Influence of growth field on NiFe, Fe3O4, and NiFe/Cr/Fe3O4 spin-valves

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Influence of Growth Field on NiFe, Fe_3O_4, and NiFe/Cr/Fe_3O_4 Spin-Valves

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Thin films of $Ni_{80}Fe_{20}$, Fe_3O_4, as well as $Ni_{80}Fe_{20}$/Cr/Fe_3O_4 spin valves, have been grown with and without magnetic fields applied during the deposition, and their magnetotransport properties have been studied at room temperature. The applied field induces an anisotropy in both single layer films, which causes notable differences in their anisotropic magnetoresistance. In the spin valve system, the applied field enables the parallel and antiparallel states to be more well-defined, which reveals a possible giant magnetoresistance in the system. The origin of this signal is likely the interaction of electrons that have been polarized by spin-dependent reflection from the Cr/Fe_3O_4 interface with the $Ni_{80}Fe_{20}$ interface.

***Index Terms*—Half-metal, magnetite, oxide spintronics, spin polarization, spin valve.**

I. INTRODUCTION

BAND structure calculations suggest magnetite (Fe_3O_4) is half-metallic, meaning that only one spin species (minority spins, in this case) is present at the Fermi level [1]. While it is questionable whether or not Fe_3O_4 (or any material) is truly half-metallic [2]–[4], materials with high spin-polarization are of critical importance for spintronics research and applications. The large resistivity of magnetite should help concentrate current in spin valves to the spacer layer, and indeed spin valve structures studied with different materials show giant magnetoresistance behavior: $CoFe_2O_3$/Au/Fe_3O_4, Fe_3O_4/Cu/$Ni_{80}Fe_{20}$, Fe_3O_4/Au/Fe, and Fe_3O_4/Au/Fe_3O_4 [5]–[7]. In this paper, we are reporting the impact of an applied field during growth on the transport properties of magnetite, permalloy (Py= $Ni_{80}Fe_{20}$), and Py/Cr/Fe_3O_4 spin valves. We find that the field helps define the parallel and antiparallel states, which may be beneficial for future spintronics studies based on these or similar materials.

II. EXPERIMENTAL SETUP

All films were grown using ultra high purity gases in a magnetron sputtering system with a base pressure of 20 nTorr. All targets were presputtered for at least 10 minutes prior to deposition. The sample holder was rotated at 40 r/min during deposition, and the gun angle has been optimized to obtain film thickness variations less than 0.4% over 75 mm. A sample platen was designed to study the effect of magnetic field on the growth of magnetic thin films. Commercially available ferrite magnets are placed on the inner perimeter of an iron yoke that was machined from a used 99.95% Fe sputtering target. As shown in Fig. 1, this design allows two samples to be grown simultaneously, one in a field of around 250 Oe between the ferrite poles at room temperature, and one in nearly zero field (due only to stray flux from yoke and magnetron guns; immeasurable with Gauss meter). Using this platen, we grew three sets of twin samples: 100 Å thick permalloy (Py, $Ni_{80}Fe_{20}$) on room temperature Si(100) substrates with a native oxide using 100 W dc power and 3 mTorr Ar at 0.67 Å/s; 500 Å thick Fe_3O_4 on MgO(100) at 300 °C by 200 W rf reactive sputtering from an Fe target in an Ar and O_2 mixture (20 and 0.75 sccm, respectively) with a total pressure of 10 mTorr and a rate of 0.26 Å/s; and two Py(100 Å)/Cr(40 Å)/Fe_3O_4(500 Å) spin valve structures. The Cr spacer is used to allow the Py and magnetite layers to switch independently; a Cr-thickness study revealed 40 Å as the thinnest Cr to do so. Magnetite's pressure-temperature phase diagram has a large area, which means it is relatively forgiving as far as thin film growth is concerned. The quality of magnetite thin films can be quickly inferred via resistance versus temperature measurements by the proximity of the measured Verwey transition temperature to the bulk value of 125 K and width of this transition [8]. The films we have made for this study show transition temperatures between 119 and 125 K, indicating good oxygen stoichiometry.

Current in-plane magnetoresistance measurements were carried out at room temperature for the Py, Fe_3O_4, and Py/Cr/Fe_3O_4 spin valve structures using pseudo-four point transport measurements. The measurement field was applied perpendicular to the current path; the growth field was parallel to the current path. In each case, a significant impact is apparent, presumably due to an uniaxial anisotropy induced by the growth field. For the Py, Fig. 2(a), there is a sharp reduction in the coercivity and anisotropic magnetoresistance (AMR) signal when grown in the magnetic field. The remaining peak is likely the result of domains present at the ends of the sample under the electrical contacts. Since the magnetization is constrained by the anisotropy to remain along the growth field direction except near the reversal field, the reversal of the magnetization occurs in a reduced field range, which gives rise to sharply shaped AMR peaks with reduced amplitude. The behavior for the Fe_3O_4 grown in a field, Fig. 2(b), is likely of similar origin, and shows similar behavior: reduced coercivity, lower magnitude. However, since magnetite films are subjected to antiphase boundaries that prevent the sample from saturating at low fields [9]–[11], the AMR signal exists through a much wider field range. No changes due to the growth field were noted for the resistivities or the Verwey Transition temperature. As is known in soft Py thin films [12], developing a uniaxial anisotropy leads to reduced coercivity. While still under investigation for

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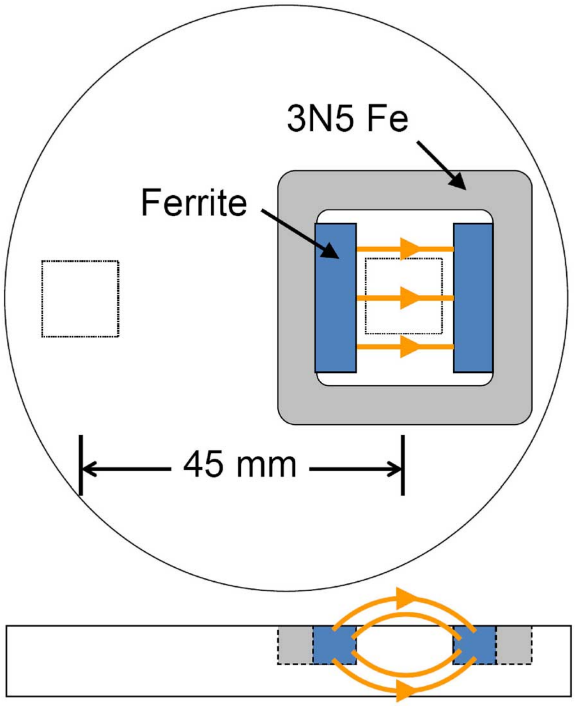

Fig. 1. Substrate platen designed for the simultaneous growth of films with a field on the order of 100 Oe isolated in one region. The iron yoke helps concentrate the field from commercial ferrite magnets while reducing stray fields from the rest of the platen. The squares represent the positions of the MgO substrates during growth for these experiments.

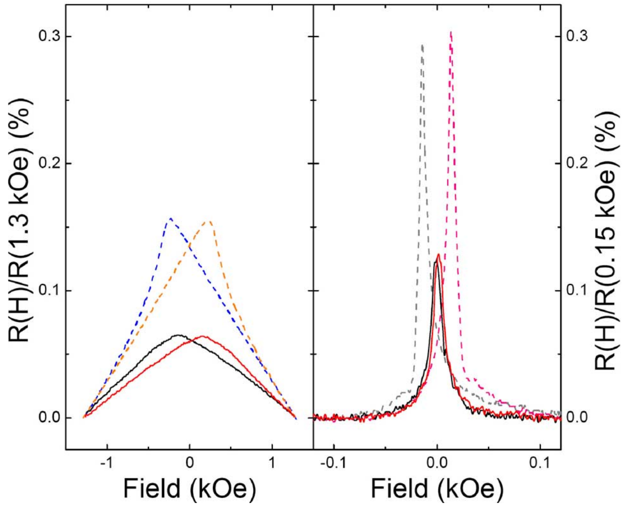

Fig. 2. Applying a field during growth induces changes to the anisotropy in the Fe_3O_4 (left) and Py (right) films that causes a reduction of the anisotropic magnetoresistance signal and the coercivity. The samples with (without) a growth field are shown in solid (dashed) lines. The field causes the coercivity to decrease from 230 to 140 Oe (14 to 2 Oe) for the Fe_3O_4 (Py). The magnetite sample does not saturate, which is likely due to antiphase boundaries.

magnetite thin films, similar behavior has been noted in other oxide materials [13].

For the spin valve structures, Fig. 3, the growth-induced anisotropy allows the parallel and antiparallel orientations of the two layers to become more well defined. In fact, with the field applied, there is clearly a shoulder that develops in the antiparallel state, despite some superposition of the tails of the Py AMR signal. As shown in Fig. 4, the transition to the parallel state is sharper than the AMR signal in the single layer magnetite films, but at the same field. Despite the impact of the antiphase boundaries in the single layer magnetite films, the magnetoresistance signal from the spin valves saturates for fields exceeding the coercive field of the magnetite. This underscores that the current flowing in the magnetite is insignificant relative to that flowing in the Py and Cr layers. This shoulder indicates a giant magnetoresistance (GMR) is present, not simply AMR. We can simply define the GMR as the difference between the resistance of the shoulder in the anti-parallel state and the saturated resistance in the parallel

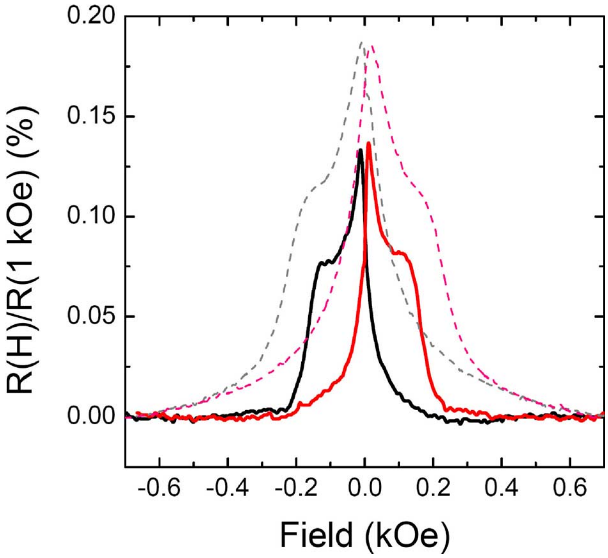

Fig. 3. Applying a field during growth of $Py/Cr/Fe_3O_4$ spin valves induces a uniaxial anisotropy in the films and makes the coercivity more well defined in these structures. This enables the parallel and antiparallel states to be established more distinctly. The sample with (without) a growth field is shown in solid (dashed) lines.

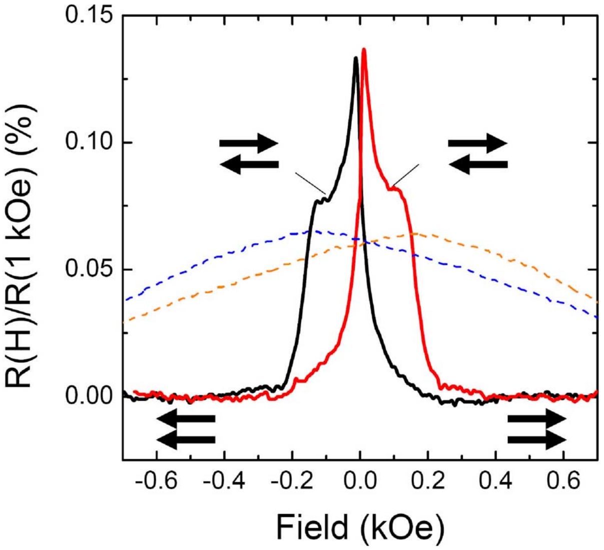

Fig. 4. The magnetoresistance signal in the spin valves is distinctly established by the reversal of the magnetite, as evidenced by the saturation of the signal corresponding with the peak of the magnetite amr signal (dashed). The parallel and antiparallel states are indicated for clarity, with the top (bottom) arrow representing the magnetite (permalloy).

state. Since a substantial fraction of the current flows in the Py and Cr, the origin of the GMR signal in this geometry is related to current becoming polarized by reflection from the Cr-Fe_3O_4 interface, then interacting at the Cr-Py interface in the typical GMR manner. The inefficiency of the polarization by reflection presumably contributes to the low level of the observed GMR. Despite the fact that the magnetite does not fully saturate due to the presence of antiphase boundaries, it appears that the GMR saturates once the magnetite reverses.

III. CONCLUSION

In conclusion, the application of a ∼100 Oe field during growth induces an anisotropy in permalloy and magnetite single layer films, as well as Py/Cr/Fe_3O_4 spin valves. We show that in the spin valves, the parallel and antiparallel states are more well defined with this growth field. This revealed a giant magnetoresistance-like signal that is most likely due to the polarization of conduction electrons after reflecting from the Cr/Fe_3O_4 interface.

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