Design and Fabrication of a Magnetic Elastomer-Dased Soft Actuator

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Abstract:

Technological advancements to date have primarily focused on stimulating only two of the five human senses: sight and hearing. Touch-based interactive technologies are still in their infancy. Haptic devices allow tactile interactions between humans and digital interfaces, assisting humans in industries such as healthcare, automotive and entertainment. Magnetorheological elastomers (MREs) based on nanoparticles constitute a promising candidate material for creating tactile interfaces [1] capable of creating high-resolution features on the micron scale [2]. These magneto-responsive elastomers must be integrated with magnetic micro-controls to create the local magnetic fields necessary to actuate deformations.

Summary of Research:

The future of touch-based haptic interfaces relies on the actuation of microscale thin films. Magnetoresponsive soft-actuators have the potential to create low-power, high-responsivity, and low-cost haptic interfaces. A process was developed to create a system of micromagnetic controls integrated into microscale beams made of an MRE. This project is structured into three main objectives: the fabrication and characterization of magnetic microcontrols, the fabrication of a micrometer thin MRE, and the integration of actuation controls and MRE.

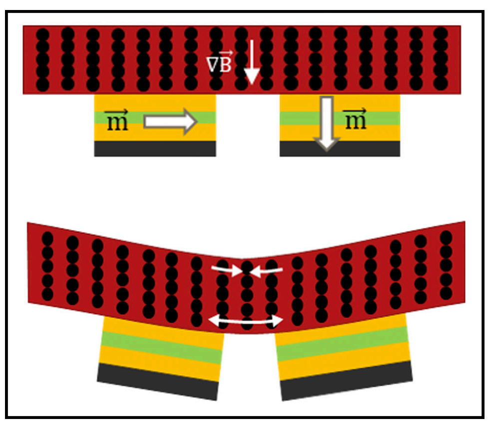

Figure 1: Device design of magnetorheological elastomer with two integrated magnetic micro controls.

The design concept involves two micromagnetic controls on the surface of an MRE thin film (see Figure 1). The MRE is constituted of a soft silicone rubber matrix and magnetic nanoparticles forming vertical chains in the thickness direction of the film. The micro controls are made of pillars with circular and elliptical base. The circular magnets (perpendicular magnetic anisotropy (PMA) magnets) are fabricated so that the magnetic moment lies preferentially in the direction perpendicular to their surface. The elliptical magnets (in-plane magnetic anisotropy (IMA) magnets) are deposited to be magnetized in the direction of the long axis. When the controls are embedded into the MRE, their magnetic fields will couple and interact with the elastomer in proximity of the gap between them, causing it to deflect.

The first step in the creation of this device is the fabrication of the magnets. Starting with a 4-inch clean wafer, 350 nm of LOR3A and 450 nm of S1805 (positive) resist were spin coated, following with a soft bake at 180°C for five minutes for the former and at 115°C for one minute for the latter. The coated wafer was then exposed in an ABM contact aligner for 1.5 seconds and developed for 60 seconds using 726 MIF solvent. The patterned wafer was then descummed with oxygen

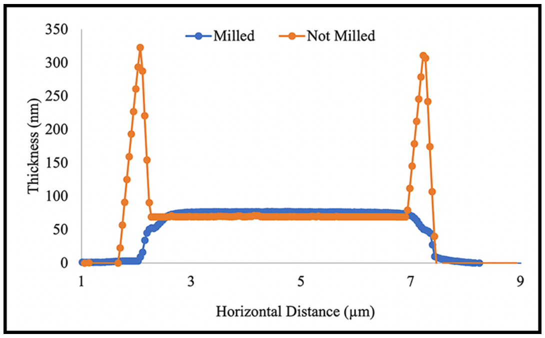

Figure 2: Ion milling to remove "rabbit ears" resulting from sputtering and lift-off.

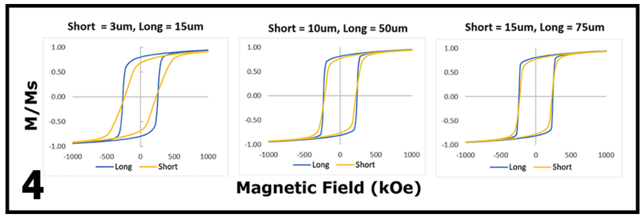

Figure 4: Magnetic hysteresis loops for short and long axis of IMA ellipses.

plasma for 60 seconds with oxygen flow of 30 sccm and 50 W of power. Then the magnets were deposited via sputtering.

The elliptical pillars were constituted of 3 nm of Ta, 5 nm of Pt, 58 nm of Co, and 5 nm of Pt. The circular pillars were sputtered with 19 alternating layers of Co (1 nm) and Pt (2 nm) and a final 1 nm layer of Co, using the same Ta/Pt underlayer and Pt capping layer as for the elliptical magnets. After sputtering, the wafer was soft baked at 115°C to facilitate the lift-off process, which was performed by first hitting the wafer with pressurized solvents at 1600 psi (C&D SmartProP9000), and submerging it in Remover 1165 for 20 minutes. Finally, an AJA milling tool was used at 600 V for 120 seconds with a 5° tilt to eliminate the "rabbit ears" caused by sputtering and lift-off (see Figure 2).

At this stage, the wafer was diced into 10 × 10 mm devices, each presenting specific geometry and dimensions. The magnetic properties of the deposited magnets were studied via vibrating sample magnetometry (VSM) and the optimal dimensions for both geometries were identified. The hysteresis loops obtained with VSM illustrate the magnetic properties of a magnetic sample, allowing to extract coercivity and remanent magnetization values. The circular pillars, with diameters ranging from 3 to 100 µm were tested for their magnetization in response to an out-of-plane applied magnetic field (see the hysteresis loops in Figure3).

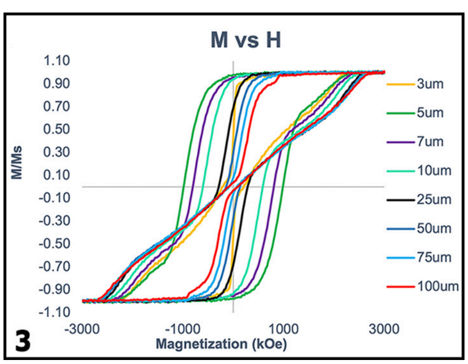

Figure 3: Magnetic hysteresis loops for PMA circles.

The elliptical samples with in-plane magnetization were measured along both the short and long axes, as shown in Figure 4. The optimal magnetic properties were found in the 5 µm diameter circular magnet (maximum remanent magnetization and coercivity) and the 3 µm (short axis), 15 µm (long axis) elliptical magnet (largest difference between hysteresis loop measured along the two axes). Atomic force microscopy (AFM) was used to confirm the dimensions of the deposited geometries.

Finally, a system of micromagnets (one IMA and PMA magnet spaced apart 1, 1.5, and 2 µm) was ultimately designed to be integrated into cantilevers and simply supported beams made of a micrometer-thin MREs to create a magnetic soft actuator. the elastomer was composed of 95 wt% Sylgard 527 and 5 wt% Sylgard 184. After mixing the two elastomers using a vortex for a few seconds, 6 vol% of Fe nanoparticles were added and mixed for about three minutes. The dispersion was homogenized for 1 hour and 15 minutes using an ultrasonicating bath. Finally, the mix was spin coated on a wafer at 7500 rpm for 60s to achieve a thickness of 2-2.5 µm.

Conclusions and Future Steps:

We demonstrated the fabrication process of micro-magnets and discussed their optimal dimensions to achieve desired magnetic properties. Magnetic simulations carried out in our lab guided the choice of a reasonable spacing between the IMA and PMA magnets when integrated into the soft actuator. Next, the developed controls will need to be embedded into cantilevers and beams with the actuation performance assessed. We believe these results serve as a foundation for the fabrication of soft magnetorheological elastomers with integrated magnetic controls.

References:

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[2] L. Cestarollo, et al. Nanoparticle-based magnetorheological elastomers with enhanced mechanical deflection for haptic displays, ACS Applied Materials and Interfaces 14 (2022),