Spin-dependent quantum interference from epitaxial thin films

Y. Z. Wu*, A. K. Schmid**, Z. Q. Qiu***

** Dept. of Physics, Fudan University, Shanghai, People's Republic of China*
*** NCEM, Lawrence Berkeley Lab, Berkeley, California 94720, USA*
**** Dept. of Physics, University of California, Berkeley, California 94720, USA*

Electron confinement in a thin film forms quantum well states. Fabry-Pérot interference is a familiar optical analog, one example of that are the colorful interference fringes in thin soapy films, which depend on film thickness and refractive index. Electronic quantum well states can dramatically influence film properties and result in many interesting phenomena, such as film stability and oscillatory magnetic interlayer coupling, etc. Many previous studies have focused on the energy range below the vacuum level. On the contrary, phenomena related to unoccupied states above the vacuum level have been explored to a lesser extent.

We use spin-polarized low-energy electron microscopy (SPLEEM) to measure spin-dependent electron reflection from epitaxial thin films grown *in-situ* on magnetic substrates. When quantum well states modulate reflected intensity of the electron beam, we can use measurements of the thickness- and energy-dependence of the reflectivity to determine the dispersion of unoccupied bands in the thin films.

It is interesting that SPLEEM images from non-magnetic overlayers reveal magnetic domains of the magnetic substrates. For example in the case of Cu films grown on fcc Co(100) layers, the domain contrast oscillates with electron energy and Cu film thickness [1]. This observation can be attributed to the spin-dependent electron reflectivity at the Cu/Co interface, which leads to a spin-dependent Fabry-Pérot electron interference in the film.

In this presentation we focus in particular on electronic states in single-crystalline insulating MgO/Fe(100). This topic is important, because it appears that electronic states of single crystalline MgO insulator-layers play a crucial role in generating large tunneling magneto-resistance in Fe/MgO/Fe(100) magnetic tunnel junctions. Experimental observations of large tunneling magnetoresistance, up to 220% at 300 K [2,3], motivates our effort to understand the basic electronic structure of this barrier material.

From our measurements we were able to determine two MgO energy bands with Δ_1 asymmetry. We find that a bulk-like MgO energy gap is fully established for MgO film thicker than 3 atomic monolayers, and that the electron reflectivity from the MgO/Fe interface exhibits a spin-dependent amplitude and a spin-independent phase change.

[1] "Spin-Dependent Fabry-Perot Interference from a Cu Thin Film Grown on fcc Co(001)", Y. Z. Wu, A. K. Schmid, M. S. Altman, X. F. Jin, and Z. Q. Qiu, *Phys. Rev. Lett*. 94, 027201 (2005)
[2] S. S. P. Parkin, C. Kaiser, A. Panchula, P. M. Rice, B. Hughes, M. Samant, and S. H. Yang, Nature Materials **3**, 862 (2004).
[3] S. Yuasa, T. Nagahama, A. Fukushima, Y. Suzuki, K. Ando, Nature Materials **3**, 868 (2004).