Correlating Interfacial Structure and Magnetism in Fe-MgO Thin Films Using Electron Microscopy, X-Ray and Neutron Reflectometry

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Project Summary

- Ferromagnetic-dielectric films of Fe-MgO are currently being explored for use in novel spintronics devices, such as spin valves and tunnel junctions.
- A rich variety of new phenomena, such as coupling between electricity and magnetism, occur in these films because of symmetry breaking at interfaces as well as non-equilibrium growth conditions.
- A combination of x-ray reflectometry, polarized neutron reflectometry, and transmission electron microscopy allows us to correlate interfacial structure, chemistry, and magnetism in these materials.

Background and Motivation

- We are at the verge of a major paradigm shift from charge-based electronics to spintronics that incorporate the electron’s spin.
- Early research of Fe-MgO thin films shows a possible coupling between magnetic and electronic order, mediated by charge redistribution in the dielectric MgO.
- We must probe interfacial structure and chemistry to understand and control the relationship between dielectric polarization and magnetic spin polarization in this system.

Methodology

- Iron films were deposited on MgO (100) substrates at 500 C and ultrahigh vacuum using electron beam deposition, then capped with a layer of gold to prevent oxidation.
- Transmission electron microscope (TEM) samples were prepared by cross-section polishing of film sections embedded in a brass cylinder with epoxy.
- Additional TEM samples were prepared using a wedge polishing technique.
- X-ray diffraction (XRD) and x-ray reflectivity (XRR) measurements were conducted to confirm the epitaxial nature of the Fe film growth and qualitatively assess interfacial roughness.
- Polarized neutron reflectivity (PNR) was conducted at the NIST Center for Neutron Research to probe the layer-by-layer magnetization of the composite.

Transmission Electron Microscopy

HRTEM micrographs indicate the presence of periodic arrays of islands, as well as a distinct 45 degree orientation relationship (Shown in FFT).

Conclusions and Future Work

- XRD and XRR indicate the growth of a high quality, epitaxial layer of Fe on the MgO substrate.
- PNR measurements suggest a magnetic “dead” layer near the Fe-MgO interface that could be caused by defects or structure.
- High resolution TEM micrographs confirm the epitaxial nature of the Fe film growth, but we also note the presence of misfit dislocations.
- We note the appearance of Fe islands, which is due to the kinetics of surface diffusion resulting from the 500 C deposition temperature.
- Future studies will include site-specific chemical analyses using local electrode atom probe tomography (LEAP).

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Background and Motivation (cont.)

- It is believed that the electric field in MgO is screened by free charges on the surface of the Fe metal.
- Because Fe is ferromagnetic this screening is spin-dependent and creates an interface magnetization.
- Currently there is little understanding of how interfacial structure contributes to the magnetization.

Schematic of spin polarization

Electric Field

Fe

MgO

E

E(N)

Defects?

Chemistry?

Magnetism?

Fe islands

Conclusions and Future Work (cont.)

- XRD patterns from the 20 nm Fe film indicate well-ordered, epitaxial growth while XRR shows a relatively smooth interface with nominal thicknesses.