Characterization of Magnetic Thin Films for Actuating Origami Devices

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CNF Project: 2018 Cornell NanoScale Science and Technology Facility Research Experience for Undergraduates Program

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Primary Source of CNF REU Funding: National Science Foundation via the National Nanotechnology Coordinated Infrastructure (NNCI) Grant No. ECCS-1542081

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Primary CNF Tools Used: Even-odd hour electron-beam evaporator, FlexUs film stress measurement system, P7 profilometer, ABM contact aligner, Class II resist room

Abstract:

Fabrication inspired by origami offers a novel method for the development of micron-scale machines, which have a wide range of potential applications. The use of magnetic thin films in tandem with ultra-thin atomic layer deposition (ALD) films allows for the creation of actuatable devices that can be controlled with external magnetic torques. We characterized cobalt, nickel, and iron films to compare their viability for these devices. We deposited our films via electron-beam evaporation at thicknesses of 25 nm and 50 nm and deposition rates of 0.3 Å/s and 0.6 Å/s, on top of a 10 nm thick titanium adhesion layer. We performed stress measurements of each film pre-and post-deposition, as well as thickness verification. We obtained the hysteresis curve of each film by using a vibrating sample magnetometer (VSM). We see that Fe and Co have significantly higher magnetizations than Ni, whereas Ni benefits from having the lowest stress. We also showed that the addition of a low stress polymer (SU-8) spun on top of the magnetic films may help to reduce the stress in the composite film. We discuss the implications of these results for our origami-inspired devices.

Summary of Research:

The goal of this work was to determine the viability of different magnetic materials for the fabrication of actuatable micron-scale devices. These devices, composed of a flexible ALD backbone and rigid magnetic panels, can be controlled with external magnetic torques to create three dimensional structures from planar Si-based processing (Figure 1). We measured the stress experienced in the magnetic films, as it imparts curvature on the underlying ultrathin ALD films and alters their bending energies. We also studied the magnetic properties of the magnetic films. These include the magnetization saturation, which relates to the magnitude of the magnetic torques we can apply, and the coercive field, which is the field required to orient the magnetic moment of the film along a given axis.

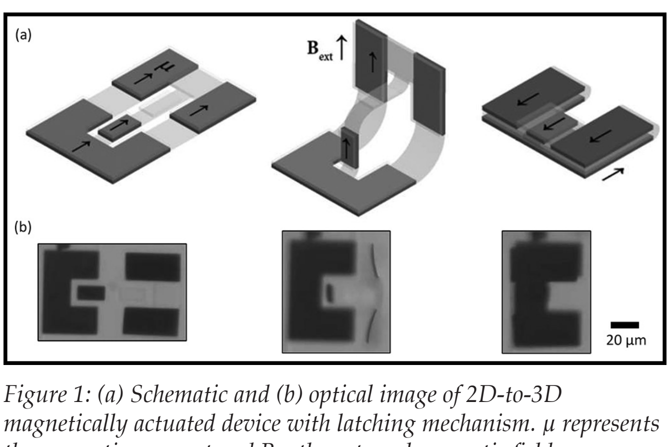

Figure 1: (a) Schematic and (b) optical image of 2D-to-3D magnetically actuated device with latching mechanism. µ represents the magnetic moment and B_{ext} the external magnetic field.

We characterized three magnetic materials: cobalt, nickel, and iron. The materials were deposited via electron-beam evaporation. A 10 nm thick titanium layer was deposited prior to any magnetic films to promote adhesion to the wafer. Each material was deposited at 25 nm and 50 nm with deposition rates of 0.3 Å/s. Additionally, we deposited 50 nm of Co at a deposition rate of 0.6 Å/s to determine the effect on the stress. Once the films were deposited, the thickness was verified using a profilometer.

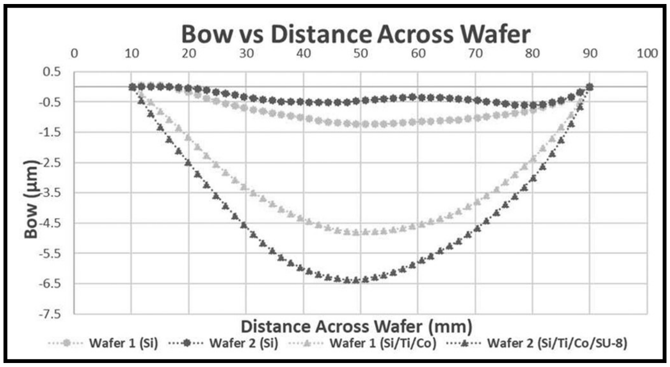

Figure 2: Bow of two wafers before and after deposition to compare the change in stress with the addition of SU-8 photoresist.

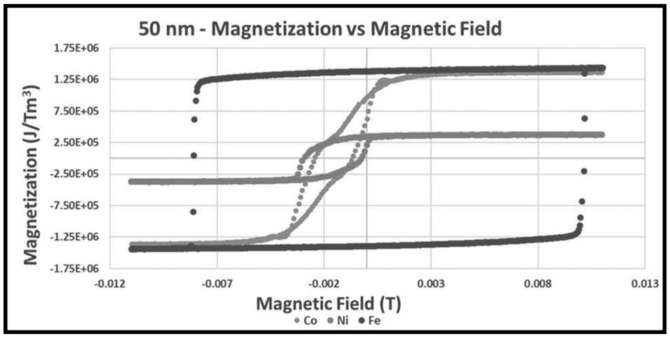

Figure 3: Magnetic hysteresis curves of 50 nm thick Co, Fe, and Ni.

Stress measurements were taken with the FlexUs film stress measurement tool. This tool measures the bow of the wafer before and after deposition. Then it relates the change in the bow with the properties of the deposited material to determine the stress in the film. To see the influence a low stress polymer has on the overall stress in a film, 70 nm of Co was deposited on two wafers in parallel, followed by spinning 1 μm of SU-8 photoresist on one wafer (Figure 2).

Samples from each thickness of each material were put through a VSM to determine their saturated magnetizations and coercivities. The data produced by the tool provides the magnetic moment as a function of the magnetic field. We normalized the magnetic moments by the volumes of the respective films to determine their magnetizations.

Results and Conclusions:

We found that Fe films have the largest amount of stress, with both the 25 nm and 50 nm thick samples having an average stress of 820 +/-14.9 MPa. The Co films had an average stress of 400 +/-19.9 MPa, and the Ni films had an average stress of 170 +/-12.0 MPa. In the case of Co, increasing the deposition rate from 0.3 Å/s to 0.6 Å/s didn't impact the stress in the film. Moreover, the addition of the SU-8 on top of the Co film did reduce the stress in the total film by approximately 90%.

The VSM data showed that Fe has the largest coercive field and magnetization saturation, while Co has the lowest coercive field and Ni has the lowest magnetization saturation (Figure 3).

The 25 nm and 50 nm samples showed similar magnetization saturations, but the coercive fields tended to increase with increasing thickness. However, we didn't expect to see Ni having a larger coercive field than Co, since Ni is considered a softer magnetic material. We think this could be due to possibly depositing oxide during our Co deposition, instead of pure Co.

We've shown that Co and Fe films have much greater stresses than Ni films, which makes them more of a risk to use as they're more likely to impact the stiffness of the ALD films in our devices. Ni films are much weaker magnets than Co and Fe films; therefore, we wouldn't be able to apply as strong of magnetic torques. To balance these factors, we can use SU-8 to reduce the stress in Co and Fe, resulting in films with both low stress and high magnetization that maximize device performance. The next steps for this project are to investigate more magnetic materials, such as magnetic alloys, and different methods of deposition.

Acknowledgements:

Thank you to Professor Paul McEuen for taking me on as an intern for this program, and Tanner Pearson for the excellent mentorship throughout the summer. This work was was performed in part at the Cornell NanoScale Science & Technology Facility (CNF) and funded by the National Science Foundation via the National Nanotechnology Coordinated Infrastructure (NNCI) Grant No. ECCS-1542081.