

**PRISM COUPLING AND OPTICAL COATINGS FOR ENHANCED SIGNALS OF
NANOMAGNETS**

Research Paper
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Submitted by: Lindsay Holiday
Faculty Advisor: Professor Ursula Gibson

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Prism Coupling and Optical Coatings for Enhanced Signals of Nanomagnets

ABSTRACT

Studying the magnetic behavior of nanomagnets has the potential to assist new developments in new sophisticated technologies particularly as magnetic information storage. Our objective was to enhance our signal contrast of these very small nanostructures. We sought to optimize our signal:noise ratio critical by exploring two methods individually and collectively: 1) with an application of a dielectric coating and 2) the use of a prism. E-beam lithography and evaporation was used to create the nickel dot and ring structures. We studied individual dots with MOKE (Magnetic-Optic Kerr Effect), a non-contact technique for measuring. A thin layer of a dielectric coating, zinc sulfide (ZnS), was evaporated on to the sample and a quartz prism was placed on the sample which collectively enhanced our MOKE signal by 10.9 times for the 5 micron dot, 13 times for a 2 micron dot and 19.5 times for a 400 nm dot. We found that there was an enhancement by a factor of 5 for planar structures, and an enhancement by greater than 10 for dot structures less than the diameter of the probe beam (10 microns), can be achieved with properly chosen dielectric coatings. For structures that are difficult to measure, where signal averaging cannot be exercised, these two methods of enhancement will permit improved detection capabilities.

INTRODUCTION

We studied two theoretical methods of enhancing the MOKE signal contrast of nickel nanomagnets by applying a dielectric coating and using a prism. By enhancing the signal contrast, we aspired to learn more about the magnetic behavior of nanomagnets because this information can potentially assist with the development of new innovative technologies particularly within the realm of magnetic information storage.

MOKE, Magneto-Optic Kerr Effect, was used instead of MFM to study nanostructures. In general, magneto-optics is the study of how light is affected by a magnetic field. A magneto optic effect occurs when light is either transmitted through (called the faraday effect) or reflected from (called the kerr effect) a magnetized material. Magneto-optic kerr effects happened when there is a small change in the polarization or intensity of light when reflected from a material in a magnetic field. For years, MOKE has been used as a tool for defining the magnetic properties of materials. In turn, we conducted experiments on the magneto-optic effects that involved polarization analysis of light reflected from magnetic materials.

In general, when linearly polarized light is reflected from a magnetized surface, a Kerr component is composed of the Kerr component and the usual Fresnel component. The polarization of the Kerr component is orthogonal to the Fresnel component. These two components can often be out of phase with one another, which produces elliptically polarized light. However, a quarter wave plate can be used to linearly polarize the light. After the light is linearly polarized, a new E-field is generated when adding the Kerr component to the Fresnel component.

A multilayer matrix method based on Abdulhalim's formulation[1, 2] was implemented in MATLAB[®] by Ursula Gibson to determine the Kerr effect response. The values determined by this program were then used to create a model to predict the measured contrast for a thin film. We gathered information from the signal contrast, $\Delta I/I_{\text{avg}}$, where ΔI is the modulation intensity induced by magnetic field reversal and I_{avg} is the DC magnitude of the signal. This method follows the analysis set forth by Allwood *et al* [3]. Single layer coatings were deposited on Ni to enhance the Kerr contrast.

Studying nanomagnets has the potential to help us accurately detect magnetic behavior which is important to develop new sophisticated technologies.

METHODS

Experimental

First, an entire silicon sample was evaporated with a thin layer of nickel. MOKE measurements were gathered of the bare nickel film and then of the nickel with a prism where the beam entered at a 90 degree angle to the prism and 45 degrees to the sample. These measurements confirmed the Professor Ursula Gibson's enhancement theories. We proceeded to create a nanodot structure (see Figures 1 and 2) using Design CAD LT 2000 software. The two structures were written to an individual sample.

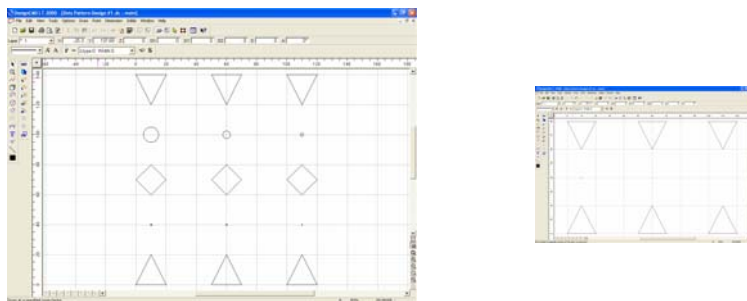


Figure 1 and 2: The triangles and diamonds in design served as markers for the location of the dots. The left structure had 10 μm , 5 μm and 2 μm on the top and 1 μm , 800 μm and 600 μm dots on the bottom. The right structure consisted of 100 nm, 200 nm, and 400 nm dots.

Meanwhile, two new silicon substrates (the second being a replica) was prepared for the e-beam lithography. PMMA was spin-coated on the sample, and then the design information was uploaded in the SEM lab for e-beam lithography (see Figure 3).

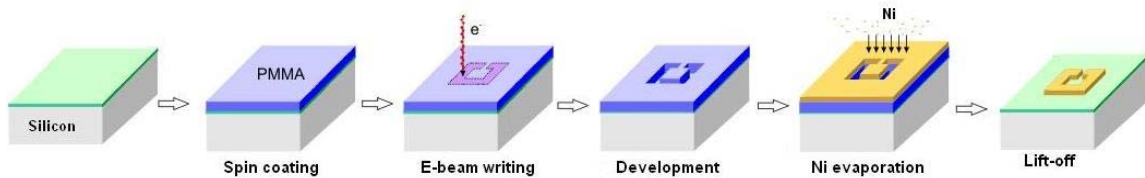


Figure 3: Preparation and process for e-beam lithography and creating dot structure.

The solution, MIBK/IPA, was used to develop the nickel then rinsed with isopropanol. The structure could be seen under a light microscope so we proceeded to deposit our target thickness of 420 angstroms of nickel onto the two substrates using the e-beam evaporator. However, after liftoff we used an alpha step device to measure the actual thickness which was about 65 angstroms which prevented us from effectively measuring its signal with MOKE.

The procedure was repeated and a new structure was created that consisted of a variety of rings. A symmetric pattern of 2 μm , 0.5 μm and 1.25 μm and an asymmetric pattern (inner hole was created offset) of 1.25 μm , 0.5 μm and a polygon 1 μm was created. The two dot patterns and two copies of the ring patterns were e-beam written two substrates (replicates) and e-beam evaporation was used to create the nickel dot and ring structures on a silicon substrate with a target thickness of 20 nm—the actual thickness was 21 nm. Only the dot patterns were measured because the ring patterns were not written well and therefore were not useful.

A quartz prism was hypothesized to increase the MOKE signal. In turn, a quartz prism was placed in the laser beams path before it reached the sample at 45 degrees

which resulted in an enhanced MOKE signal in the dot structure. Then, a thin layer of a dielectric coating, ZnS, with a target thickness of 57 nm was deposited on the sample in an attempt to enhance our signal by reducing laser light reflection from the sample. The combination of prism use and dielectric coating to the nickel film was performed and MOKE measurements were taken.

MOKE Model

A matrix method, was used to model the optical response of the dielectric sample of interest, based on the approach of Abdulhalim[2, 3], assuming there was plane wave propagation. A model was created in MATLAB by Professor Ursula Gibson which allowed us to calculate the kerr contrast, which is the height of the kerr loop divided by the total intensity, as described by Allwood et al [1]. Graphs were created using a scatter plot of kerr contrast ($dI/\Delta I$) versus angle analyzer (degrees). The NanoMOKE II[®] magnetometer provided two values called the dI , the change in signal intensity and the applied magnetic fields, and ΔI , the average intensity [D.A. Allwood (2003)]. These two values were deemed useful by Allwood by mathematical derivation. The angle analyzer began at its null value where the change in degrees equaled zero denoted as ∂ , theta. Small changes in the angle analyzer allowed us to map the changes of the kerr contrast; the scatter plot graphs revealed information about its signal behavior. In some cases, usually for larger dots, the maximum kerr contrast value occurred at very small angles, less than 1 degree. It was sufficient to assume that $\Delta I \sim \partial^2$ for angles less than 1 degree and use a correction scheme to find the theta value for these points. A constant denoted, I_0 was used to find ∂ which is found by rearranging the proportion.

Steps to find $\Delta\partial$:

$$I_0 = I(1 \text{ degree}) - I(\text{null})$$

$$I(1 \text{ degree}) = I_0 \partial^2$$

$$I(1 \text{ degree}) / I_0 = \partial^2$$

$$\sqrt{I(1 \text{ degree}) / I_0} = \partial$$

$$\Delta\partial = \sqrt{((\Delta I(\partial) - I(\text{null})) / I_0)}$$

Otherwise, changes in angles higher than 1 degree were calculated for each individual point.

RESULTS

After creating nickel dot and ring structures, we used the MOKE micrometer to measure the kerr contrast at each angle. The resulting graphs show the amount of percentages of kerr contrast signal.

Tables 1 is a modeled response for the nickel film. Table 2 shows the actual MOKE measurements of bare nickel, nickel with a prism, nickel coated with ZnS and nickel coated with ZnS and with a prism. The values closely correlate except nickel coated with ZnS and the combination enhancement.

Table 1.

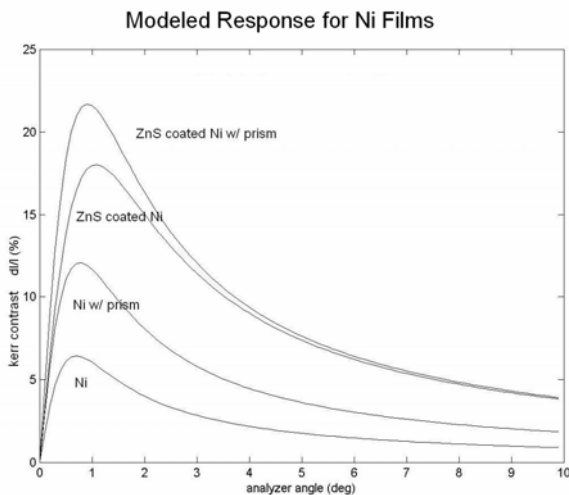


Table 2.

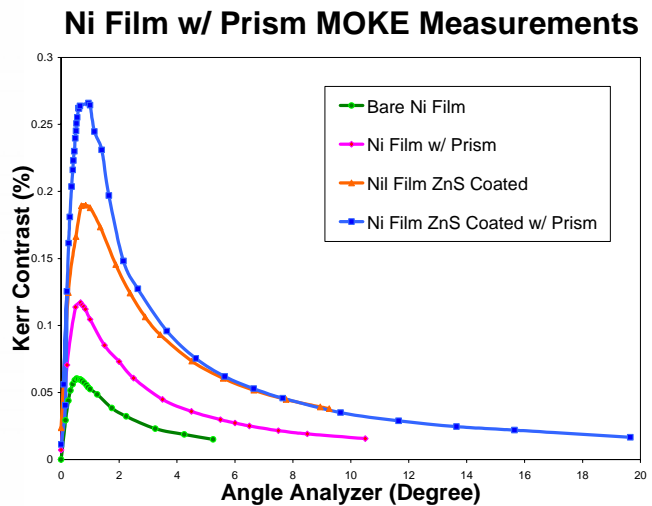


Table 3.

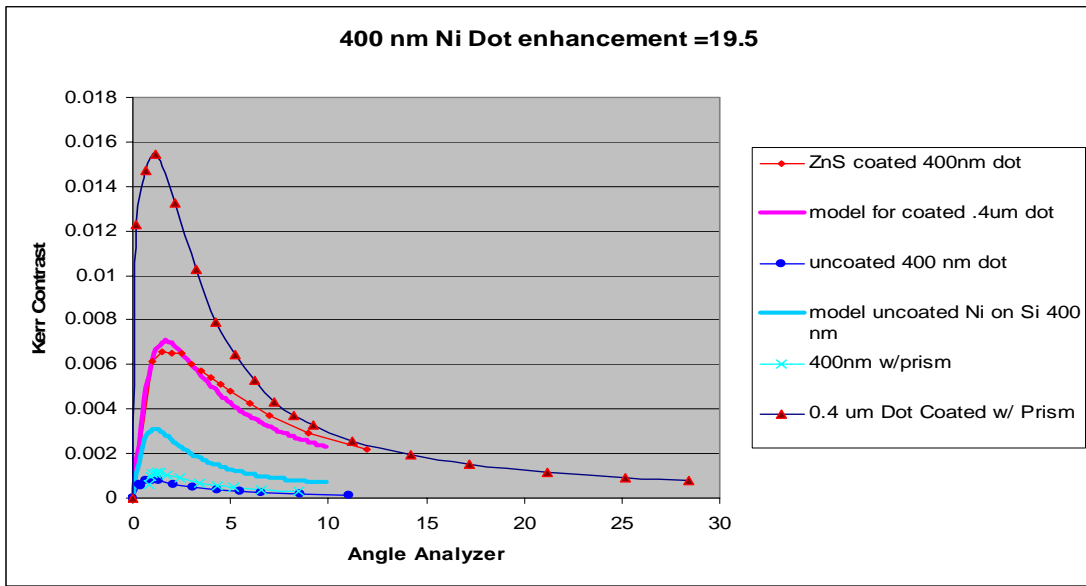


Table 4.

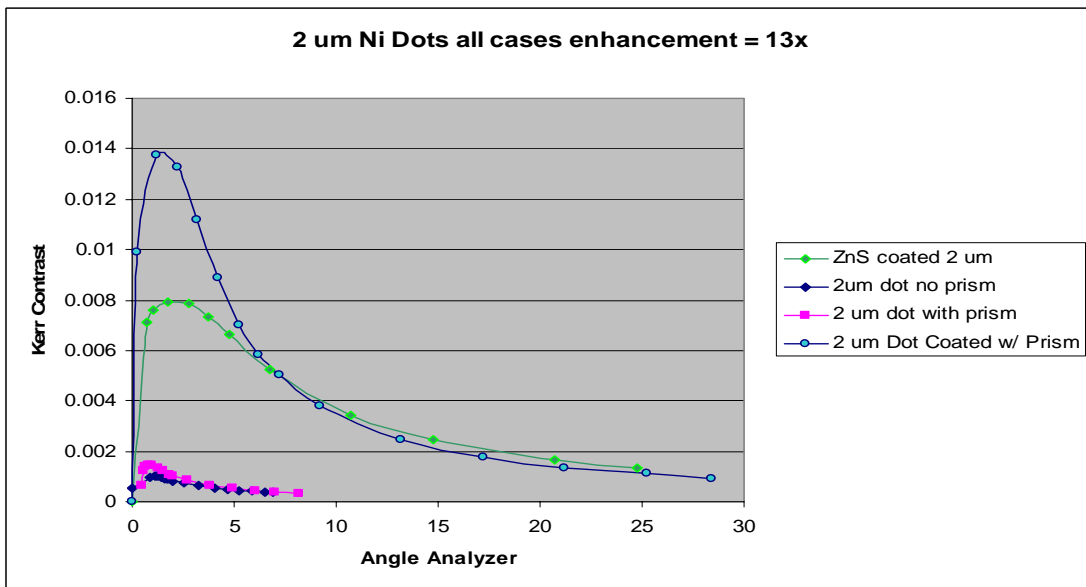
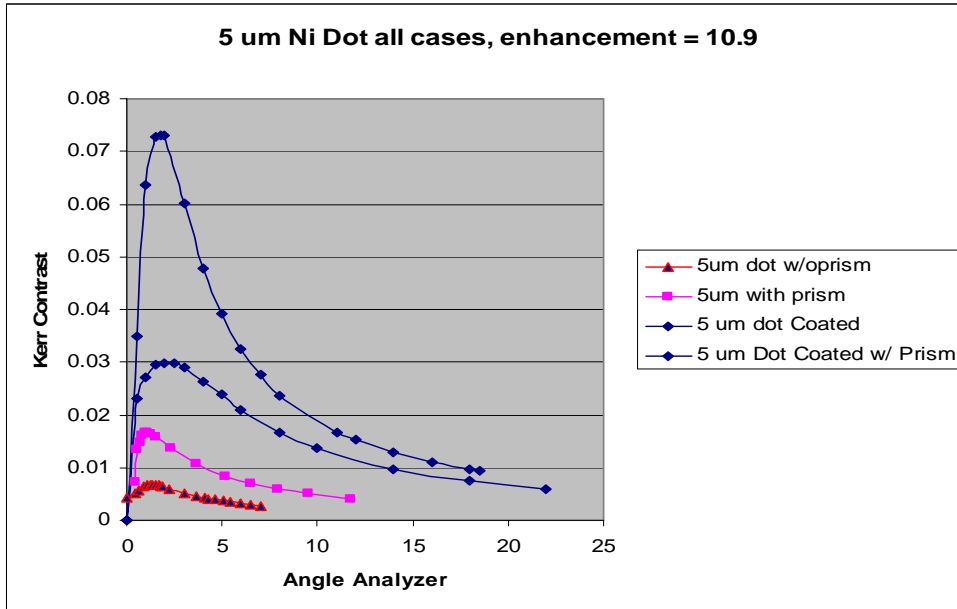


Table 5.



Tables 3, 4 and 5 show the graphs of three different sized dots. We studied individual dots with a MOKE (Magneto-Optic Kerr Effect) magnetometer in four different states, bare nickel, nickel with prism, nickel with ZnS coating and coated ZnS with a prism. A thin layer of a dielectric coating, zinc sulfide (ZnS), was evaporated on to the sample and a quartz prism was placed on the sample which collectively enhanced our MOKE signal by 10.9 times for the 5 micron dot, 13 times for a 2 micron dot and 19.5 times for a 400 nm dot.

DISCUSSION

For Tables 1 and 2, the experimental results for bare nickel and nickel with a prism followed the theorized modeled response for nickel films. However, the experimental values for the nickel with ZnS, and nickel coated with ZnS and with a prism yielded unexpectedly higher values. This is most likely due to a parameter in the model that accounts for imperfections in the optical system. This is due to scattering and the

range of incident angles (because of the focusing lens). This parameter was used to fit the data for the bare nickel film. When we use a prism, or overcoat with the ZnS, we reduce these effects, but in a way that is difficult to quantify, so we don't adjust the parameter.

Studying the magnetic behavior of nanomagnets has the potential to assist new developments in new sophisticated technologies particularly as magnetic information storage. Our objective was to enhance our signal contrast of these very small nanostructures. We sought to optimize our signal:noise ratio critical by exploring two methods individually and collectively: 1) with an application of a dielectric coating and 2) the use of a prism. We found that there was an enhancement by a factor of 5 for planar structures, and an enhancement by greater than 10 for dot structures less than the diameter of the probe beam (10 microns), can be achieved with properly chosen dielectric coatings. For structures that are difficult to measure, where signal averaging cannot be exercised, these two methods of enhancement will permit improved detection capabilities.

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