Magneto-Optical Kerr Effect Measurement of Magnetic Thin Films on Self-Assembled Nanospheres

Brian L. Flores

Faculty Mentor: Dr. Jiyeong Gu

Department of Physics and Astronomy

Abstract

We are exploring how the topography of substrate surface alters the magnetic property of ferromagnetic monolayer system. Ferromagnetic monolayer has presented an interesting magnetic switching behavior originating from its dependence of the substrate's topography. Using nanospheres we modified the topography of substrate: 880 nm polystyrene nanospheres were uniformly self-assembled on silicon substrate and magnetic materials were deposited on them. Magnetic hysteresis measurements were made with a homemade Magneto Optical Kerr Effect (MOKE) system using a HeNe laser with maximum magnetic field of 1300 Oe. It is observed that nanosphere topography has made a considerable change in switching behavior of thin films compared to the films grown directly onto silicon substrate.

Introduction

Magnetic thin films are a current interest in the experimental physics community due to their unique electric and magnetic properties. Thin films are layers of material ranging from fractions of a nanometer, monolayer, to several micrometers in thickness, usually featuring a planar terrain. Due to their magnetic qualities, significant advances in electrons, semiconductor-materials, photonic devices and thin-film metallurgy were possible. Thin films of magnetic materials application potential are vast, including usage of high-speed read/write heads in disk memory devices or as permanent memory for computer applications. However, currently, manipulating the topography the wafers substrate vastly alters its overall magnetic properties. As such, their huge attractions are due to their promising potential for high density magnetic storage and sensor application. More so, their ability to overcome superparamagnetism, a common plague of small-sized, continuous thin films when attempting to increase data storage, is a distinguishing feature of these topologically curved magnetic films. For our purposes, this extra degree of freedom has the potential to engineer an array of magnetic behavior for study and implementation [1].

Our interest pertains to the deposition of magnetic materials on nanospheres and the unique magnetic properties they exhibit. The magnetic properties of thin films on nanospheres may differ considerably from the constituent bulk. These nanostructures are monodisperse and magnetically isolated from neighboring nanocaps and maintain uniform magnetic anisotropy with the potential for switching. Their magnetic property is dependent on the size and curvature [2] of the nanospheres of the system compared to their planar counterpart [3]. The deposition techniques being used to deliver the nanospheres also plays a role since the availability of instruments and ability to accurately replicate the desire topological patterns after several trials may be a leading factor for many errors in the deposition of the ferromagnetic material and the measurement from the MOKE [4]. Therefore, the uniformity of nanospheres is largely considered and popular techniques are investigated for the best coverage of the substrate [5–7].

Wide varieties of ferromagnetic materials are used to deposit on thin films (Iron (Fe), Cobalt (Co), Nickel (Ni), etc.) with varieties of techniques to create these nanostructures. One of the methods is to pattern material with a strong Perpendicular Magnetic Anisotropy (PMA) such as CoPt and FePt [8], especially on Silicon (Si) nanospheres [9]. Doing so, considerable enhancements of its coercivity and anisotropy is reported and has undergone extensive studies. Studies have ranged from the angle dependent magnetization reversal behavior [4], the size effect in the magneto-optical response of thin layers of Co nanoparticles [10], and the effects of several material capping layer's tendencies for induced magnetic polarization [10]. These studies lead towards the thin film's magnetic properties being attributed to the surface effects on the nanospheres. Thus, adding a curvature to the substrate where the magnetic materials are deposited is worth expanding to a multilayer system considering these preliminary results of monolayer thin films.

In this study, Py or SmCo were deposited on uniformly self-assembled 880 nm nanospheres on Si substrate. By forming this on nanospheres, enhancements of the coercivity during magnetic switching is expected, based from pervious experiments with monolayer. However, very little is known about this speculation considering this particular structure has yet been fully explored on curved topography. To elucidate the topological dependence of magnetic switching, we are assuming that the magnetic switching of the curved thin films are distinguishable at a micro to nanometer scale compared to their planar counterpart. As such, the magnetic behavior of topologically modified magnetic thin films grown on the self-assembled nanospheres is investigated using Magneto-optical Kerr Effect

Methodology

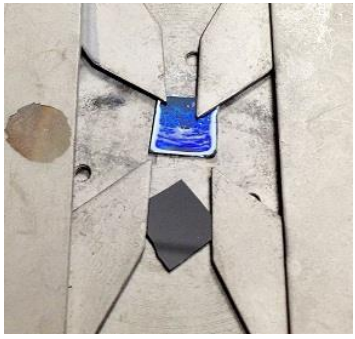
Silicon (Si) substrate was chemically treated with piranha solution, a 3:1 mixture of concentrated Sulfuric Acid and 30% solution of Hydrogen Peroxide. Monodisperse spherical polystyrene particles with diameters of 880 nm were diluted in nanopure water to a 50% solution. A self-assembled monolayer of nanospheres was formed from a 20 μL drop, coating the chemically clean wafer and slowly evaporated in a container

in ambient conditions on a tilted surface. Several samples of Permalloy (Py) and Samarium Cobalt (SmCo) was deposited on the spheres by sputtering from Py, Sm, and Co targets at an Ar pressure of 1.5×10^{-3} torr. Power used for deposition of Py, Sm and Co targets were 100 W, 30 W, and 150 W, respectively. Samples were stored in Secador Desiccator Cabinets to prevent oxidation of thin films.

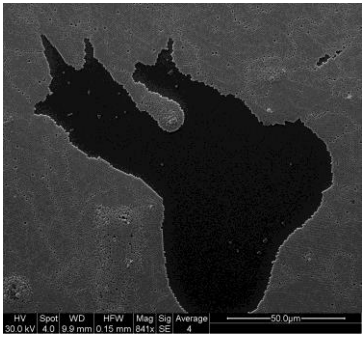
Magnetic hysteresis loop of the sample was measured by Magneto-optical Kerr Effect (MOKE) system in longitudinal geometry, within H-field up to 1300 Oe. Scanning electron microscopy (SEM) was used to study the self-assembly of the nanospheres and to survey the potential areas where good measurements is possible.

Results and Discussion

Formation of 2D ordered colloidal array of nanospheres. Chemically treating the 1x1 cm^2 silicon substrate with piranha solution is known to remove any organic debris and hydroxylate its surface; in doing so, the deposition of the nanosphere solution droplet spreads out evenly. Having the nanosphere solution evaporate on a tilted surface is important to the uniformity of the nanospheres; having it tilted forces the solution to monotonically evaporate from the top down. Thereupon by the capillary force, the nanospheres will form a well-ordered monolayer region on the wafer. Qualitatively, the deposited 880 nm nanospheres are mostly informed with a vibrate gleam, which our group calls a “good spot”; the area that are milky or patchy in appearance are “bad spots”, as shown in Figure 1(a).



(a)



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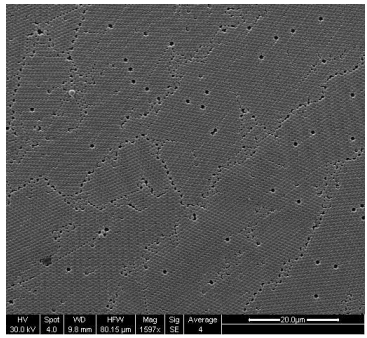
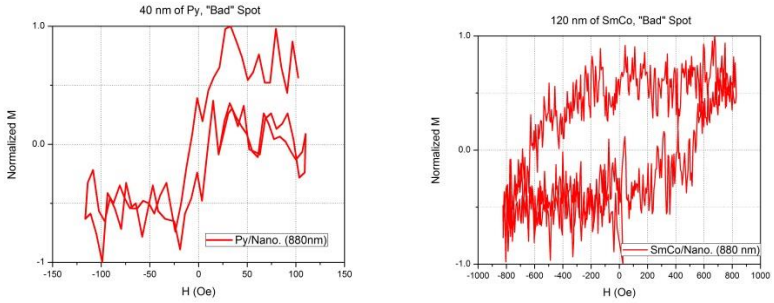


(c)

Figure 1: (a) Photograph of two different substrates ready for sputtering: The top substrate was chemically treated with piranha solution and had nanospheres (880 nm) deposited; the bottom has the chemically cleaned and acts as the control. (b) and (c) are SEM images, taken by Russell Gleason, of the nanospheres of different location, depicting the "bad" and "good" spots, respectfully.

1(b) is an example of a "bad" spot from a nanoscopic scale where the exposed Silicon and excessive layers of nanospheres would skew the MOKE's measurements whereas 1(c), the "good" spot, shows very little imperfections. To assure that we fabricate more "good" spots, we used a 50% concentration of the 880 nm nanosphere with nanopure water in a 20 µL drop consistently which resulted in the most ordered array.

MOKE measurement. The extra degree of freedom from the topography of the nanosphere has influenced the magnetic switching of the thin films. Note that the hysteresis loop in Figures 2, 3 and 4 have been normalized and range of the applied H-field have been truncated after the sample has been fully saturated. However, when taking the measurements on the MOKE system, it is preferable to take readings from the "good" spots; if taken from the "bad" spot, the hysteresis loop will more likely be too noisy and deformed, as shown in Figs. 2 (a) and (b), to make a comparison with their planar counterpart.

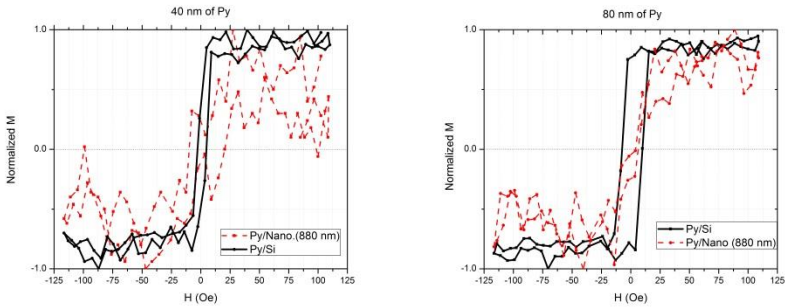


(a) (b)

Figure 2: Examples of MOKE measurements of thin films of Py and SmCo on "bad" spots.

As mentioned before, the "bad" spots exposed Silicon substrate and multilayer nanospheres could have caused the reflected laser to become more decoherent than what we would like to allow. Even if we allow the lowest angle of incident, the multilayer nanospheres could have caused enough decoherence to render the hysteresis loop noisy.

Figure 3 shows the hysteresis loops of the normalized magnetization of Py/Si and Py/Nano/Si (880 nm) as a function of the applied H-field. As the H-field approaches



(a) (b)

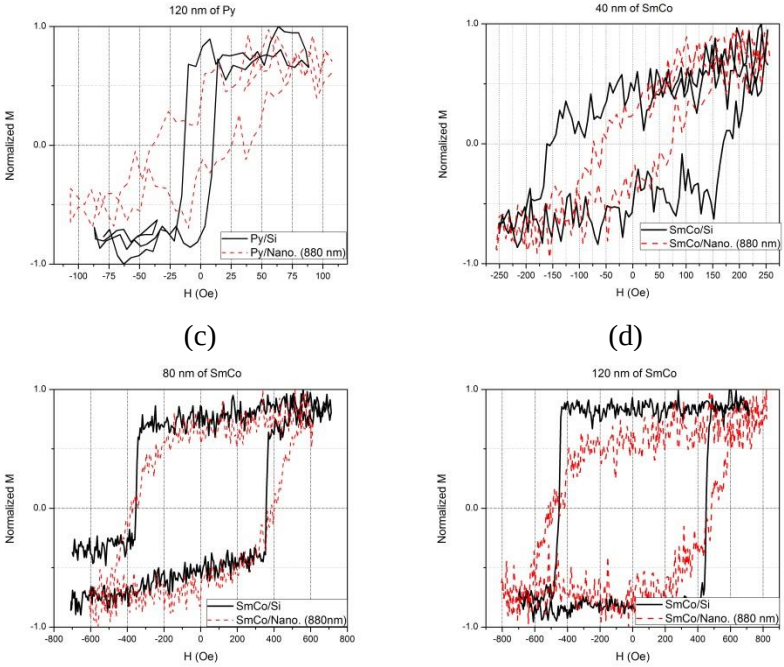


Figure 3: Magnetic hysteresis loops of different Py thickness (a, b, and c), as well as SmCo (d, e, and f), grown on 880nm nanospheres

20 Oe for Py/Si, we observed a well-defined shift in the magnetization for each thickness of Py. However, for Py/Nano (880 nm), its magnetic switching softens; this could be by the effect that the individual nanocaps shifts at different time independently of their neighbors. Another possible cause that may have produced these graphs is that the spot size of the laser is too large to measure the local difference in magnetization of the nanocaps, giving us an average measurement of the direct area. This seems to be a common trend as we increase the thickness of the thin-film on the nanosphere, until the limit where the thin film is indistinguishable compared to those grown directly onto the Silicon wafer, and with SmCo. However, for the thinner thin film, an error can occur due to the laser ability to penetrate through and read into the nanospheres;

according to the modified wave equation for the electric and magnetic field in a conductor,

$$\nabla^2\mathbf{E} = \mu\varepsilon\frac{\partial^2\mathbf{E}}{\partial t^2} + \mu\sigma\frac{\partial\mathbf{E}}{\partial t}, \qquad \nabla^2\mathbf{B} = \mu\varepsilon\frac{\partial^2\mathbf{B}}{\partial t^2} + \mu\sigma\frac{\partial\mathbf{B}}{\partial t} \qquad (1)$$

their solution are given as,

$$\tilde{\mathbf{E}}(\mathbf{z},\mathbf{t}) = \tilde{\mathbf{E}}_\mathbf{0}e^{-\kappa z}e^{i(kz-\omega t)}, \quad \tilde{\mathbf{B}}(\mathbf{z},\mathbf{t}) = \tilde{\mathbf{B}}_\mathbf{0}e^{-\kappa z}e^{i(kz-\omega t)} \qquad (2)$$

where μ and ε are the permeability and permittivity of the material, respectfully, σ is the conductivity of the medium, and κ results in an attenuation of the wave. The distance it takes to reduce the amplitude by a factor of 1/e is called the skin depth:

$$d \equiv \frac{1}{\kappa} \; where \; \kappa \equiv \omega\sqrt{\frac{\varepsilon\mu}{2}}\left[\sqrt{1+\left(\frac{\sigma}{\varepsilon\omega}\right)^2}-1\right]^{1/2} \qquad (3)$$

where it measure how far the wave penetrates into the conductor. Since both Py and SmCo are good conductor ($\sigma \gg \omega\varepsilon$), the laser's penetration may have penetrated through the thin films especially around the areas where the thin films may taper off. This could strengthen the notion of that the some of the MOKE's signals were from the nanospheres rather than the thin films themselves, thus the discrepancy between the 40 nm thin film and the thicker ones. Though we were unable to find any paper suggesting this, it is worth mentioning as a possible source of errors.

To improve the localized measurements and improve the signal loss due to scattering, two converging lens were implemented: one in the path of incident and another in the path of reflection. To do so, the converging lens in the path of incident needs to be placed such that the spot size decreases, qualitatively, while the second lens capture the reflected laser and focuses it into the photo detecter, improving the hysteresis loop's curve. Figure 4 provides a comparison of the hysteresis loop of the 120

nm Py on 880 nm nanospheres with and without lens. The lens has made a vast improvement of the curve, and depicts an expansion of Py's coercivity, hence providing a plausible correlation between the magnetic property of the thin film with topological surface where it is grown on.

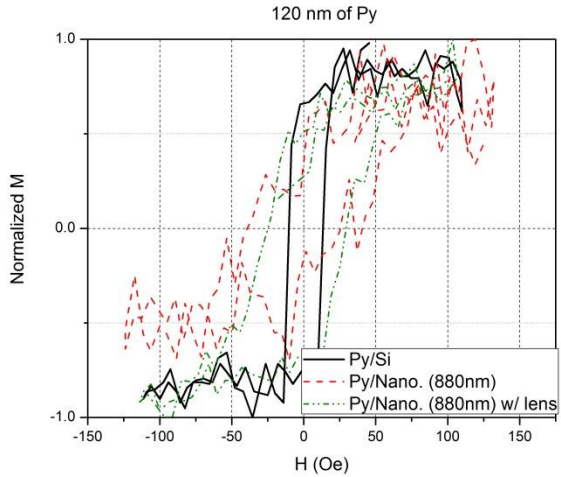


Figure 4: Magnetic hysteresis loops of thin films grown on nanospheres and directly onto the Si substrate of the same thickness. A third hysteresis loop was measured of the thin films on nanospheres with two converging lens.

Further studies are required to assure ourselves of the correlation of the magnetic switching of the thin film with it topological shape it takes on the nanospheres. This would include: the usage of variable sizes of nanosphere; optimizing the local measurement of thin films on nanospheres by the continual use of variable lens to decrease the spot size of the laser; and varying the size of the Silicon substrate.

Conclusion

In this study, magnetic monolayer systems were fabricated from several magnetic materials deposited on uniformly self-assembled 880 nm nanospheres. In doing so, the 8 magnetic behaviors of topologically

modified magnetic thin films grown on the self-assembled nanospheres are investigated using Magneto-optical Kerr Effect measurement. Further experimentation with refinement of methods and multilayer systems are underway.

Acknowledgement

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