MAGNETORESISTANCE AND HALL EFFECT OF Fe_3O_4 THIN FILMS ON MgO SUBSTRATES

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Half-metallic compounds are compounds with only one spin direction at the Fermi level. This kind of compounds is desired because the output of spintronic devices based on such materials are optimized. Fe_3O_4 is one candidate material to half metallicity which, in addition, has a large Curie temperature (860 K), which is attractive for room-temperature applications. Prior to application in real devices, one should be able to control the growth, magnetic and transport properties of Fe_3O_4 in the form of thin films.

We have grown epitaxial Fe_3O_4 thin films on single-crystal (001) MgO substrates by pulsed laser deposition using a KrF laser (248 nm). MgO substrates have been chosen due to the good lattice matching with Fe_3O_4 [$a(MgO)\approx 4.21$ Å; $a(Fe_3O_4)\approx 8.40$ Å]. The Fe_3O_4 target has been prepared by conventional solid-state reaction method. The films have been deposited at a substrate temperature around 400ºC in (ultra) high vacuum (base pressure $\sim 5\times 10^{-9}$ Torr). Electron diffraction patterns of a 40 nm-thick film (shown in figure 1) indicate the single-crystalline nature of the films. X-ray diffraction measurements ($\theta/2\theta$ and ϕ-scan) confirm the epitaxial growth with the expected out-of-plane orientation Fe_3O_4 [001] // MgO [001] and in-plane orientation: Fe_3O_4 [100] // MgO [100].

In this contribution we report the magnetoresistance and Hall effect of the grown films. The films were patterned by optical lithography techniques in order to have a well-defined geometry for the transport measurements. The optical lithography process implies the following processes: Fe_3O_4 film growth, photoresist spin coating, mask alignment and U.V. illumination, photoresist development, Ar+ ion beam etching, Au pads fabrication by lift-off and wire bonding onto chip carrier. As shown in figure 2, the current flows through an electrode typically 100-300 μm wide and pads have been patterned for the measurement of the voltage drop.

In figures 2 and 3 we summarize the results of resistivity, magnetoresistance and Hall effect obtained in a 40 nm-thick film [1]. The resistivity versus temperature curve shows similar behaviour to that of bulk Fe_3O_4, with resistivity value at room temperature ~9.3 mΩcm and a substantial increase of the resistivity at the Verwey transition at around 115 K. The magnetoresistance ratios are small, as expected for epitaxial Fe_3O_4 thin films, and caused by spin-polarized transport through antiphase boundaries [2]. The field dependence is quadratic or linear, depending on the geometry used. The Hall resistivity at room temperature is 17.2 μΩcm, close to the value found in reference [3]. As shown in figure 3(a), the Hall resistivity is proportional to the magnetization, which strongly suggests that the main contribution comes from the anomalous Hall effect. For the first time on epitaxial Fe_3O_4 thin films, we report the enhancement of the Hall resistivity as the Verwey transition temperature is approached [figure 3(b)], reaching the value of ρ_H=100.76 μΩcm at 100 K.

Currently, we are performing a study of these phenomena as a function of the film thickness (down to 10 nm) and in a wider temperature range (much below the Verwey transition temperature, down to 50 K).

References:

[1] J.M. De Teresa, A. Fernández-Pacheco et al, Microelectronic Engineering (2007), in press
[2] W. Eerenstein et al., Phys. Rev. Lett. **88**, 247204 (2002); A. Ramos et al., J. Appl. Phys. 100,103902 (2006)
[3] D. Reisinger et al., Appl. Phys. Lett. **85**, 4980 (2004)

Figures:

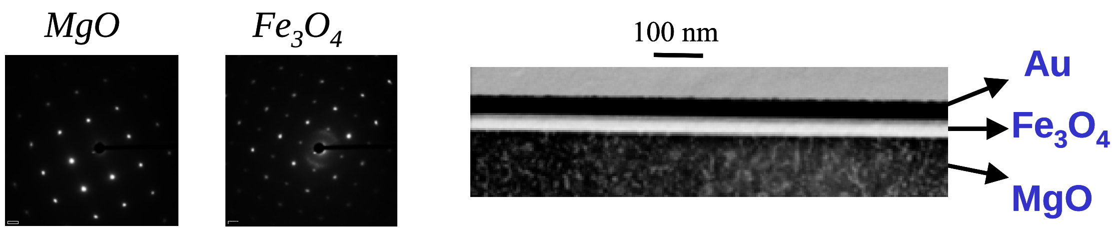
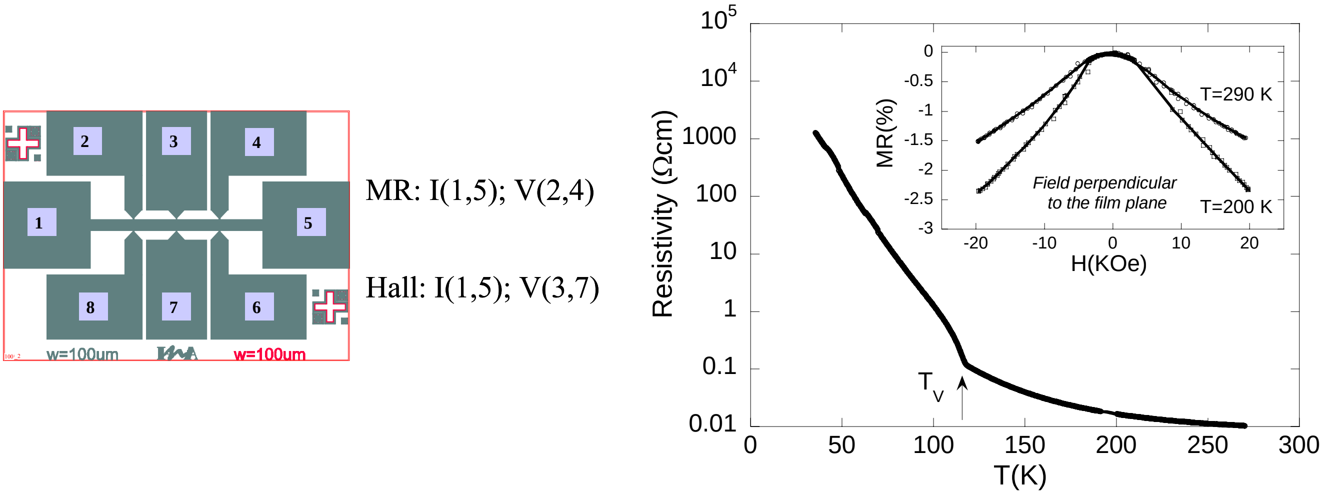


Figure 1 TEM image and electron diffraction of a MgO//Fe_3O_4(40nm)/Au(45nm) film



MR: I(1,5); V(2,4)

Hall: I(1,5); V(3,7)

Figure 2 Mask design for the measurements of the magnetoresistance (MR) and Hall effect. Resistivity versus temperature of a Fe_3O_4 (40 nm) film and MR.

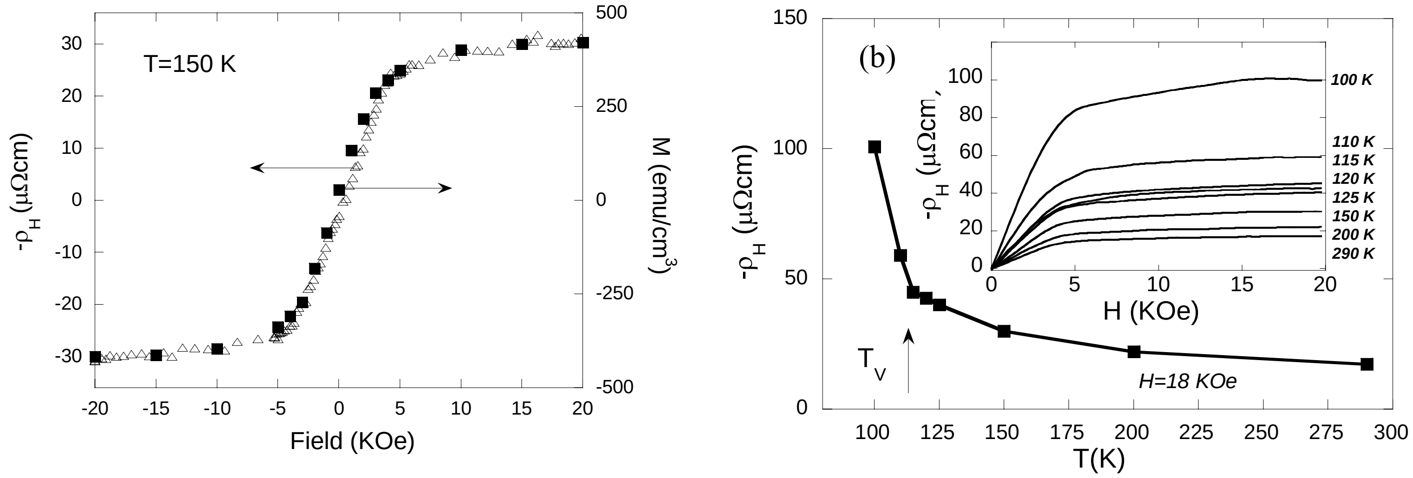


Figure 3 (a) Comparison of the Hall resistivity and magnetization (taken with the field applied perpendicular to the film plane) as a function of the applied magnetic field. A clear correlation is observed; (b) Hall resistivity at 18 KOe as a function of temperature. The inset shows the isotherms corresponding to the Hall resistivity measurements