Magneto-Optic Characterization of Ferromagnetic Thin Films for Use in Nano-Scale Computer Applications

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Abstract:

Magnetic tunnel junctions (MTJs) utilizing materials with perpendicular magnetic anisotropy (PMA) are an attractive area of research due to applications in nanoscale computing. In particular, PMA facilitates spin-transfer-torque switching (STT) and high thermal stability in magnetic random access memory. While previous studies have shown that $L1_0$ ordered iron platinum (FePt) films exhibit strong PMA, we illustrate that epitaxial Fe/Pt bilayers on MgO<001> can exhibit PMA if annealed after the initial deposit. All films were grown in the MBE system in the Palmstrøm Lab at UCSB. *In situ* magneto-optic Kerr effect (MOKE) measurements were taken in the in-plane and out-of-plane directions to determine the magnetic anisotropy of each sample. In order to investigate the effects of annealing on interdiffusion and chemical reactions, we performed x-ray photoemission spectroscopy (XPS) measurements on samples before and after annealing at different temperatures. Component fitting shows a decrease in Pt peak area and increase in Fe peak area with increasing annealing temperature, suggesting Fe outdiffusion into the Pt cap or Pt indiffusion into the Fe. Therefore, we suspect the formation of an ordered Fe-Pt phase between the Fe base layer and the Pt cap. We believe that performing x-ray diffraction (XRD) and transmission electron microscopy (TEM) studies on future samples will give valuable insight into how annealing changes the crystal structure and affects compound formation.

Background:

Energy efficient data storage systems are required by battery-powered portable devices and large-scale internet server farms. Magnetic random access memory (MRAM), which uses magnetic tunnel junction (MTJ) arrays to represent computer bits, is a very promising solution. MRAM is desirable because its data storage method requires little energy to write, no energy to store, is nonvolatile and remains stable for years [1]. In a magnetic crystal, we can consider the crystal anisotropy as the energy required to magnetize a material in a given direction. It is advantageous for the magnetic films used in MTJs to exhibit perpendicular magnetic anisotropy (PMA), in which it is energetically favorable for the magnetic moments in the material to lie out of plane. PMA is advantageous for two main reasons:

- Decrease of spin transfer torque critical current, aiding device writing efficiency [2]
- High thermal stability, facilitating device scalability and long-term storage [3]

$L1_0$ ordered Fe/Pt films have been shown to exhibit PMA, but Fe/Pt bilayers on MgO have not been previously investigated. Studying the Fe/Pt interface may give insight into the mechanism that causes PMA, helping to advance the nanoscale computing industry.

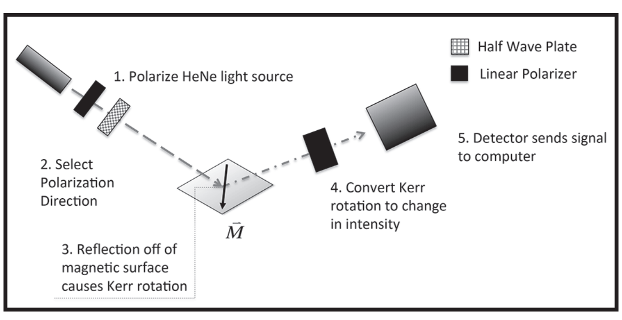

Figure 1: Magneto-optic Kerr effect (MOKE) schematic.

Experimental Procedure:

All samples were grown on MgO<001> crystal substrates in the Palmstrøm Lab at University of California, Santa Barbara. All growth and characterization was performed under continuous ultra high vacuum (UHV). After growth, samples were analyzed *in situ* using the magneto-optic Kerr effect (MOKE), which takes advantage of the fact that light changes polarization and intensity when reflected off of a magnetic surface (see Figure 1 for schematic).

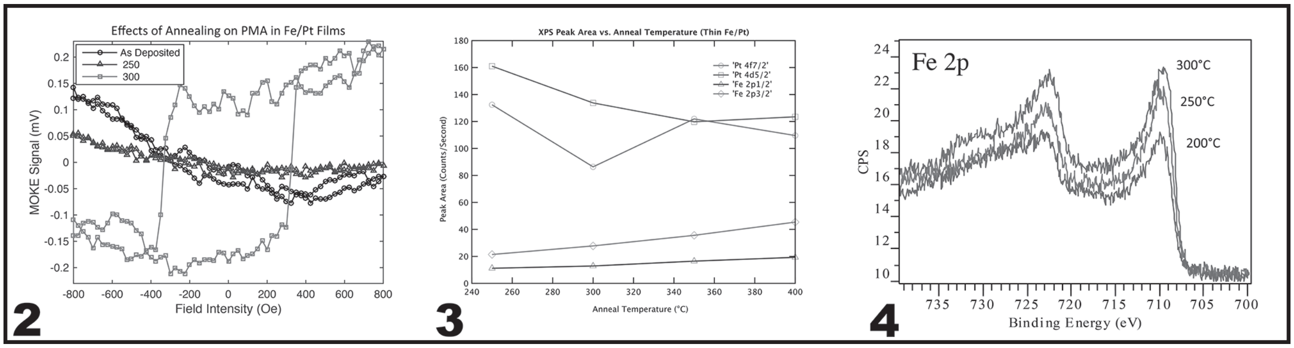

Figure 2, left: *MOKE hysteresis loops indicate transition to ferromagnetic behavior at 300°C.* ***Figure 3, middle:*** *XPS peak area as a function of annealing temperature.* ***Figure 4, right:*** *Sample XPS results for Fe 2p orbital.*

This phenomenon can be used to measure magnetic hysteresis loops that show changes in sample magnetization as an external field is applied. For our samples, we used an electromagnet to generate a maximum external field of ±3500 Oersteds (Oe). Due to the small size of the magnetic samples, one Oersted of applied field intensity approximately corresponds to one Gauss of magnetic flux. Samples were measured *in situ* using MOKE and x-ray photoemission spectroscopy (XPS) both before and after annealing at temperatures ranging from 200°C to 400°C.

XPS is a useful technique because it can be used to examine changes in atomic composition and bonding near the sample surface. Samples that exhibited PMA were re-measured by *ex situ* superconducting quantum interference device (SQUID) magnetometry to verify magnetic behavior and saturation magnetization.

Results and Conclusion:

Hysteresis loops collected via MOKE reveal that while Fe/Pt does not exhibit PMA as deposited, annealing to 300°C significantly changes the magnetic behavior (see Figure 2). After annealing to this temperature, MOKE hysteresis loops transitioned from a hard-axis to an easy-axis in the out-of-plane direction. That is, after annealing, the sample magnetized almost completely in the perpendicular applied field direction and created an approximately square hysteresis loop. This loop shape is indicative of strong PMA in the sample. XPS measurements in Figures 3 and 4 indicate an increase in Fe peak area and a decrease in Pt peak area as annealing temperature increases.

XPS is only sensitive to the top few nanometers of a given film, so an increase of Fe peak area indicates that Fe atoms may be migrating into the Pt cap or vice versa. The correlation between the PMA transition detected by MOKE and the peak area trends in XPS suggest that annealing produces a very thin $L1_0$ ordered FePt phase, which has been previously shown to exhibit strong PMA in bulk samples [4]. Another possibility is that annealing produces a highly ordered interface between the Fe and Pt layers, facilitating novel interfacial spin-orbit interactions between the magnetic Fe and high atomic number Pt atoms. Future studies will focus on using x-ray diffraction and transmission electron microscopy to verify the behavior of the Fe-Pt interface and the origin of PMA in Fe/Pt heterostructures.

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