Magnetomechanics of Magnetic Shape Memory Micropumps

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Magnetic Shape Memory Alloys: An Alternative to Mechanical Pumps?

Why do we need Micropumps?

Microfluidic pumps are an essential part of experimentation across many scientific disciplines, but current models use complicated mechanical parts such as microvalves and micropumps. Microfluidic pumps are an essential part of pharmaceutical research in drug discovery, development and delivery. The MSM micropump works without moving parts from the pump design.

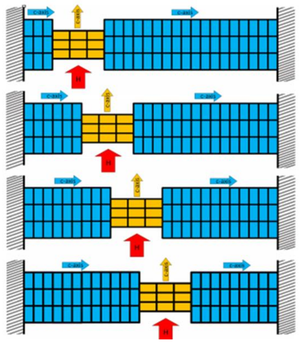


Figure 1: Shrinkage caused by a localized magnetic field in a MSM element constrained on both sides. (S. Barker et. al)

What are Magnetic Shape Memory (MSM) Elements?

MSM Elements are Ni-Mn-Ga alloy sticks that can return to their original shape after deformation in a magnetic field. The action of a relatively small magnetic field to MSM elements generates a strain of up to 6% through reorientation of the unit cells (Figure 1). We built a pump that utilizes the controllable mechanical properties of MSM elements to pump fluid.

Our Pump Design

In our pump design, rotation of a diametrically magnetized cylindrical magnet utilizes the shape change of MSM elements in a magnetic field to create ripples through the element that allow for the movement of microfluids. The pump was printed with resin on a formulabs printer. Below are the schematics for the pump design (Figure 2).

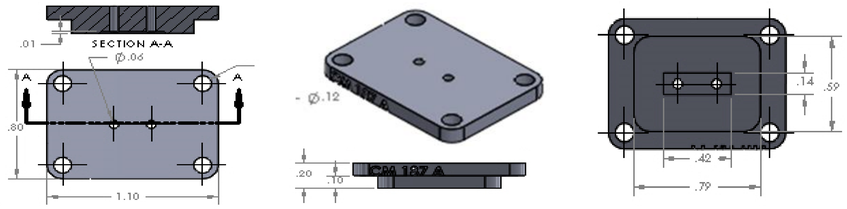


Figure 2: The SolidWorks design of the pump parts including holes to pump fluids designed to the length of the element in a top plate and a bottom plate to close the system.

Characterization of the Elements

Topological Analysis

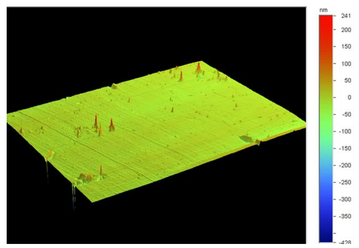


Figure 3: 3D analysis before micropeening.

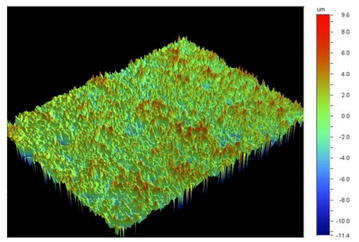


Figure 4: 3D analysis after micropeening.

Switching Field

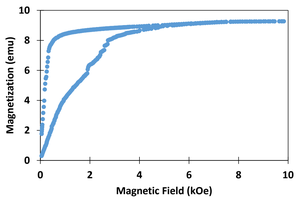


Figure 5: Switching Field test parallel to long axis. The sample switches at a field strength of about 1 kOe.

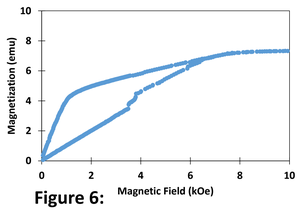


Figure 6: Switching Field test parallel to intermediate axis. The sample switches at a field strength of 3.75 kOe.

Compression Test

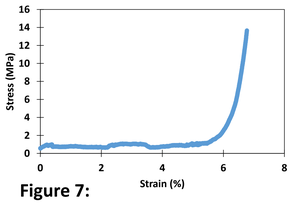


Figure 7: Stress-Strain curve before micropeening.

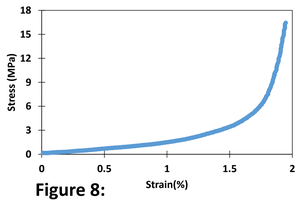


Figure 8: The Stress-Strain curve after micropeening was smoother.

Methods of Characterization

Before constructing the microfluidic pumps, the elements were characterized using

- Topological analysis with an optical profilometer to analyze surface roughness (Figure 3 and Figure 4)
- Vibration sample mangetometry to determine the switching field(Figure 5 and Figure 6) and the transformation temperatures (Figure 9 and Figure 10) of the elements
- Compression tests to generate a stress-strain curve (Figure 7 and Figure 8)
- X-Ray Diffraction to identify the structure (Figure 11 and Figure 12)
- Optical analysis to measure displacement caused by the rotating magnet (Figure 13 and Figure 14)

The elements were then micropeened and re-characterized to compare how prolonging the life of the element by increasing surface roughness affects their pumping ability.

Transformation Temperature

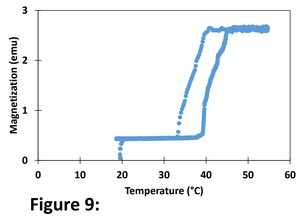


Figure 9: Transformation hysteresis before micropeening. The sample changes phase at about 37.5°C.

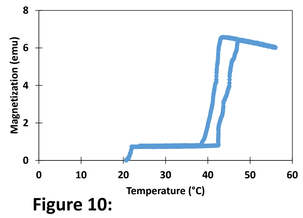


Figure 10: Transformation hysteresis of after micropeening. The sample changes phase at about 42°C.

X-Ray Diffraction

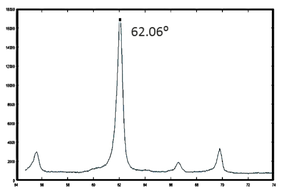


Figure 11: X-Ray Diffraction of Sample 1 with peaks showing 10M structure.

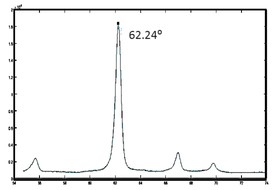


Figure 12: X-Ray Diffraction of Sample 2 with peaks showing 10M structure.

Optical Analysis

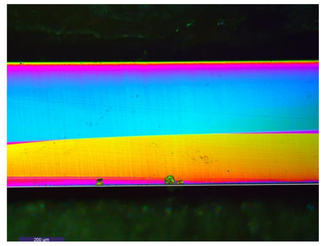


Figure 13: Side view before micropeening without twins present.

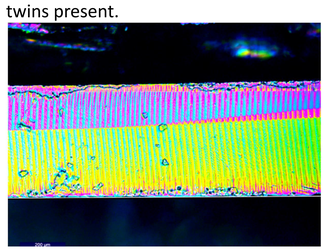
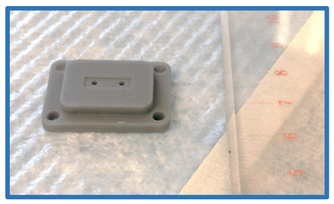


Figure 14: Side view after micropeening with a dense pattern of thin twins.

Results and Future Work

Analysis and Conclusion

- I characterized two MSM Elements before and after micropeening which showed that micropeening causes a reduction in movement as well as smoothening of movement.
- These classifications will help determine the relationship the characteristics of the MSM elements and their ability to pump microfluids at different rates with varying back pressure.



What's Next?

Following characterization of the elements, we will build the micropumps and measure flow rate and back pressure. Further work is needed to identify the optimum between the beneficial impacts of micropeening in smoothening out the elements' movement and its tendency to reduce the MSM deformation.

References and Acknowledgements:

Barker, S., et. al. (2016). Magnetic Shape Memory Micropump for Submicroliter Intracranial Drug Delivery in Rats. *Journal of Medical Devices, 10*(4), 041009. doi:10.1115/1.4034576 // This work was supported by the National Science Foundation via the REU Site: Materials for Society at Boise State University (DMR 1658076).