Microfabrication and Dynamic Testing of Electromagnetic Microactuators for Endomicroscopy

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Abstract and Introduction:

Current endoscopic imaging, while sufficient for detecting gastrointestinal polyps, is unable to see below the tissue surface where cancer can begin [1]. Unlike conventional white light endoscopy, which is limited to horizontal (XY) planar imaging, more advanced endoscopy tools such as dual-axes confocal endomicroscopes can perform rapid optical sectioning and permit vertical (XZ) cross-sectional images of the tissue by using z-displacement scanning microactuators. Consequently, how far these endomicroscopes can see into the tissue is limited by how much z-displacement actuation can be achieved in small diameter (3-5 mm) endoscopes [2].

In this work, we successfully fabricated electromagnetic z-displacement microactuators using semiconductor micro-fabrication techniques and by characterizing the electroplating parameters of permalloy (20% iron, 80% nickel), a material that exhibits strong magnetic properties. A laser Doppler vibrometer (LDV) was used to determine the microactuator's z-displacement at different resonant frequencies.

Second generation microactuators were then designed and fabricated with the objective to exhibit greater z-displacement by using silicon dioxide (SiO_2) as the material for the bending beams in the microactuators. The testing results of the first generation devices demonstrate that electromagnetic microactuators could prove an attractive alternative to current piezoelectric, electrostatic, and thermal microactuators, which are complicated to assemble due to electrical connection requirements.

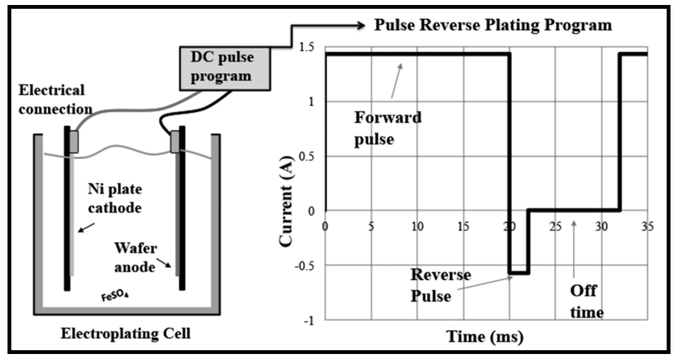

Figure 1: Electroplating set-up and program.

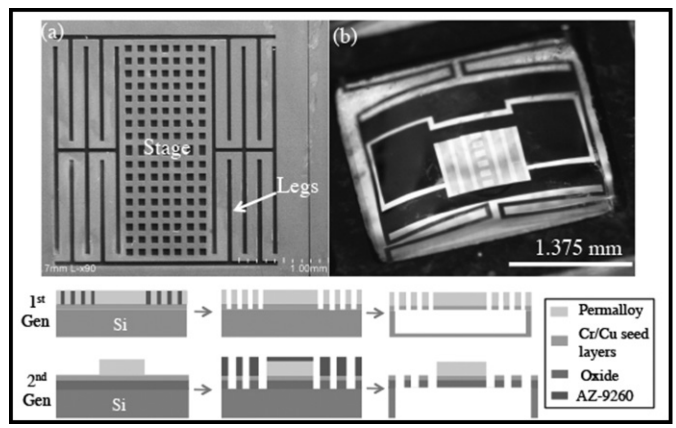

Figure 2: (a) SEM image of device. (b) Fully released 2nd generation device, process flows (below).

Fabrication Process:

First Generation: Seed layers—50Å of chrome (Cr) and 500Å of copper (Cu), respectively—were deposited onto a silicon (Si) wafer using electron beam evaporation. AZ-9260 photoresist was then spin-coated and patterned onto the wafer, and then inserted into a nickel-iron electroplating bath.

Our main goal was to electroplate a thin film (8-10 μm) permalloy with low residual stress since any deformation in the actuators will interfere with its performance. After characterization, we employed a pulse-reverse plating program with an anodic (forward) current density of 20 mA/cm^2 for 20 milliseconds (ms), a cathodic (reverse) current density of -8 mA/cm^2 for 2 ms, and an off time of 10 ms (see Figure 1) [3]. After 120 minutes of electroplating, 8 μm of low residual stress permalloy was deposited onto the actuators. Energy dispersive x-ray spectroscopy analysis revealed the permalloy was 88.25% nickel, 11.75% iron, and magnetic. After etching the seed layers, the wafer was processed with xenon difluoride to isotropically etch the Si and release the devices (Figure 2a).

Second Generation: To fabricate actuators with only SiO_2 as the legs, three masks were designed in AutoCAD to allow for backside etching and selective electroplating. Similar to the first generation devices, 50Å of Cr and 500Å of Cu seed layers, respectively, were deposited onto a 2 μm SiO_2-coated wafer via electron-beam evaporation. AZ-9260 photoresist was then spin-coated and patterned onto the wafer which was placed into the electroplating bath.

Due to a small conductive area—less than 20% total wafer area—copper sulfate initially formed instead of permalloy because of the low applied forward current (0.21A). We discovered that increasing the plating program's forward current, which is typically determined by multiplying the current density by the conductive plating area, yielded magnetic permalloy. After increasing the forward current such that the effective area was more than 80% of the total wafer area, we were able to electroplate 6.95 μm of magnetic permalloy after 20 minutes. AZ-9260 photoresist was spin-coated and patterned using the second mask; this layer also protected the permalloy structures during etching. Next, the seed layers were etched, and the oxide layer on the front side of the wafer was patterned using reactive ion etching. Finally, backside lithography, reactive ion etching, and deep reactive ion etching were completed to fully release the microactuators (see Figure 2b).

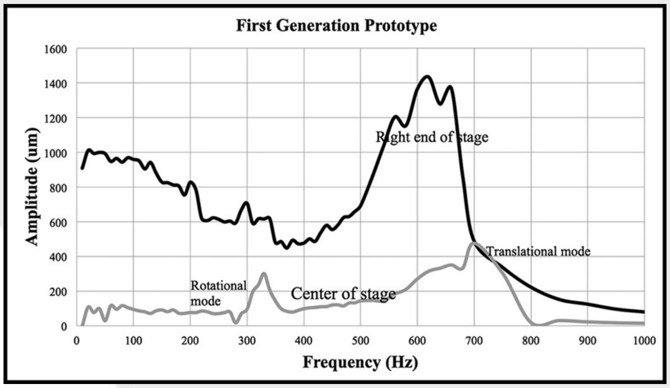

Figure 3: Results.

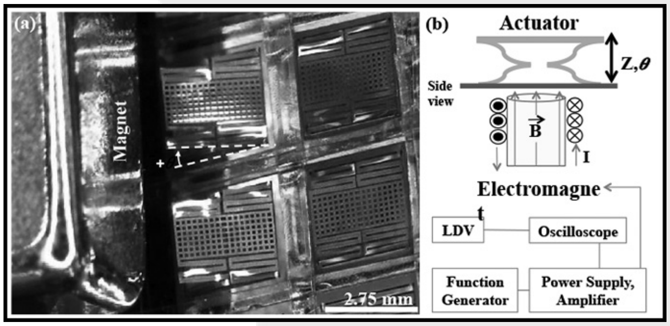

Figure 4: (a) First generation prototype tilting. (b) Testing set-up.

Dynamic Testing Results:

A custom made electromagnet—ferrite core wrapped with magnet wire—was placed under an actuator normal to the magnetic field generated by running current through the coil. 16 V AC peak-to-peak with 8 V offset was applied to the electromagnet such that the microactuators would generate only positive z-displacement. The effective magnetic field measured was 270 Gauss. LDV was used to measure z-displacements achieved during the frequency sweeps and to locate resonant frequencies. For testing, the LDV was focused on two parts of the actuator: the stage center and the right end of the stage. A MATLAB code was written to process the data as seen in Figure 3 (center of stage curve). Two resonant peaks at approximately 340 Hz (300 μm) and 680 Hz (476 μm) were observed. Figure 4 shows a microactuator responding to a high magnetic field gradient.

Conclusion and Future Work:

We determined a pulse reverse plating program that yielded thin film permalloy and discovered that the forward pulse has the most influence on plating. First generation prototype testing results indicate that large (more than 200 μm) z-displacement was achieved at resonant frequencies. Although the current electromagnet is too large to be placed in an endoscope, this work demonstrates the exciting potential of electromagnetic actuators in endomicroscopy due to its wireless assembly.

Future testing of second generation devices, further characterization of permalloy electroplating, and improved design of future microactuators must be done to implement electromagnetic actuators in a prototype endomicroscope.

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Acknowledgements:

I owe many thanks to my mentor Jongsoo Choi, my PI Professor Oldham for his guidance, the Oldham lab group, the Lurie Nanofabrication staff, and Brandon Lucas for all of their help. I also thank the NNIN REU Program and the National Science Foundation for this great opportunity and funding.

References:

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