kyoto University, Uji 611-0011, Japan*
[b]*Faculty of Science and Technology, Keio University, Yokohama 223-8522, Japan*

Abstract

Magnetization reversal phenomena in a submicron magnetic wire with a trilayer structure were investigated by measuring the electric resistance in external magnetic fields. The critical field for domain wall nucleation was observed to be slightly different for each field sweep. The magnetoresistance measurements were repeated 200 times with a sweep rate of 6 Oe/s. The obtained distribution of critical fields had two peaks and both moved to higher fields as temperature was decreased. This result suggests that domain wall nucleation occurs through a thermally activated process down to 5 K. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Magnetization reversal; Submicron magnetic wire; Magnetic domain wall; Giant magnetoresistance

Magnetism in mesoscopic systems has become an important topic from both scientific and technological points of view. However in general, experimental studies of magnetic nanostructures have been made on samples consisting of a large number of nearly identical particles, since most measurement techniques are not sensitive enough to measure the magnetization of a single particle. Most of the single-particle or single-wire properties were inevitably hidden behind the distribution of size or shape. Recently the techniques of magnetic force microscopy (MFM) [1], electron holography [2], and micro-superconducting quantum interference device (SQUID) magnetometery [3–5] have made it possible to study individual magnetic particles. While these experiments give us crucial information, they have considerable technical difficulties. As reported in a previous paper [6], the authors demonstrated that very small magnetization changes in a single NiFe(200 Å)/Cu(100 Å)NiFe(50 Å) trilayer wire with 0.5 μm width can be detected by using the giant magnetoresistance (GMR) effect.

In ferromagnetic wires, it is expected that magnetization reversal takes place by nucleation and propagation of the magnetic domain wall which lies in a plane perpendicular to the wire axis. The process of magnetization reversal attracts interest especially at low temperatures where the macroscopic quantum tunnelling (MQT) process may be dominant. The MQT of a domain wall in a ferromagnetic metal wire has been recently investigated from both theoretical [7] and experimental points of view [8]. To determine the mechanism of magnetization reversal, the temperature dependence of the critical field should be very useful.

In this paper, we present the results of measurements on the nucleation field of the magnetic domain wall in a single submicron wire based on a non-coupled-type GMR effect at several temperatures. The samples were prepared by lift-off techniques on electron-beam evaporated NiFe(400 Å)/Cu(200 Å)/NiFe(50 Å) trilayer films. Due to the large Cu-layer thickness, the interlayer exchange coupling between NiFe layers is negligible. The magnetoresistance (MR) measurement was performed at 5, 20 and 50 K. The external magnetic field H_{ext} was applied along the wire axis. The resistivity was determined using a four-point DC technique. As seen in an image of scanning electron microscopy in Ref. [6], the sample has four current–voltage terminals where the voltage is probed over a distance of 20 μm. Furthermore, the sample has an artificial neck

* Corresponding author. Tel.: + 81-774-38-3104; fax: + 81-774-38-3109; e-mail: shigeto@scl.kyoto-u.ac.jp.

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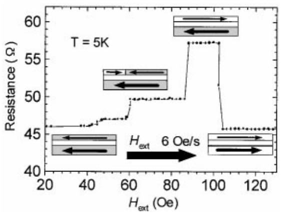

Fig. 1. Resistance as a function of the external magnetic field at 5 K. The magnetic field was applied along the wire axis. The magnetic domain structures inferred from the resistance measurement are schematically shown.

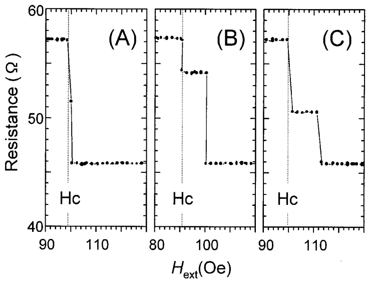

Fig. 2. Observed three types of resistance change corresponding to magnetization reversal of 400-Å thick NiFe layer at 5 K.

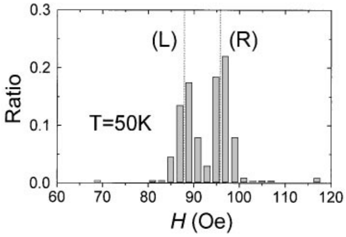

Fig. 3. Histogram of the nucleation field of the magnetic domain wall in the 400-Å thick NiFe layer at 50 K.

(0.35 μm width) introduced at $\frac{1}{3}$ distance from one voltage probe.

Fig. 1 shows a typical resistance change of the trilayer system as a function of the applied field at 5 K. Prior to the measurement, a magnetic field of 1000 Oe was applied in order to achieve magnetization alignment in one direction. Then the resistance was measured as the field was swept continuously towards the counter direction at a rate of 6 Oe/s. The result shown in Fig. 1 essentially confirms the previous results found for a NiFe(200 Å)/Cu(100 Å)/NiFe(50 Å) trilayer wire with 0.5 μm width [6]. The ratio of the resistance changes at first and second leap is 1 : 2. This means that one-third of the total magnetization of the thin 50-Å-thick NiFe layer changes its direction at the first leap in Fig. 1, since the GMR changes are proportional to the fraction of the layer that switches. The ratio of one-third corresponds to the ratio of length between one voltage probe and the neck to the overall length of the wire between the voltage probes. Therefore, in this case, a magnetic domain wall nucleates in the shorter part of the wire and propagates to the neck in the field up to 60 Oe and then the wall is pinned up to 86 Oe at the neck. An abrupt resistance decrease at 100 Oe corresponds to the magnetization reversal of the 400-Å-thick NiFe layer. The domain wall in the thinner layer can nucleate more easily than in the thicker layer, since wall energy in the thinner layer is smaller.

The feature of magnetization reversal is reproducible but the numerical values of critical fields have certain distributions. Therefore, the same measurement as described in a previous paragraph was carried out 200 times at 5, 20, and 50 K. We focus on the magnetization reversal of the 400 Å-thick NiFe layer, since the magnetization reversal field of the 50 Å-thick NiFe layer is too small to obtain a quantitatively confident result. All results can be categorized into the three types as shown in Fig. 2. Type (A), (B) and (C) corresponding to the following magnetization reversal process, respectively. (A) The magnetic domain wall nucleates in either the shorter or longer part of the wire and passes through the artificial neck and propagates to the end of the wire. (B) The magnetic domain wall nucleates in the shorter part and is trapped in the artificial neck. (C) The magnetic domain wall nucleates in the longer part and is trapped in the artificial neck. The ratio of occurrence of these three types at 5 K is (A) : (B) : (C) = 135 : 28 : 37. The ratio of type (A) decreases with decreasing temperature. Fig. 3 shows a histogram of the observed field for all three cases as indicated by H_c in Fig. 2. The H_c corresponds to the nucleation field of the magnetic domain wall. Fig. 3 suggests that the observed values are in a rather narrow field range but the distribution has two peaks and these two peaks were also recognized at 5 and 20 K. The reason why the two peaks exist is not clear at this stage. In the present sample, the 20 μm wire is not magnetically isolated but is connected with probes for MR measurements which are also composed of the same magnetic layer. Therefore, it is hard to identify the initial structure of domain nucleation. It is considered that domain wall nucleation starts on the outside of the wire and there exist effectively two potential barriers. Although the reason for two potential barriers is not understood at this stage, we can compare their temperature dependence. In Fig. 4, the fields of the two peaks, which are indicated by (L) and (R) in Fig. 3, are plotted as a function of temperature. The peak fields increase with decreasing temperature down to 5 K, suggesting that the nucleation takes place by a thermally activated process. The study at lower temperatures, using a dilution refrigerator, is now in progress to investigate the effect of MQT.

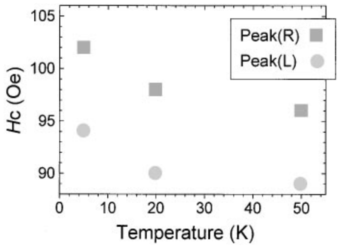

Fig. 4. Temperature dependence of the nucleation field of the magnetic domain wall. The fields of the two peaks, which are indicated by (L) and (R) in Fig. 3, are plotted as a function of the temperature.

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