Magnetoresistance anomaly in DyFeCo thin films

J. C. Wu[a)] and C. S. Wu
Department of Physics, National Changhua University of Education, Changhua, Taiwan 500

Te-ho Wu
Department of Humanities and Sciences, National Yunlin University of Science and Technology, Touliu, Taiwan 640

Bing-Mau Chen and Han-Ping D. Shieh
Institute of Electro-Optic Engineering, National Chiao-tung University, Hsinchu, Taiwan 300

Microstructured rare-earth–transition-metal DyFeCo films have been investigated using magnetoresistance and extraordinary Hall-effect measurements. The Hall loops reveal variation of coercive fields depending on the linewidth and the composition of the films. The magnetoresistance curves, with changes up to as high as 1.3%, show positive/negative magnetoresistance peaks centered on the coercive fields depending on the linewidth of the films only. The variation of the coercivity can be attributed to the magnetic moment canting between the Dy and FeCo subcomponents and the existence of the diverged magnetization on the edges, and the anomalous magnetoresistance peaks observed are discussed with the existing theories. [DOI: 10.1063/1.1357116]

I. INTRODUCTION

Magneto-optical (MO) thin films have been under extensive investigation due to their superior magnetic perpendicular anisotropic properties and extensive applications in ultra-high-density data storage recording. Recently, people have even started to study microstructured MO films using the MOKE technique and magnetic-force microscopy.[1–5] However, the information extracted from the electrical measurements on these MO films is always a valuable way of knowing their magnetic properties. Herein, we present a series of magnetoresistance (MR) and extraordinary Hall-effect (EHE) measurements on patterned amorphous rare-earth (RE) transition–metal (TM) DyFeCo films having different compositions and various linewidths. Attention was paid to the MR changes, MR peaks, and the coercivity variation.

II. EXPERIMENT

Microstructured DyFeCo films were made combining standard electron-beam lithography and dc-magnetron sputtering through a lift-off technique. First, Hall bar-shaped trenches were exposed in electron-beam resist using a commercial scanning electron microscope (SEM) modified for direct writing.[6] After the sample was developed in a 1:3 mixture of methyl isobutyl keytone and 2-propanol, a dc-magnetron cosputtering system was used for amorphous DyFeCo film deposition, in which the thickness was fixed at 50 nm for all of the films studied. The film was protected using a subsequent dc-sputtered SiN film from oxidation. During the MO sputtering, the substrate temperature was kept at room temperature and no external magnetic field was present. The four-terminal shape of films, having a fixed active length of 30 μm and widths of 10 and 2 μm, respectively, were then completed after a lift-off process in acetone. In this study, two different compositions of amorphous MO materials, $Dy_{20.6}(Fe_{80}Co_{20})_{79.4}$ and $Dy_{26}(Fe_{80}Co_{20})_{74}$, were made. Notice that in order to get well-defined edges on the devices made using the sputtering technique, a bilayer electron-beam-resist system was employed for a better undercut profile in the developed trenches of the electron-beam resist. Details of the fabrication process can be found in our previous publications.[3–5] Room-temperature MR and EHE measurements were carried out with 1 mA dc-sensing current and under an external magnetic field applied perpendicular to the film plane, as schematically shown in Fig. 1.

III. RESULTS AND DISCUSSION

The experimental data are shown in Figs. 2 and 3 for $Dy_{20.6}(Fe_{80}Co_{20})_{79.4}$ and $Dy_{26}(Fe_{80}Co_{20})_{74}$ devices, respectively. Figure 2(a) shows the MR curve of a 2-μm-wide device, while Figs. 2(b) and 2(c) show the MR curve and EHE loop of a 10-μm-wide device. Figures 3(a) and 3(b) show the MR curve and EHE loop of a 10-μm-wide device, respectively, while Fig. 3(c) shows the EHE loop of a 2-μm-wide device. Some distinct phenomena need to be addressed: (1)

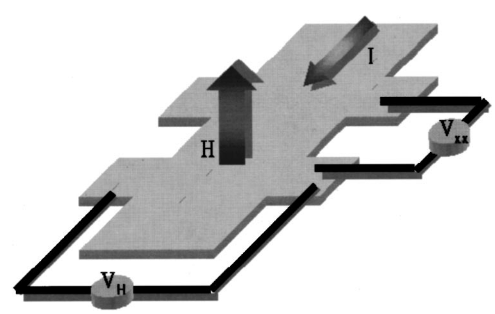

FIG. 1. Schematic setup drawing for the MR curves and EHE loop measurements.

a)Electronic mail: phjcwu@cc.ncue.edu.tw

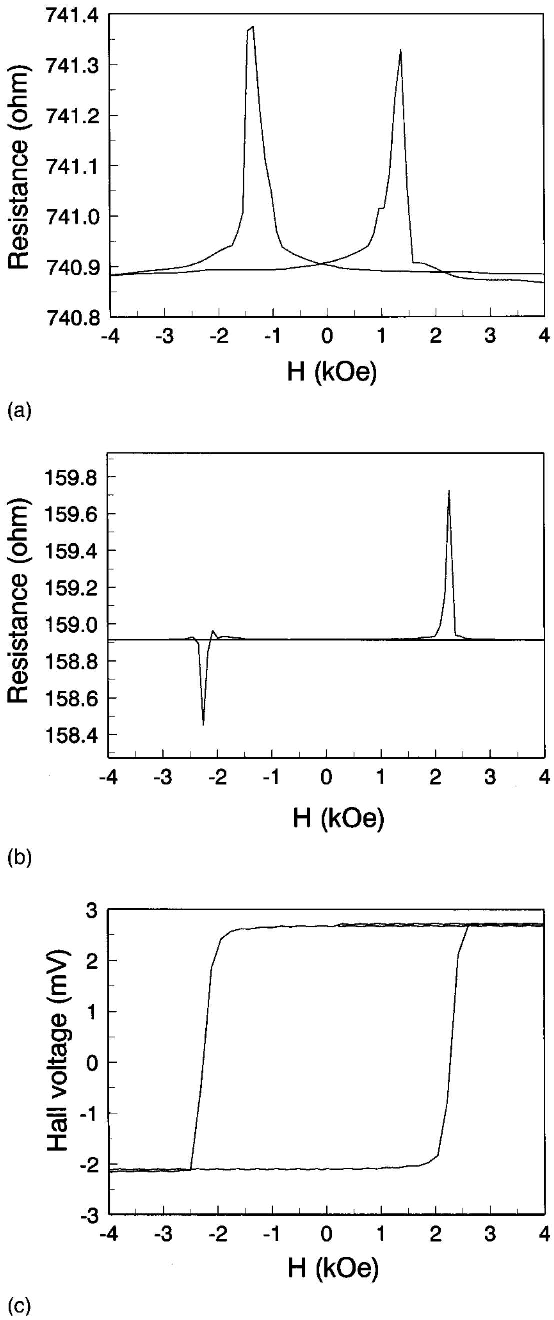

FIG. 2. MR curves and EHE loops measured on $Dy_{20.6}(Fe_{80}Co_{20})_{79.4}$ samples. (a) shows the MR curve of a 2-μm-wide device, while (b) and (c) show the MR curve and EHE loop, respectively, of a 10-μm-wide device. Notice that the MR peaks are centered at the coercive fields identified by the EHE loop measurement and the coercive field is lower on the 2-μm-wide device.

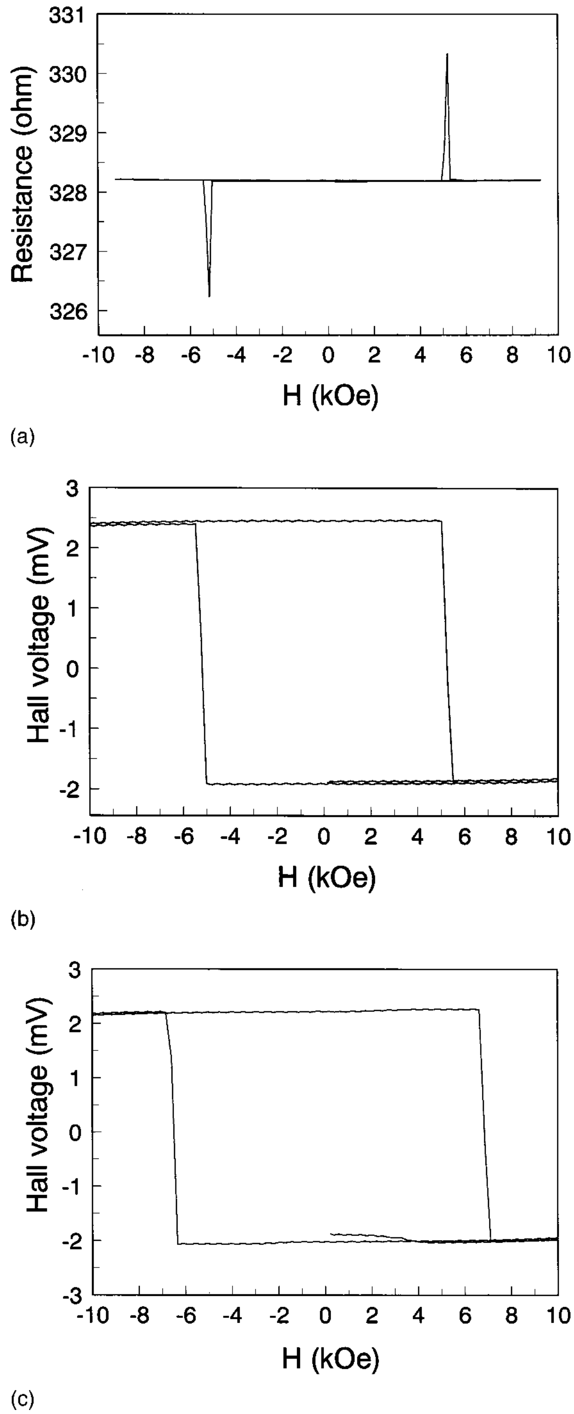

FIG. 3. MR curves and EHE loops measured on $Dy_{26}(Fe_{80}Co_{20})_{74}$ samples. (a) and (b) show the MR curve and EHE loop of a 10-μm-wide device, while (c) shows the EHE loop of a 2-μm-wide device. Notice that the MR peaks are centered at the coercive fields identified by the EHE loop measurement and the coercive field is lower on the 10-μm-wide device.

Good squareness in the EHE loops indicates a strong perpendicular anisotropy in these films. (2) Sharp MR peaks occur and are centered on the coercive fields. The width of the peaks corresponds to the transition region in the vicinity of the coercive fields in the EHE loops. (3) On both compounds, the MR peaks always point in the same direction on 2-μm-wide devices (referred to as positive MR peaks), whereas they point in the opposite directions on 10-μm-wide devices (referred to as positive/negative MR peaks). (4) The coercivity becomes larger on the 10-μm-wide devices than 2-μm-wide devices on $Dy_{20.6}(Fe_{80}Co_{20})_{79.4}$ devices. This coercivity change is reversed on $Dy_{26}(Fe_{80}Co_{20})_{74}$ devices.

In our previous studies, we have shown that the variation in coercivity in patterned DyFeCo films with different hole shapes and depths is mainly due to the canting behavior between the RE and TM antiparallel subcomponents and the existence of magnetization perpendicular to the sidewall.[4,5] In this study, the finite width of the film causes the magnetization to diverge on the edges, which is similar to our previous findings. Therefore, the present result can be explained with the same argument.

Usually, the resistance changes of MO films exhibit positive or negative magnetoresistance at high magnetic field, which can be interpreted by *s–d* scattering[7–9] and the dispersion of submagnetic moment component.[10] In the low-magnetic-field regions, magnetoresistance peaks occurred that are attributed to the anisotropic magnetoresistance effect;[11,12] i.e., that conduction electrons, scattered from the magnetization within the domain walls, cause the resistance to increase. Consequently, positive MR peaks take place around the coercive field, during which the magnetic thin film is in a demagnetized state. On the contrary, the secondary Hall effect studied by Hajjar gives negative MR peaks.[13] However, our results, show positive and negative MR peaks depending on the linewidth of the films. Both TM- and RE-dominated films exhibit the same one positive and one negative MR peaks on wider devices but only positive MR peaks on narrower devices. Sheet films of both compositions reveal one positive and one negative MR peaks as well, not shown. Notice that the MR changes in RE- and TM-dominated 10-μm-wide devices are up to as high as 1.3% and 0.8%, respectively, whereas it is only about a 0.1% MR change in 2-μm-wide devices. Here, the MR changes are taken as the ratios of the differences between the highest and the lowest resistance divided by the resistance at the zero magnetic field. We now conclude that the aforementioned results cannot be explained by the existing theories.

The finite-size effect may account for these MR peaks anomaly. Therefore, we performed an additional experiment to test the effect of diverged magnetization on the edges to this MR anomaly. We have found that similar one positive and one negative MR peaks occurred on the sheet films with the micrometer size of hole array patterns along the active region but with much higher MR changes. These results may indicate that the sidewall plays an important role in this MR change. Details of the MR changes as well as the corresponding MOKE data will be published elsewhere.

The mechanism for these one positive and one negative MR peaks is unknown thus far. We suspect that further studies, such as temperature dependence measurements, are necessary to work out the size and the magnetic-field dependence of these anomalous negative/positive MR peaks. Nevertheless, one can think of a practical application by adopting this anomalous high MR change and lowering the coercivity to make a sensitive magnetic-field sensor.

IV. CONCLUSION

In summary, we have performed magnetoresistance and extraordinary Hall-effect measurements on two different compositions of DyFeCo MO films with linewidths of 10 and 2 μm for each compound, respectively. The coercivity was higher in the wider TM-dominated device, whereas the coercivity was lower in the wider RE-dominated device. The variation in coercivity is believed to result from the magnetic moment canting between the RE and TM subcomponents and the existence of the diverged magnetization on the edges. The magnetoresistance curves reveal changes as high as 1.3% and positive/negative MR peaks centered around the coercive fields for both RE- and TM-dominated films depending on the linewidths. This MR peak anomaly cannot be explained by existing theories. However, adopting this high MR change and lowering the coercivity may lead to a practical application for making a sensitive magnetic-field sensor.

ACKNOWLEDGMENT

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