Epitaxial growth of Fe_3O_4 Thin Films and Fe_3O_4/MgO/Fe heteroepitaxial structures for magnetic tunnel junctions

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Magnetite (Fe_3O_4) is a half-metallic ferromagnet with a high Curie temperature (860 K) that is expected to exhibit suitable properties for its implementation in spintronic devices [1-3]. In addition, the interest in spintronic structures based on magnetic oxides has increased recently [4]. MgO is a serious candidate as tunnel barrier because of the small lattice mismatch with the Fe_3O_4 (0.3%) electrode [5-7]. We believe that prior to application in real devices, the epitaxial growth of heterostructures with Fe_3O_4 and MgO should be further optimized. Additionally, recent magnetization studies on epitaxial Fe_3O_4 thin films grown on MgO [100] show that the ultrathin films (<5 nm thickness) are ferromagnetic and their magnetic moments are much greater than those of bulk magnetite, particularly at a thickness of 20 nm or below [8]. The observation of a ferromagnetic nature in ultrathin magnetite films is in contrast to the previously accepted dead layer interface model or a superparamagnetic behavior for ultrathin films of magnetite.

In this work we report the growth of epitaxial Fe_3O_4 thin films and Fe_3O_4/MgO/Fe heterostructures on MgO (001) substrates by means of pulsed laser deposition (PLD) and their structural and magnetic properties.

Fe_3O_4 and Fe thin films have been grown on single-crystal MgO (001) substrates by PLD using a KrF laser (248 nm). All layers have been deposited in ultra-high vacuum (base pressure < 5 $\times 10^{-9}$ Torr) at substrate temperatures of 400ºC for Fe_3O_4 and between room-temperature (RT) and 400ºC for Fe and MgO layers. Individual thin films and Fe_3O_4/MgO/Fe heterostructures on MgO (001) have been characterized by x-ray diffraction (θ-2θ, ω scans, ϕ scans, and reciprocal space maps) and x-ray reflectivity (XRR), high-resolution transmission electron microscopy (HRTEM) and VSM and SQUID magnetometry. Previous magnetoresistance and anomalous Hall effect measurements in our epitaxial Fe_3O_4 thin films have been published elsewhere [9, 10].

In Figure 1 we show the dependence of the magnetization with the nominal thickness of the films, which show a similar behavior as the observed by Arora et al [8]. For thickness below 20 nm the magnetization reaches values higher than the obtained for Fe_3O_4 single crystals (498 emu/cm^3) and for ultrathin films (< 5nm) values higher than 1000 emu/cm^3 can be observed. The origin of this unexpected behavior is still unclear. The non-compensation of spin moments between the tetrahedral and octahedral sublattices at the surface and antiphase-domain boundaries are inferred to be the main factor contributing to the observed enhanced magnetic moment [9].

After optimizing the growth conditions and fully characterizing the single Fe_3O_4 and Fe layers onto MgO (001), we undertook the growth of the full Fe_3O_4/MgO/Fe heterostructures by PLD. HRTEM data (not shown here) demonstrate a high crystallinity of the MgO (001) tunnel barrier and sharp interfaces. From the XRR analysis in a selected heterostructure where both MgO barrier and Fe counterelectrode have been deposited at RT, a rms roughness relatively low, ~ 0.2 nm, is obtained, this being indispensable for future MTJs. The RT hysteresis loop in a sample grown in similar conditions, Fig. 2, reveals an independent switching of both Fe_3O_4 and Fe electrodes, this also being required for tunnel magnetoresistance. The low field (500 Oe) temperature dependence of the magnetization of the same heterostructure (not shown here) displays a clear and sharp drop at the Verwey transition, T_V=115 K, demonstrating the high quality of the Fe_3O_4 layer.

We have produced high quality epitaxial Fe_3O_4/MgO/Fe heterostructures by PLD. To our knowledge, this type of heterostructure has not been grown before by PLD. Microfabrication of MTJs from these is in progress.

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Figures:

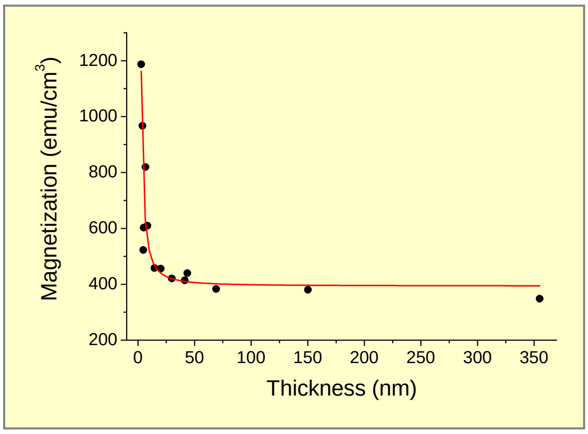

Figure 1. Dependence of the magnetization on the nominal thickness for the Fe_3O_4 thin films. The line is a visual guide.

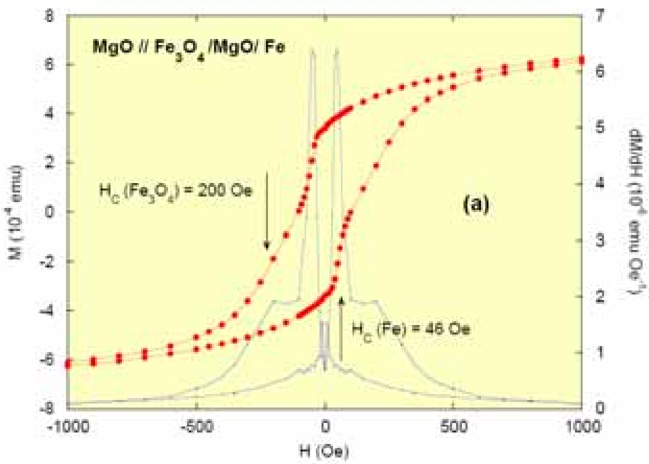

Figure 2. Room-temperature hysteresis loop of a Fe_3O_4 (70.9 nm)/MgO (3.7 nm)/Fe (5.6 nm)/Au (5.3 nm) heterostructure. The switching fields of both electrodes have been marked.