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Improving exchange-coupling field in the same thickness of pinned magnetic layer

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ABSTRACT

A conventional Ta/NiFe/Cu/NiFe/FeMn spin valve was prepared to investigate the exchange bias properties with the variations of deposition field. By enhancing the deposition magnetic fields from 50 to 650 Oe, increase of exchange bias fields at a given thickness of the pinned NiFe layer has been found in the spin valves. In this paper, we show that this increase is due to the change of magnetic moment distribution at the ferromagnetic and antiferromagnetic interface by comparison of measured results with the interfacial uncompensated model. Therefore, by enhancing deposition magnetic fields, a large exchange-coupling field can be achieved in relatively thicker magnetic films for application.

1. Introduction

Exchange coupling at interface between a ferromagnetic (FM) layer and an antiferromagnetic (AFM) layer can cause exchange bias, which is often described as an in-plane unidirectional anisotropy. It has been known for more than 50 years [1,2] and extensively studied by both experiments and theoretical analysis [3–12]. However, its physical mechanism remains unappreciated. Considerable interest in FM/AFM exchange coupling has been revived because of its key role in giant magnetoresistance (GMR) spin valve (SV).

For magnetic random access memory (MRAM) and magnetic sensor applications, a large exchange bias between the pinned FM layer and the AFM pinning layer promotes magnetic stability of the pinned layer, which is the key to production of reliable, high-quality SV structure with increased sensitivity. It is well known that the pinning achieved in an AFM/FM bilayer is produced either by heating the sample to above the blocking temperature of the AFM, applying a magnetic field and then cooling to room temperature with the field on, or by applying a magnetic field during sample growth [13]. Using field-cooling process, a large exchange bias field H_{ex} can be achieved in the sample comparing with field growth method [14]. However, field-cooling process may bring interface diffusion, oxidize and destroy the properties of the sample. Therefore, using field-cooling process to get large H_{ex} is disadvantage in device preparing procession. Since the exchange bias field H_{ex} is usually inversely proportional to the FM layer thickness [13,15], a more direct way to get large exchange-coupling field is based on decreasing the thickness of pinned FM film when applying a magnetic field during sample growth. However, thin films cannot supply enough spin polarization, which is responsible for the effect of decreasing GMR. Therefore, many researches on the enhancement of exchange bias for relatively thicker FM film have been conducted, such as changing seed layers, adding surfactant [16–18]. In addition, surveying most of the experimental results on the exchange coupling between FeMn and NiFe, the deposition magnetic fields for developing the necessary exchange bias are in a large area, from several oersted to several hundred oersted [3,19–21]. Little attention has been given to the magnitude of deposition magnetic fields. Therefore, we have studied in great details on exchange bias with a variation of magnetic field when applied during film deposition, and find a feasible way to achieve large exchange bias for application.

2. Experiment

Multilayer thin films with a composition Ta (5 nm)/NiFe (10 nm)/Cu (4 nm)/NiFe (t)/FeMn (15 nm) with $t = 4$–10 nm were deposited by DC magnetron sputtering using LS500 automatic sputtering system at a base vacuum better than 7×10^{-8} Torr, and working pressure 5×10^{-4} Torr. Deposition rates of all the layers were around 0.1 nm/s and controlled by a quartz crystal

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deposition monitor. A magnetic field was applied during the film deposition to define the easy axis and the unidirectional axis of the film and changed from 50 to 650 Oe. The exchange bias field was obtained from the hysteresis loop measured by a BHV-525 vibrating sample magnetometer (VSM).

3. Results and discussions

The magnetization curves for a series of samples with four different deposition magnetic fields of 50, 200, 400 and 650 Oe are displayed in Fig. 1.

In Fig. 1 the two parts of the hysteresis loop match well with the relative thickness and magnetizations of the two NiFe layers. Notice one interesting feature of the curves: H_{ex} increased with increasing deposition magnetic field for a given NiFe layer thickness. Furthermore, the exchange-coupling fields and the deposition magnetic fields for the samples are also plotted as a function of pinned NiFe layer thickness in Fig. 2. It is obvious that H_{ex} is proportional to $1/t_{FM}$ (t_{FM}: the thickness of pinned magnetic

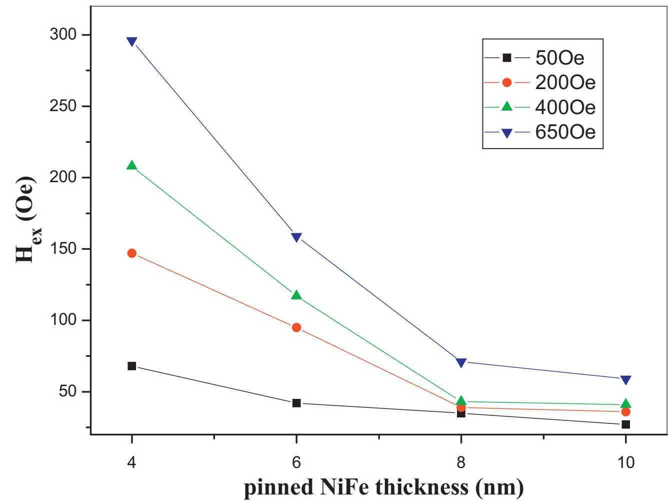

Fig. 2. Exchange bias variation of the deposition fields as a function of pinned NiFe layer thickness.

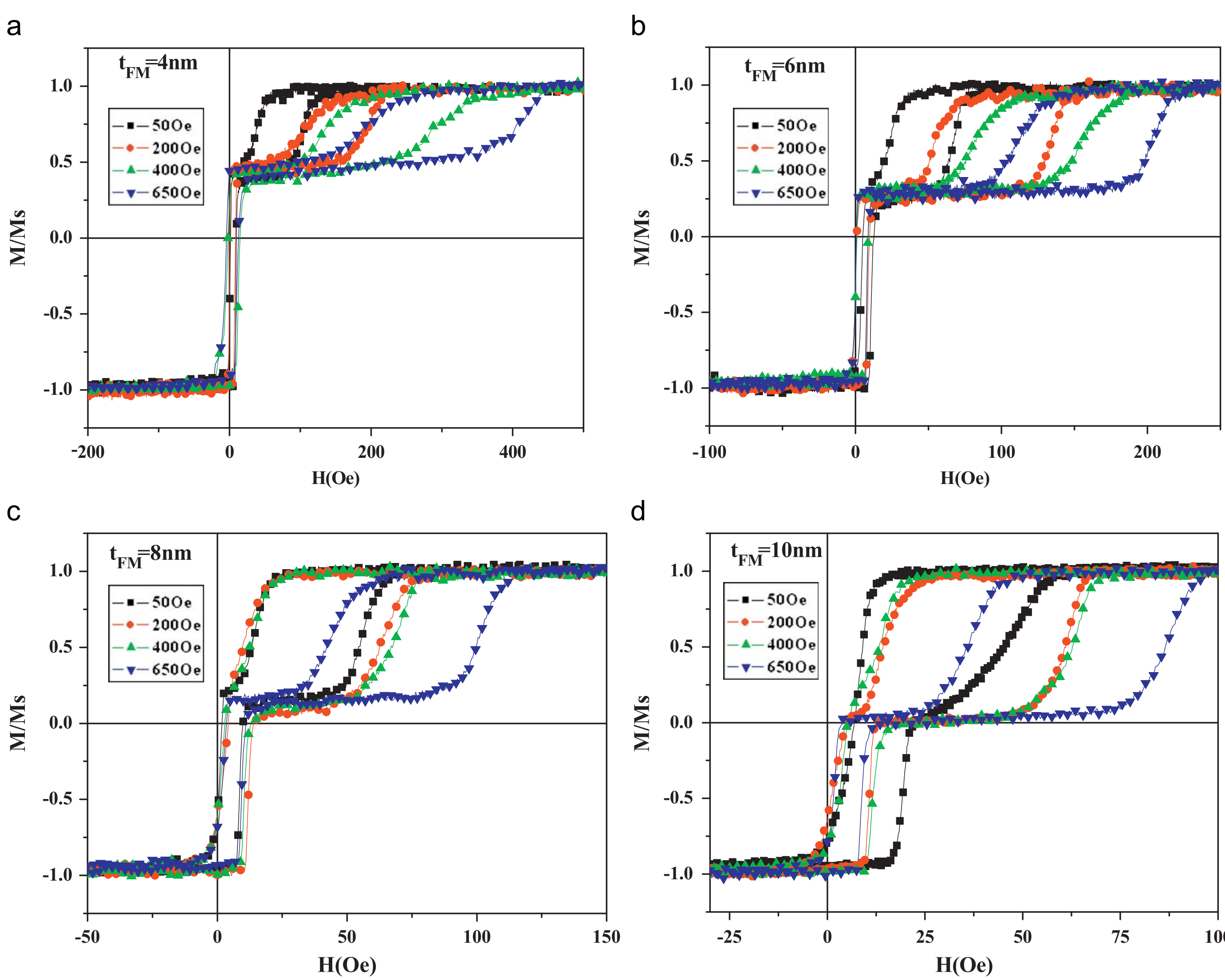

Fig. 1. The magnetization hysteresis loops of Ta (5 nm)/NiFe (10 nm)/Cu (4 nm)/NiFe (t)/FeMn (15 nm) multilayer at different deposition fields, for (a) $t = 4$ nm, (b) $t = 6$ nm, (c) $t = 8$ nm and (d) $t = 10$ nm.