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Solid-state Electromagnetic Drive

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Abstract

We built a solid-state electronic circuit that controls the flow of current to a series of electromagnetic coils. The electromagnetic coils substitute permanent magnets to apply a magnetic field to a magnetic shape memory alloy (MSMA) element, which undergoes physical deformation where the magnetic field is applied. These deformations manifest in the MSMA element as regions of shrinkage, which can be used to transport a small volume of liquid if the location of the shrinkage is moved.

We construct the circuit from discrete semiconductor devices on a solderless breadboard. An Arduino microcontroller provides control, and a 1500 W power supply provides power. We aim to integrate the control circuit, coils, and MSMA element into a single battery-operated package at a later date. We explored various system configurations with the circuit simulation software LTspice and the finite element magnetics simulation software FEMM. We achieved consistent control of the solid-state electronic circuit and generated considerable magnetic flux at the required locations on the MSMA element. Our circuit shows promise as a substitute for permanent magnets in the actuation of an MSMA element.

A solid-state drive for an MSM micropump

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I. Background/objective

We have developed a solid-state electromagnetic drive for BSU's breakthrough MSM micropump. Electromagnetic coils substitute permanent magnets to apply a magnetic field to a magnetic shape memory alloy (MSMA) element, resulting in a new crystallographic twin variant. These deformations manifest in the MSMA element as regions of shrinkage, which can be used to transport a small volume of liquid if the location of the shrinkage is moved.

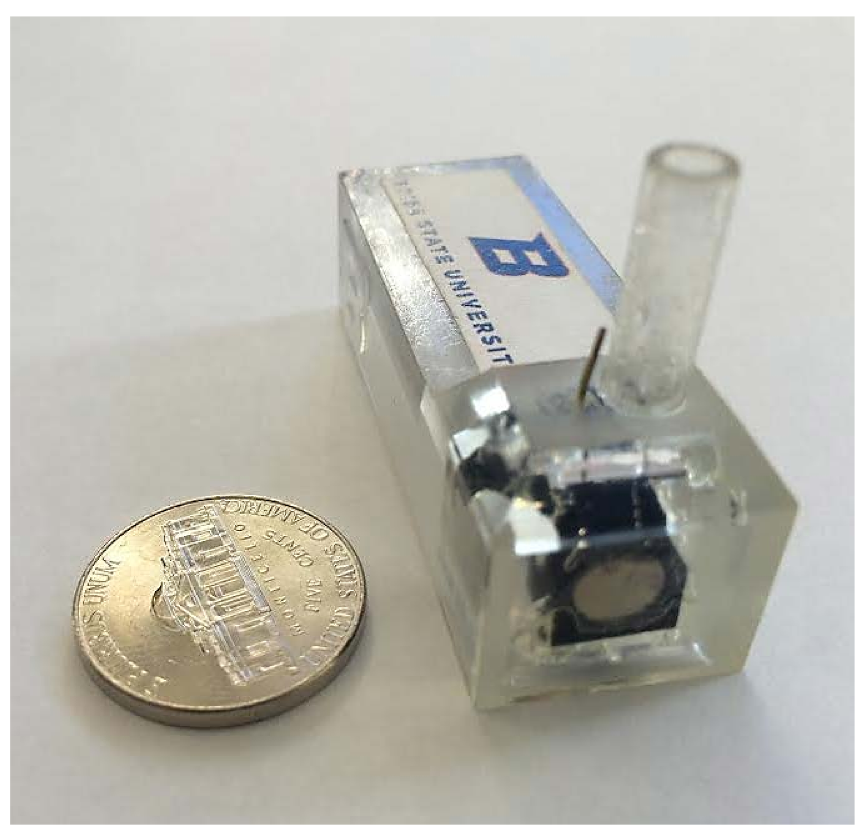

Fig. 1. BSU micropump used to inject ketamine to the subject rodent's hippocampus

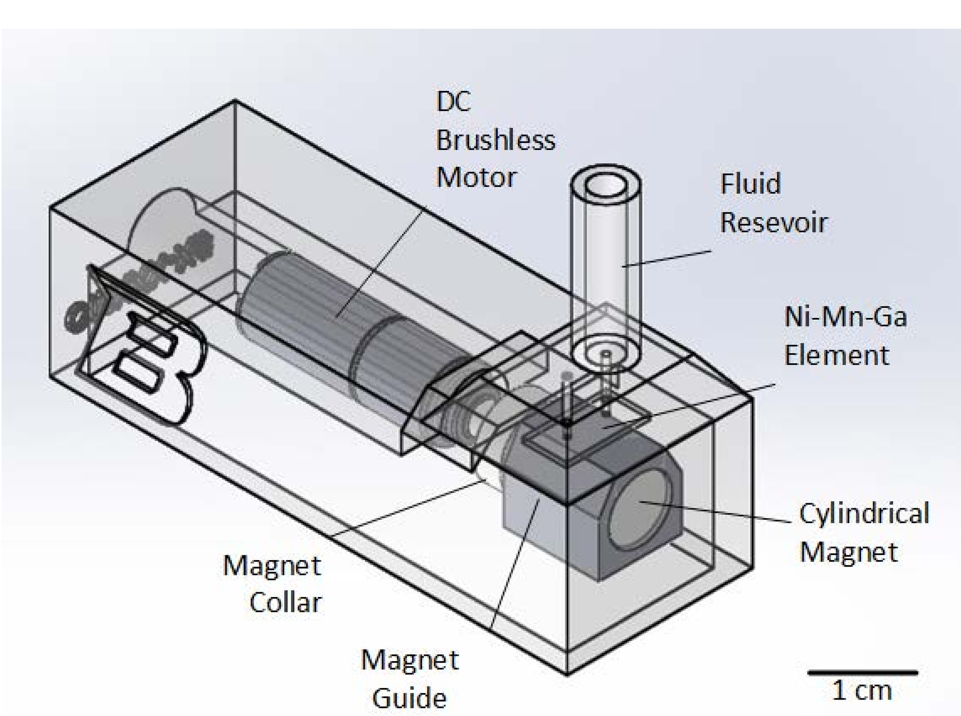

Fig. 2. Internal components of the permanent-magnet-actuated BSU micropump

II. Simulation and construction

- LTspice to model control circuit and FEMM to model behavior of magnetic flux
- Three coils wrapped around iron core, with MSMA element positioned above coil assembly
- Magnetic field concentrated above one of two pole pieces; we control which pole is active by changing current flow through coils
- We use an Arduino microcontroller to control switching of semiconductor devices

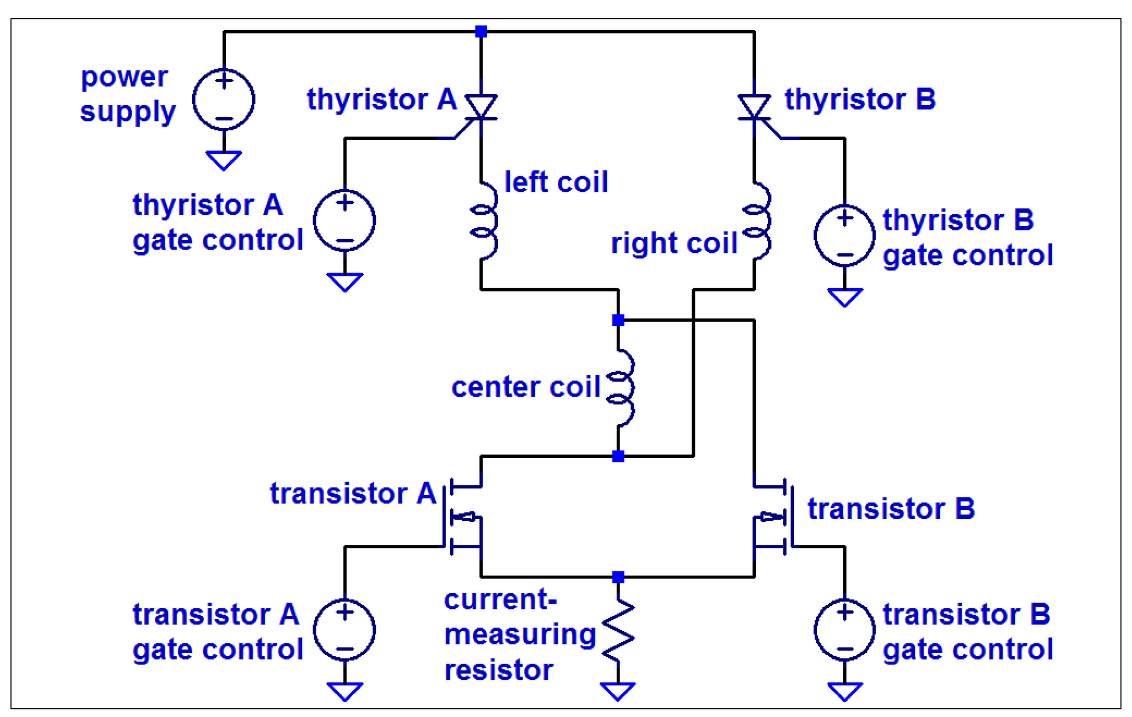

Fig. 3. LTspice schematic showing power supply, control circuit, semiconductor devices, and coils

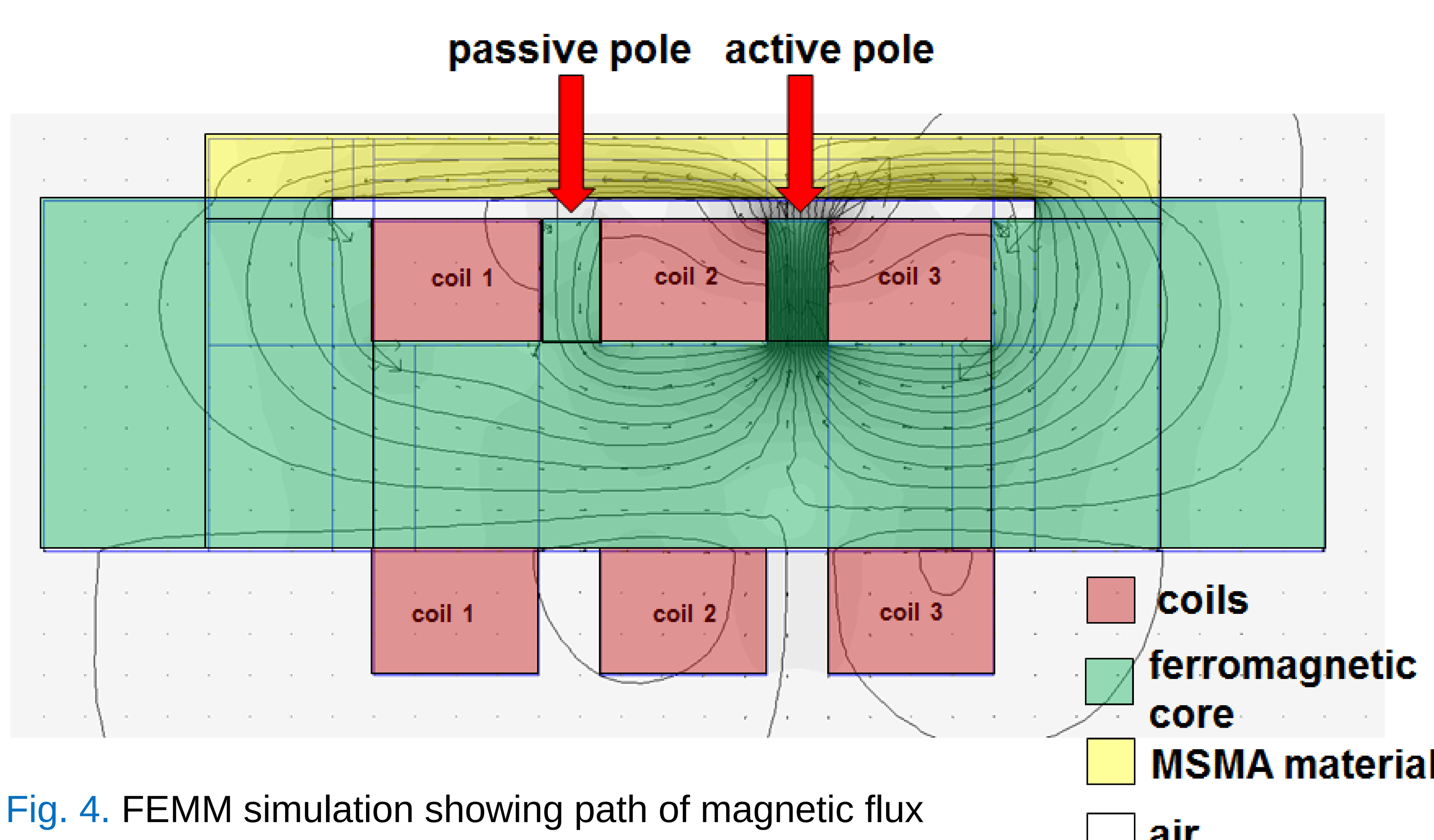

Fig. 4. FEMM simulation showing path of magnetic flux through MSMA element and iron core when coils 2 and 3 are active

III. Results

- We have reliable control of position and intensity of magnetic field
- Flux density of 0.5 Tesla possible above active pole
- The magnetic field is sufficient to cause shrinkage
- We make shrinkage above one pole disappear and reappear above the other pole

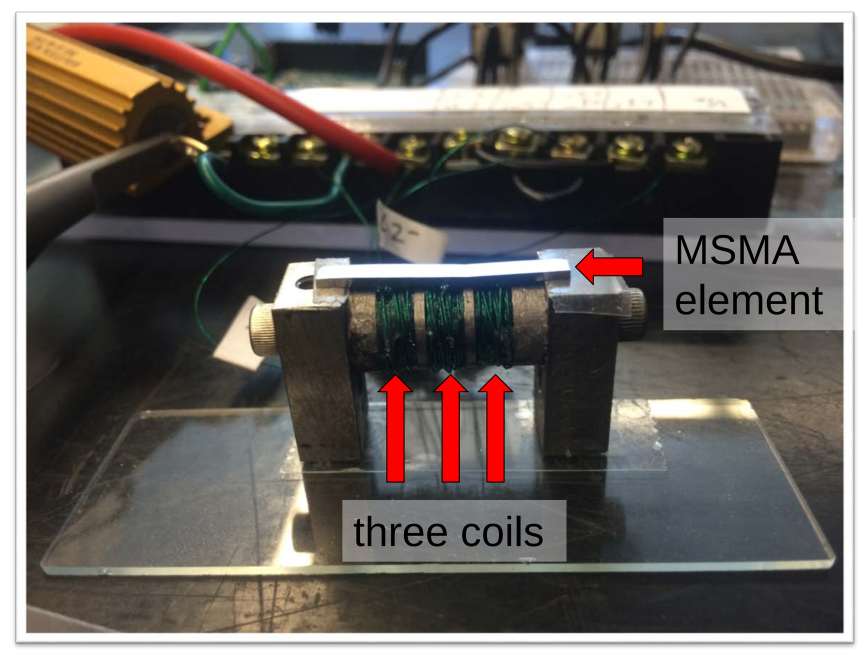

Fig. 5. Image of coils, ferromagnetic assembly, and 27-mm-long MSMA element

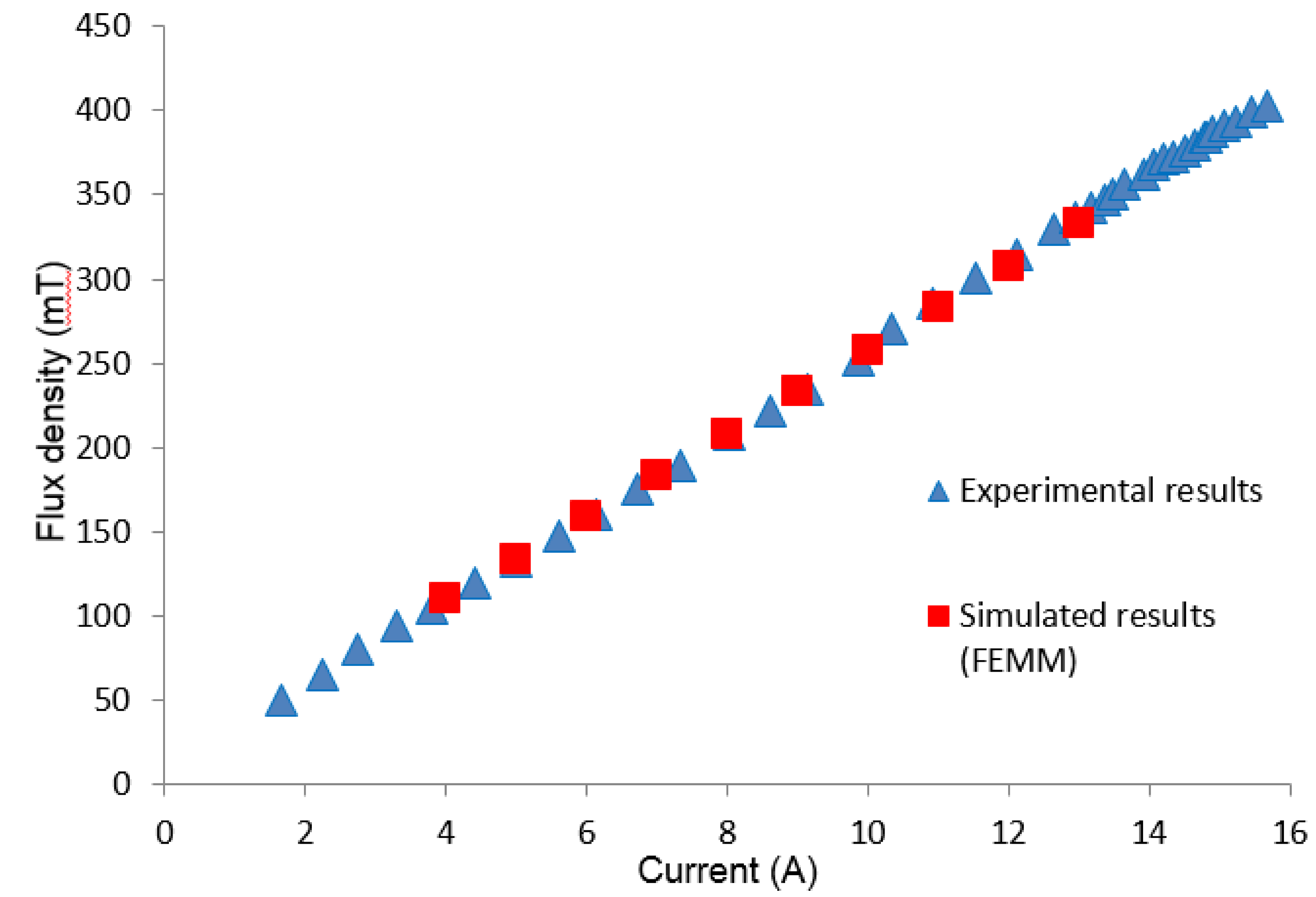

Fig. 6. Simulated and experimental magnetic flux density as a function of coil current

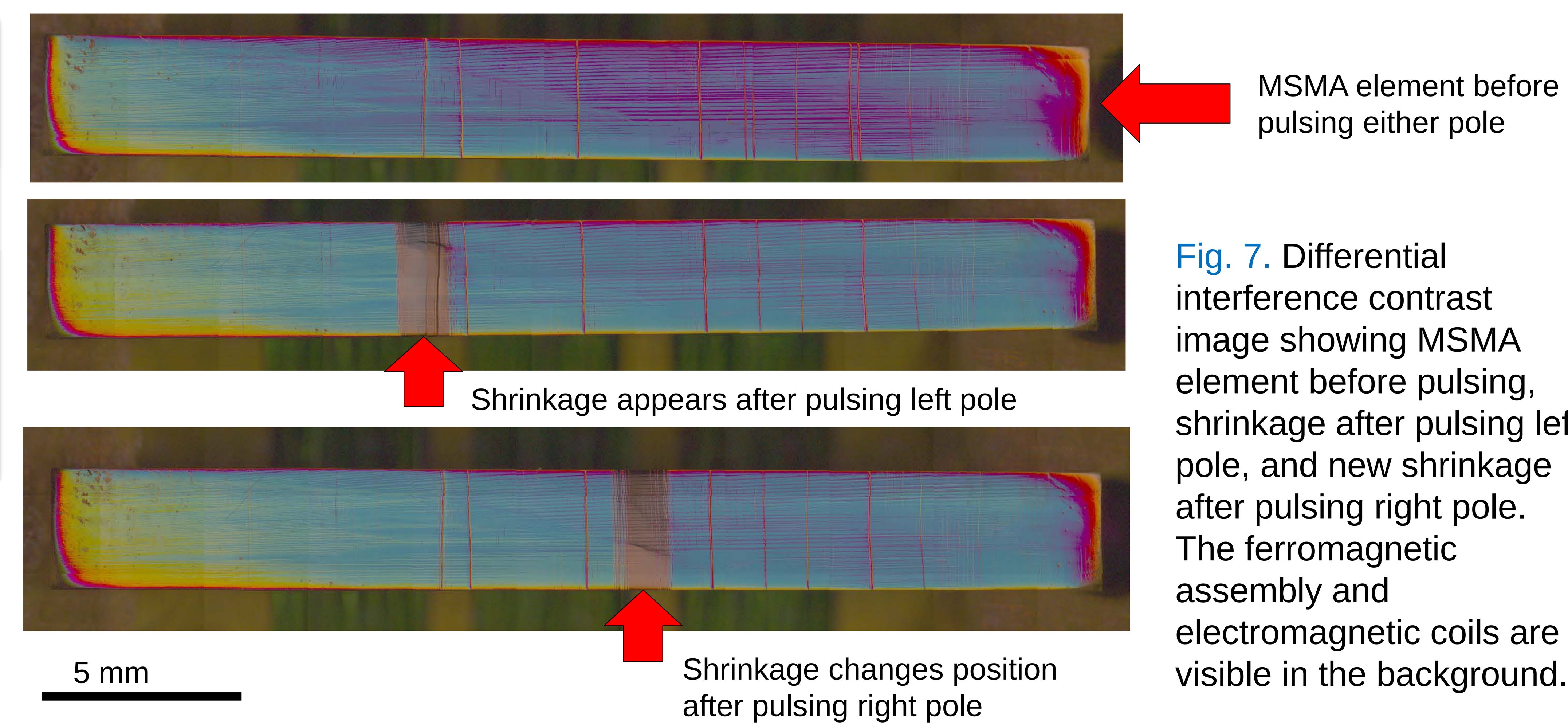

Fig. 7. Differential interference contrast image showing MSMA element before pulsing, shrinkage after pulsing left pole, and new shrinkage after pulsing right pole. The ferromagnetic assembly and electromagnetic coils are visible in the background.

IV. Conclusions

Our electrical circuit produces localized magnetic fields comparable to those of permanent magnets in the actuation of an MSMA element. We succeeded in causing twinning and forming shrinkages at specified locations in the MSMA element via magnetic flux pulses from the control circuit. We aim to increase the number of poles beyond two to further increase controllability of the position of the shrinkage in the element. We also aim to integrate the control circuit, coils, and MSMA element into a single printed circuit board at a later date.

Acknowledgment

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