Untethered Foldable Soft Robot with Magnetic Coercivity Engineering

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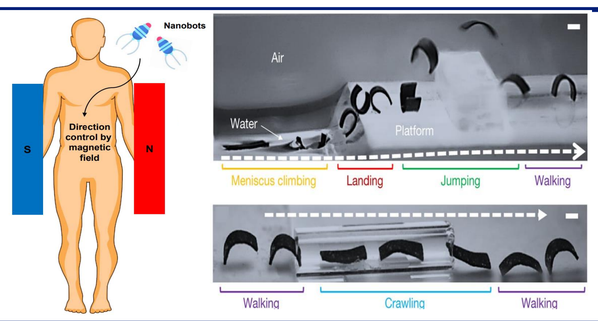
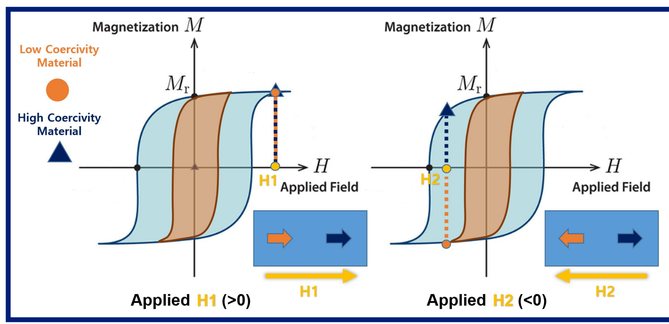
Introduction



Magnetic Actuated Soft Robot

Magnetic soft robot has high potential for healthcare and bioengineering device. Depending on the design of the robot, it can easily access to complex and small regions of human body. Furthermore, it can be remotely controllable to achieve medical functions. In this sense, the field of magnetic soft robots has been utilized for various application such as drug delivery, targeted therapy or tissue engineering

Main Idea

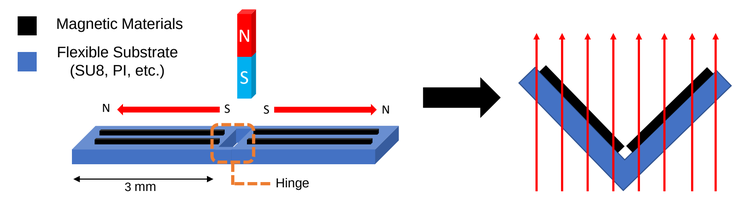


Coercivity Engineering

The device that we design is a magnetic soft robot that can be folded by external magnetic field. In order to realize this movement, coercivity engineering is applied with two different kinds of magnetic nano particles (MNP). According to the different features of their magnetization curves, magnetization direction can be controlled by applied magnetic field.

Experimental Methods

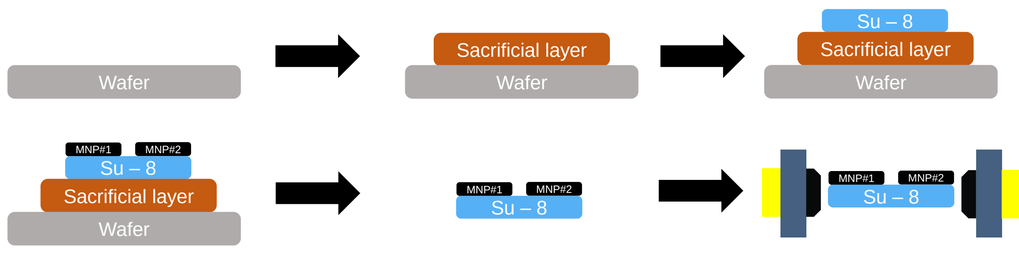
Folding Motion Mechanism



The magnetic actuation mechanism utilizes the basic characteristic of the magnetized materials **to align** in a specific direction according to **their magnetization direction under the external magnetic field**

For our foldable soft magnetic robot, we used $Zn_{0.4}Fe_{2.6}O_4$ @ $CoFe_2O_4$ octahedron shaped **MNP** whose sizes are **50 nm (MNP#1)** and **33 nm (MNP#2)** respectively. As coercivity of MNP depend on their sizes, we can utilize **magnetic coercivity engineering.**

Device Fabrication Process



Results

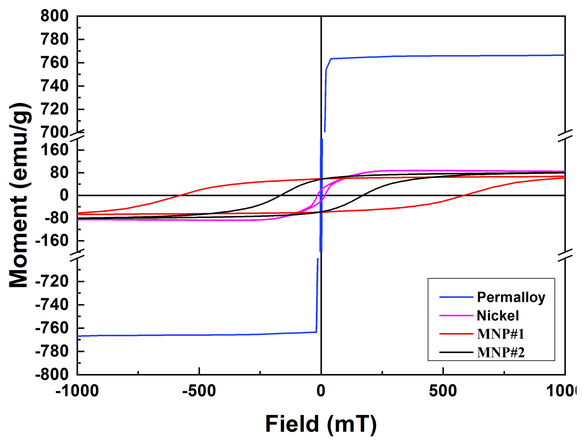
1. Material

Material	Coercivity (Hc)	Moment* @ 15mT	Weight*
MNP#1	600 mT	0.47 memu	28.8 μg
MNP#2	170 mT	0.43 memu	26.9 μg
Permalloy	3 mT	1.10 memu	1 μg
Nickel	16 mT	0.02 memu	6 μg

* Weight / Moment are measured at once (e.g., 6 μg Nickel - 0.02 memu under 15 mT)

* Requirements

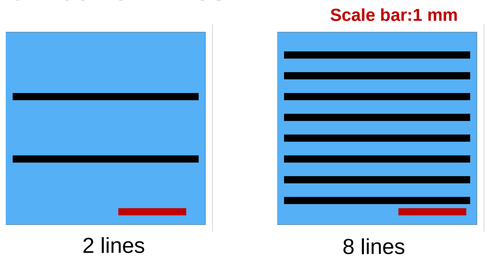
	Weight Balance	Moment Balance	Fab Difficulties
Printing	O	O	▲
Deposition	X	X	▲



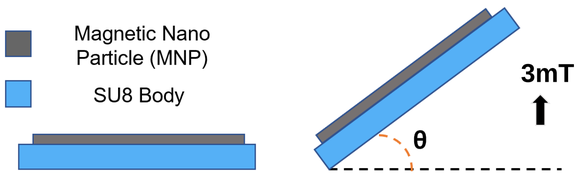
Overall, the benefits of using MNP printing overweigh the deposition as it meets the qualifications for balancing weight and moment, which is essential for our foldable machine. Further, the large margin of coercivity enables easy engineering and stable operation. Permalloy has slow deposition rate (25 nm for 12 min) and shows extremely bad adhesion with Su-8 Polymer. That's the case for nickel as well.

2. Optimization

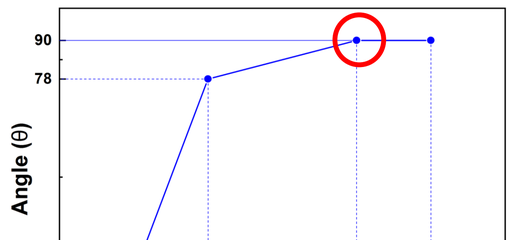
1) Number of Lines



Different numbers of MNP pattern

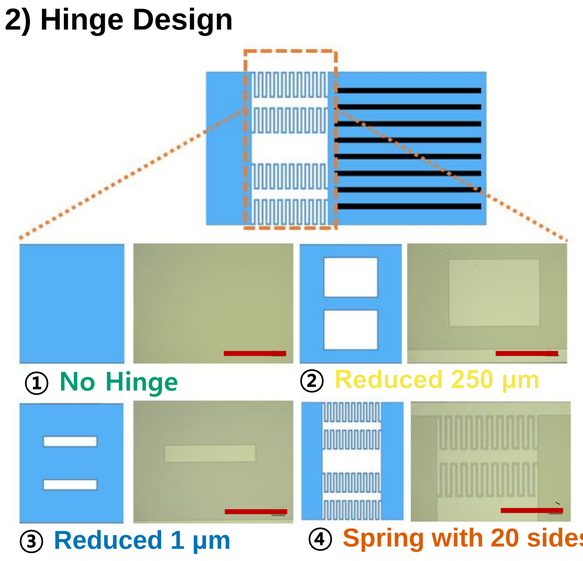


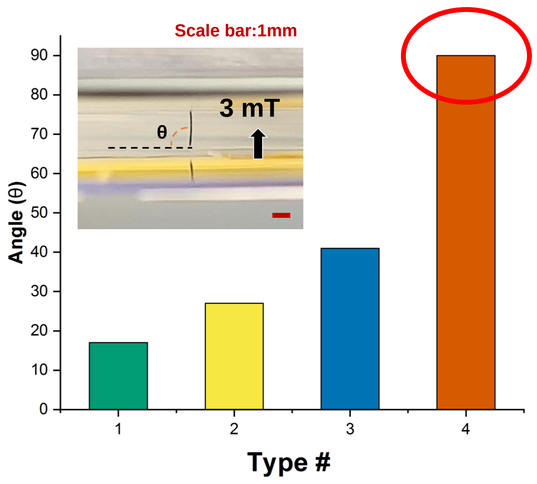
Side View & Angle Measurement



→ **8 lines** of MNP pattern is optimized

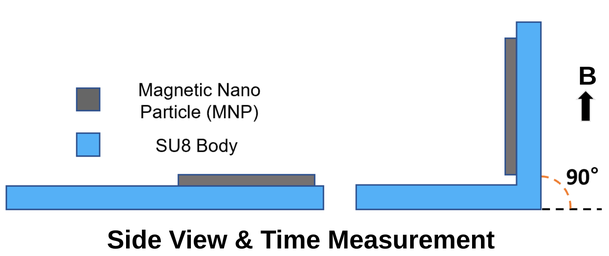
2) Hinge Design



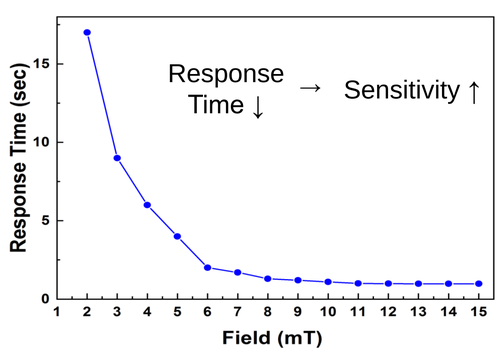


→ **Spring with 20 sides** is optimized

3) Magnetic Actuation Time Response



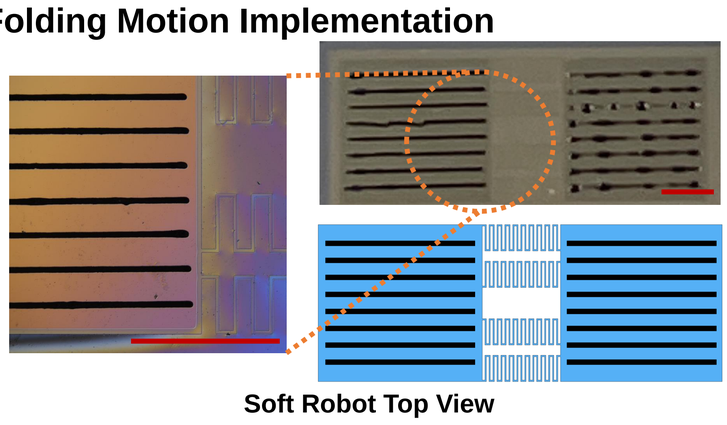
Side View & Time Measurement



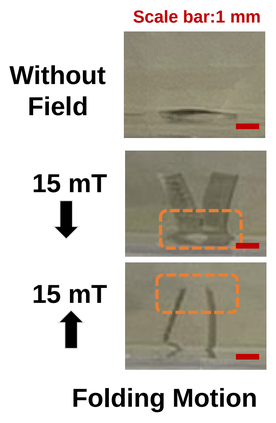
→ **Larger Field, Faster Response**

3. Two Panel Magnetic Actuated Soft Robot

- **Folding Motion Implementation**

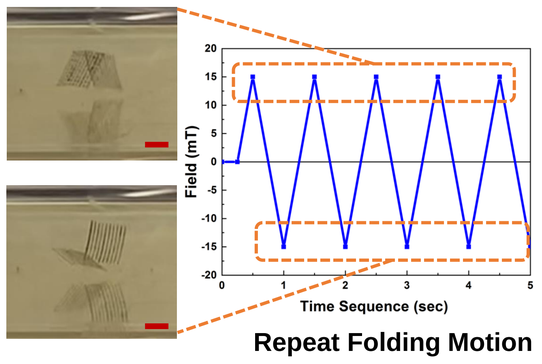


Soft Robot Top View

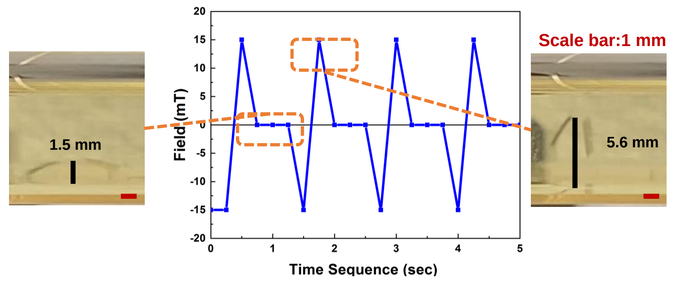


Folding Motion

- **Complex Motion Implementation with Programming**

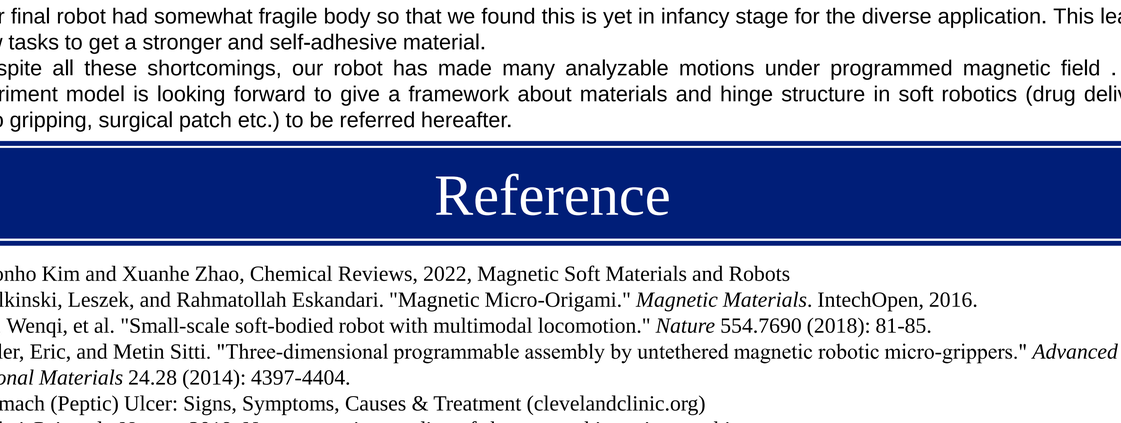


Repeat Folding Motion



Floating Upward Motion

- **Application**



Liquid flowing out through small hole

Migration to targeted place

Closing the hole with folding motion under magnetic filed

Conclusion & Further Study

Conclusion

We carried out Experiments by four different kinds of magnetic materials and Hinge designs on Su8 polymer. Finally, Magnetic nanoparticles having different coercivity combined with spring shaped hinge are turned out to be the most optimal set for our foldable soft robot. Our robot responds to a minimum field of 3mT and be folded within a seconds when it is under 10mT or more.

Further Study

Our final robot had somewhat fragile body so that we found this is yet in infancy stage for the diverse application. This leaves a few tasks to get a stronger and self-adhesive material.

Despite all these shortcomings, our robot has made many analyzable motions under programmed magnetic field . Our experiment model is looking forward to give a framework about materials and hinge structure in soft robotics (drug delivery, micro gripping, surgical patch etc.) to be referred hereafter.

Reference

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