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Magnetoresistance of Nanojunction Configured With Crossing Two Film Edges

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Co and Ni thin films of 50 nm thickness are contacted with their edges crossing so that the current junction of small cross-section area is formed. Because the coercivities of Co and Ni films are different, their magnetizations have antiparallel direction during the magnetization process, introducing the magnetic domain wall at the edge contact. When the cross-section has nanometer size area, the wall is expected to become very thin such as atomic size and cause the ballistic magnetoresistance. In our sample configuration we observed the magnetoresistance which mechanism is similar to the ballistic magnetoresistance, although the the magnetoresistance ratio is very small as less than 0.1 %.
Key words: BMR, nanojunction, film edge, magnetoresistance

1 INTRODUCTION

Magnetic nanostructure has been a field of rapidly expanding area of extensive researches. Transport property concerning with nanocontact has attracted many experimental and theoretical works. Break junction exhibiting the quantization of conductance was a beginning of the study[1]–[3] and the ballistic magnetoresistance (BMR) was an epoch-making discovery[4],[5]. BMR is the huge resistance increase when the domain wall with atomic size width is introduced at a nanojunction. BMR can be observed only in the contacts which are prepared carefully with technique of artisan. BMR has its origin in very thin magnetic domain wall confined in the nanocontact[6]–[8]. The wall behavior of the nanostructure is also an important issue[9] and dynamic characteristic of the wall is expected to be revealed.

Fabrication of the nanocontact is also tried with the lithographic method[10]. However, the resolution of the electron beam lithography and lift off procedure is still insufficient to achieve the goal. In this work we try to configure the nanocontact using thin film edges. Thin films deposited on the glass substrates are easily cleaved and the film edges appear. If we put two films contacting with thier edge and geometry is crossing direction, the junction size is defined by film thicknesses, that is, 10 nm films produce $10 \times 10\text{nm}^2$ junction area. When the films have different coercivities, magnetization of the one film switches at lower filed and introduces the domain wall at the junction. This might be a new technique to fabricate the nanojunction.

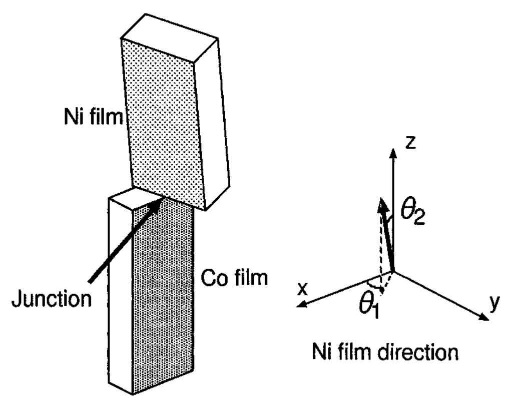

Fig. 1: Schematic illustration of the junction configuration.

2 EXPERIMENTALS

Co and Ni films were deposited on 1 mm thick glass substrates by vacuum evaporation. Background pressure was below 4×10^{-5} Pa and the pressure was kept lower than 1.3×10^{-4} Pa during deposition. The deposition rate was 0.1 nm/s and 10, 20, 30 and 50 nm thick films were prepared. Films are cut in the size of 2 mm × 15 mm and stuck to each other using expoxy resin. Figure 1 shows the two films configuration investigated in this work. Although two films should be configured with exactly right angle for an ideal jucntion, such geometry could not produce stable conductance. Hence as shwon in the figure we inclined the film so that the films contact well. The angles which have been decided by experiments were $\theta_1 \approx 25^\circ$ and $\theta_2 \approx 15^\circ$.

Magnetization property was measured by vibrat-

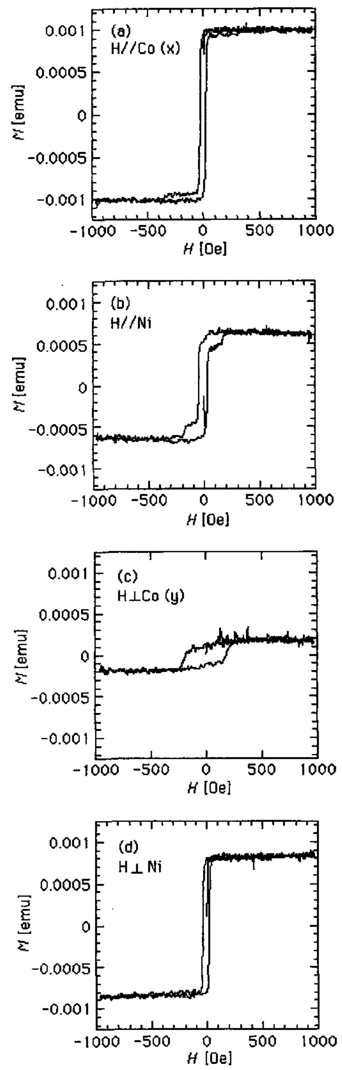

Fig. 2: Magnetization hysteresis loops of the junction assembly. The coordinates indicated in the figure correspond to the direction in Fig. 1

ing sample magnetometer. Magnetoresistance (MR) was measured at room temperature with dc 2-terminal method.

3 RESULTS AND DISCUSSION

Magnetization process of the junction film with thickness of 50 nm is shown in Fig. 2. The junction is set in the magnetic pole pieces as it formed. The size of the junction is larger than the sample holder, it is difficult to determine accurate value of the magnetization, when we calibrate with the standard Ni specimen. Hence the value of the vertical coordinate is not normalized with the magnetic sample volume. The field H is applied in four directions. In the case of (a) the field is applied parallel to the Co film and indicated as x direction in Fig. 1. In

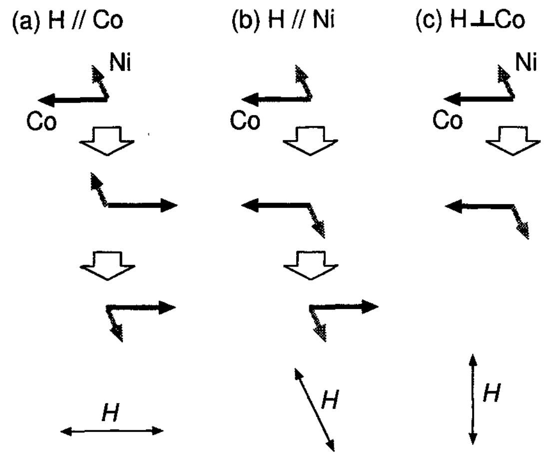

Fig. 3: Schematic illustration of Co and Ni magnetization switching corresponding to Fig. 2.

this case the angle between the field and the Ni film normal direction becomes $\approx 29°$. Magnetization reversal at $H = 20$ Oe is therefore the switching of the Co magnetization, because the Ni magnetization is still in the film plane in this field range. A small step is observed around $H = 300$ Oe. Since the Ni film is canted against z axis, this step is the saturation of the Ni magnetization in the Ni film plane direction. Schematic images of the magnetization process is illustrated in Fig. 3 (a). The Co magnetization switches first at low field. After that the Ni magnetization switches in its film plane at $H = 300$ Oe. If we apply much larger field, the Ni magnetization will turn to the field direction which is out of the Ni film plane.

When the field is applied along Ni plane, Fig. 2 (b), the magnetization reversal of the Ni film is seen at $H = 50$ Oe. Here again the step appears around H =200 Oe. The Co magnetization switching may causes this step as shown in Fig. 3 (b). In both Fig. 2 (a) and (b) small height of the steps reflects the field direction component of the Ni and Co magnetizaion, respectively. Figure 3 (c) corresponds to the field perpendicular to the Co film and the direction is near to Fig. 2 (b). Because of the large saturation field of the Co in this direction (this amounts to more than 16 kOe), the Ni magnetization reversal only is observed as illustrated in Fig. 3 (c). The geometry of Fig. 2 (d) results in similar magnetization process as (c). It has a simple square shape of the Co magnetization. Two step magnetization precess appears owing to the non rectanglar geometry of the junction film when H is applied parallel to either Co or Ni films.

The field directions were basically in the $x - y$ plane in the case of Fig. 2. When we consider the domain wall formed at the film edge junction, 90° wall should be formed in this $x - y$ plane field case. On the other hand, 180° wall with head-to-head or tail-to-tail geometry will be realized when the field

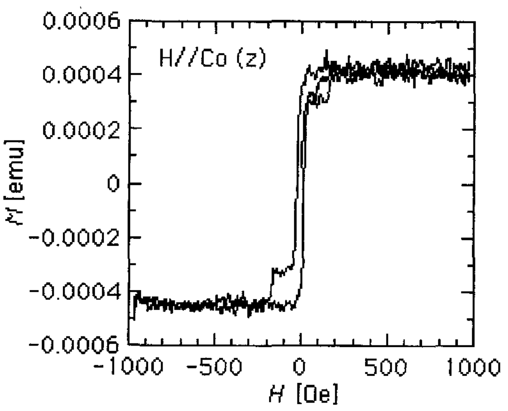

Fig. 4: Magnetization hysteresis loop with field parallet to z direction.

is applied parallel to z axis. Figure 4 indicates the hysteresis loop with the field parallel to the Co film, that is, z direction. Clear two step magnetization switching is also observed in this case. Because the coercivities of Co and Ni films are different, 20 Oe and 50 Oe in as-deposited films, respectively, the step appears and antiparallel magnetization configuration is realized. However the step appears between H =20 and 200 Oe. Since the field direction is not parallel to the Ni plane, the reversal of the Ni magnetization may occur at larger field than that of the single Ni film (50 Oe).

The results of MR measurement are shown in Fig. 5. The field direction of curve (a) is parpendicular to the Co film (y direction in Fig. 1), on the other hand parallel to the Co film (z) in the case of (b). In both cases dc drift of the resistance R is quite large and the curves could not form loops. The field sweep starts with positive direction, followed by coming back to zero and the negative direction sweeping. R decreases with measurement and we at present attribute this decrease in R to the junction reconfiguration, that is, the current focuses to narrow junction and increases the temperature at the junction, resulting in the formation of atomically adhesive contact. Because the measurement of long duration, however, destroyed the junctions, we had to start measurement before the drifting converges.

When the field is applied perpendicular to the Co film (y direction), R increases with H up to 250 Oe and rapidly decreases. Co and Ni magnetizations are basically normal to the current direction and we can ignore the effect of anisotropic magnetoresistance (AMR). Therefore the MR curve is attributed to the increase of magnetic randomness at the Ni coercivity. As shown in Fig. 2 (c), which is corresponding hysteresis loop, the Ni magnetization switches around 200–250 Oe and it is consistent to MR loop shape.

In Fig. 5 (b) geometry, AMR effect is ruled out

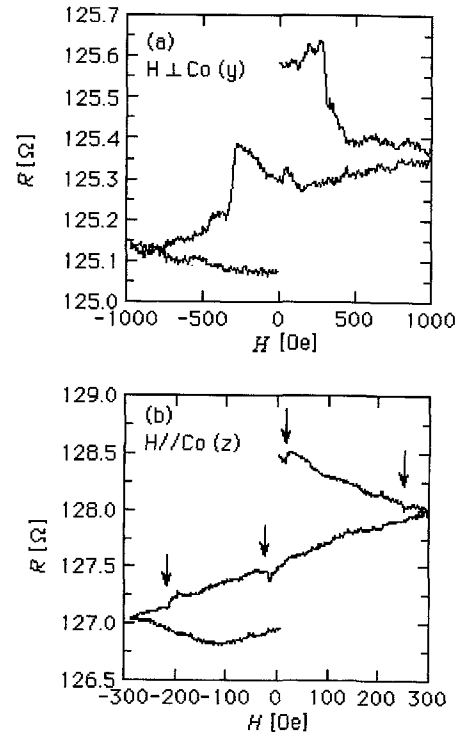

Fig. 5: MR curves of the junction. (a) H is perpencular to the Co film and (b) parallet to the Co film. Arrows in (b) indicate BMR like change in R.

because both magnetizations are basically parallel to the current. H is in the plane of either Co or Ni and the wall is introduced into the junction for H between 20 and 200 Oe as shown in Fig. 4. MR curve exhibits a small stepwise increase at H = 20 Oe and decrease at H = 210 Oe. The steps are indicated by ↓ in the figure. In the negative field region this stepwise behavior is also observed. The wall should be introduced in the junction for this field region and the increase in R might be the effect of this wall. MR ratio of this stepwise change is only 0.08% and very small compared to reported value of BMR. However, we speculate that this R change occurs by the same mechanism as BMR, because the increased R region corresponds to the antiferromagnetic magnetization configuration and no spacer layer exists between the Co and Ni films. This R increase is the result from the formation of the domain wall between the films. The size of the junction here is 50×50 nm^2 and this large junction area results in the very small MR ratio.

Figure 6 is a schematic image of speculated MR curves corresponding to Fig. 5 after virtual subtracting of the voltage drifting. (a) exhibits so-called butterfly shape, on the other hand, (b) seems to have stepwise changes.

Other thickness films such as 10–30 nm thick-

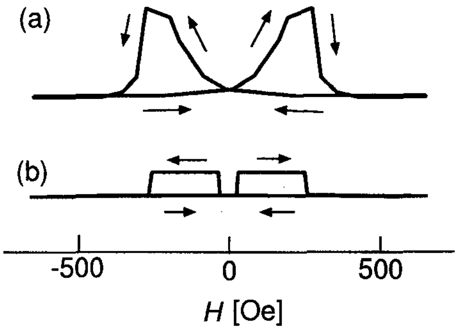

Fig. 6: Illustration of speculated MR curve after subtracting drift effect.

ness could not exhibit stable conductance and we could not investigate the MR property. We need to fabricate the junction having smaller size and measure the transport property. Electropolished Ni wire exhibiting more than 2000 % MR ratio has tips with the raidus $\approx$ 40 nm and the final contact is prepared by electrodepositon[5]. This might be the size required to BMR occurence.

Also we need to analyse the wall structure around the junction. Micromagnetic simulation of the local magnetization is now under way. It is reported that, if the wall width is reduced down to the electron wavelength, the spin should be conserved in the conduction process and BMR exceeding a few hundred % appears[7]. The film thicknesses of our junction to exhibit BMR must be estimated by calculation.

4 CONCLUSION

We have prepared nanojunction configuring Co and Ni films with the geometry of crossing edges. By this method the junction of which contact area was 50×50 nm^2 was fabricated without using lithographic microfabrication technique. Since the Co and Ni films had different coercivities, the junction assembly had two step magnetization process when the field was applied to in-plane direction of each film. The magnetic domain wall is introduced at the junction when the antiparallel magnetization alignment is realized during magnetization process. Stepwise MR increase was observed for this magnetization configuration and is attributed to the wall existence. This may occurs owing to the same mechanism as BMR effect. MR ratio was only 0.08 % and very small, probably due to large junction area.

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