Giant Magnetoresistance in NiO/Co/Cu/Co/Ti spin valve fabricated by EBPVD

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Abstract. In this paper, glass/NiO/Co/Cu/Co/Ti magnetic multilayers were deposited by electron beam evaporation system. A magnetic field of a few tens Oe was applied during the deposition of some of the layers in order to pin the magnetic moments of the ferromagnetic layer to the adjacent antiferromagnetic layer. The thickness of NiO layer is 140 nm and Co/Cu/Co/Ti layers thickness is 15 nm. The dc 4-point probe technique was used to measure the magnetoresistance (MR) of the prepared samples while the magnetic field was applied in the film plane and in the current direction. The giant magnetoresistance values up to 12% and 8% achieved respectively in samples deposited in presence and absence of magnetic field.

1. Introduction

Fret et al and Grunberg et al separately discovered giant magnetoresistance (GMR) in 1988 respectively in Fe/Cr multilayer and Fe/Cr/Fe three layer [1,2]. For some thicknesses of Cr layer around 1 nm, Fe layers may show antiferromagnetic coupling and have antiparallel magnetic moments in the absence of external magnetic field. By applying magnetic field, electrical resistance of the structure reduces as their magnetic moments start to align in a same direction toward the applied magnetic field. Because this resistance reduction is very large in comparison to other phenomena they call it Giant. The ratio of the resistance change to the minimum resistance, ΔR/R, is called GMR. In 1991 Dieny et al introduce a more practical GMR structure, spin-valve. This new structure consists of a soft ferromagnetic layer called free layer, a nonmagnetic layer and a second ferromagnetic layer called pinned layer which has exchange coupling with an antiferromagnetic layer adjacent to it. The interaction between these two last layers is the origin of an asymmetric exchange that pins the magnetization of the second ferromagnetic layer in a definite direction [3].

In the present work, we exhibit a cost-effective spin-valve structure prepared by electron beam evaporation on a glass microscope slide and functions at room temperature still shows a high GMR effect.
2. Materials and methods

Figure 1. Evaporation chamber with a coils for applying magnetic field of 50 Oe.

Figure 2. Cobalt pallet & Titanium granules in graphite boats.

2.1 Sample fabrication

Figure 1 show the deposition chamber used in this study. For raw material in powder form some pellets have been made by press the powder with 25 ton weight to the use in the deposition chamber. An image of a cobalt pellet and titanium granules in graphite boats are seen in figure 2. We used glass microscope slide as a substrate. Cobalt, nickel oxide and titanium have been deposited using electron beam evaporation. For copper deposition we used thermal evaporation and a tungsten boat with an electrical current order of 100 A. deposition parameters are indicated in table 1. A pair of coils with magnet cores inserted inside the deposition chamber to create in plane magnetic field in the order of 50 Ga during cobalt layer deposition. To avoid electron beam deflection caused by this magnetic field, aluminium foil used as a shield around the mentioned coils as could be seen in figure 1.

| Material    | Chamber pressure \((\times 10^{-5} \text{ mbar})\) | Substrate Temperature \(\text{C}\) | Layer thickness \(\text{nm}\) |
|-------------|-----------------------------------------------|---------------------------------|-----------------|
| NiO         | 4                                             | 27-42                           | 140             |
| Co/Cu/Co    | 3                                             | 29-44/-/45-51                   | 10              |
| Ti          | 3.5                                           | 27-42                           | -               |

2.2 Magnetoresistance measurement

The prepared sample is shown in figure 3. To measure the change in sample resistance by applying magnetic field, four-point probe technique (figure3 right) was used. In this technique, the two outside contacts used for conducting the current through the sample and the inside ones for voltage measurement. Keithley instrument 225 direct current power supply applied the current in the range of 50-150 nA through the sample and Keithley 160 B digital multimeter used to control the current. The sample voltage in the range of 20-65 µV was measured by 163 Digital Voltmeter Keithley. Magnetic field was applied in plane of the multilayers by 20 mT steps and up to 250 mT.

Figure 3. left: schematic sketch of the spin-valve sample, center: spin-valve sample with electrical contacts, right:schematic sketch of a four-point probe technique.
3. Results

Roughness and inter layers diffusion have a great effect on GMR. Some studies show that in Fe/Cr layers magnetic resistance increases with roughness [4,5]. On the other hand it has been shown that as a result of the large resistance in mixed NiFe/Cu layers, interface roughness of NiFe/Cu/NiFe/FeMn spin valve leads to reduction in magnetic resistance [6,7]. In Co/Cu layers, this inter layer diffusion effect may cause different GMR results [8-10]. AFM images from the NiO and the multilayer (figure 4) show that surface roughness in both sides is around 2.8 nm. Magnetoresistance measurement result is shown in figure 5. Magnetization of the sample measured by magneto optical Kerr effect (MOKE) technique and the arising hysteresis loop is shown in figure 6. Magnetoresistance curve and hysteresis loop indicate an extreme consistency. Both increase in the same manner. This show that in-plane easy axis was developed as a result of NiO layer and its adjacent Co layer coupling. Applying the magnetic field causes magnetic moment of the soft cobalt layer to rotate toward magnetic field direction and increases the angle between the two Co layers.

4. Conclusion

Although we used a cost-effective technique and substrate, our structure shows spin-valve effect at high value. Magnetoresistance curve and hysteresis loop show the same behavior and support the interpretation of GMR as caused by spin-valve effect.
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