Ferromagnetic Shape Memory Alloys - Device Applications

Steve Murray

Midé Technology Corporation

56 Rogers Street

Cambridge, MA 02142

Tel: (617) 252-0660

http://www.mide.com

Outline

- Program Overview
- Previous Device Work
  - Prototype FSMA Actuator (done at MIT)
  - Results (at MIT)
    - Field Generation
    - Displacement Response
- Conclusion

Program Scope

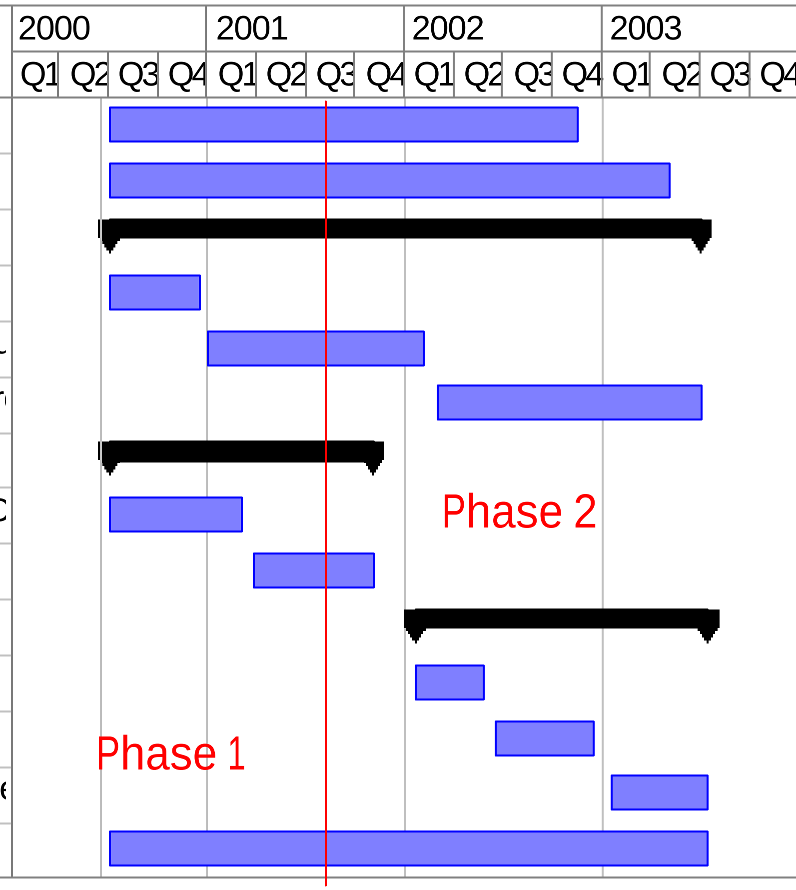
- Develop Advanced FSMA Materials
  - Composition Refinement of Ni-Mn-Ga for high performance
  - Explore other compositions (Fe-Pd, and new alloys)
  - Processing for high yield
- Test FSMA Performance
  - Frequency
  - Fatigue
- Develop Devices Based on FSMA
  - Magnetic designs for high flux
  - Integration into systems

FSMA Team

- Mide Technology Corporation
  - Cambridge, MA
- ITN Energy Systems
  - Boulder, CO
- Massachusetts Institute of Technology
  (Bob O'Handley and San Allen)
- University of Maryland (Manfred Wuttig)
- University of Minnesota (Richard James)
- Subcontractors
  - Crystal Systems Inc.
  - Boeing
  - Sturman Industries

Program Timeline

ID	Task Name
1	Materials Characterization
2	Material Optimization
3	**FSMA Material Production**
4	Technology Transfer
5	Phase I Small Production Ru
6	Phase II Medium Volume Pr
7	**Actuator Development**
8	System Requirements and D
9	Proof of Concept Testing
10	**Integrated Hybrid Design**
11	Detailed Specification
12	Detailed Design
13	Prototype Fabrication and Te
14	Management and Reporting

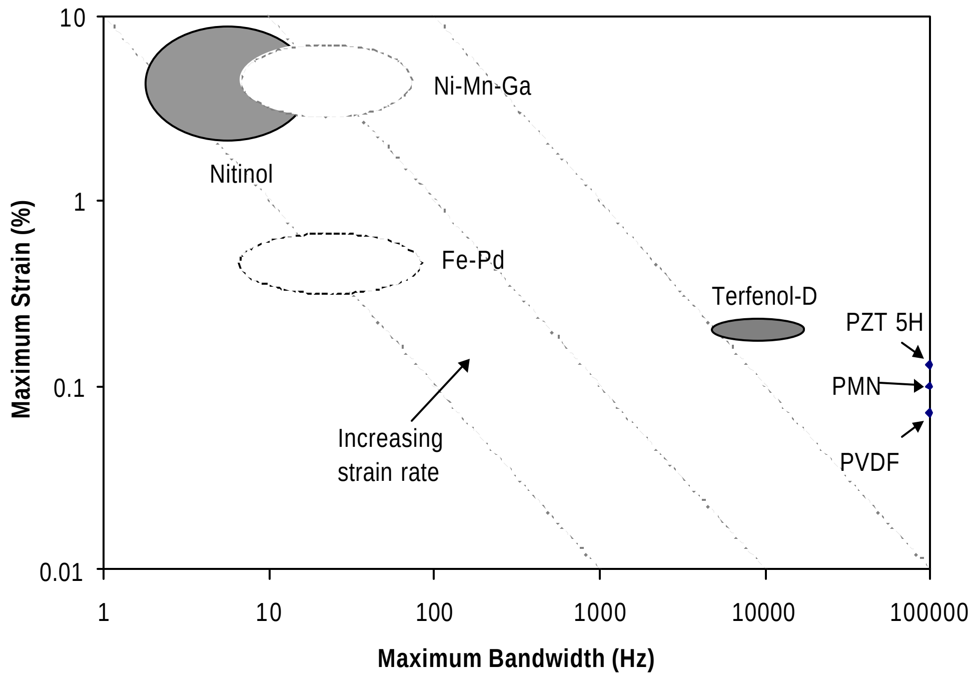


Program Highlights

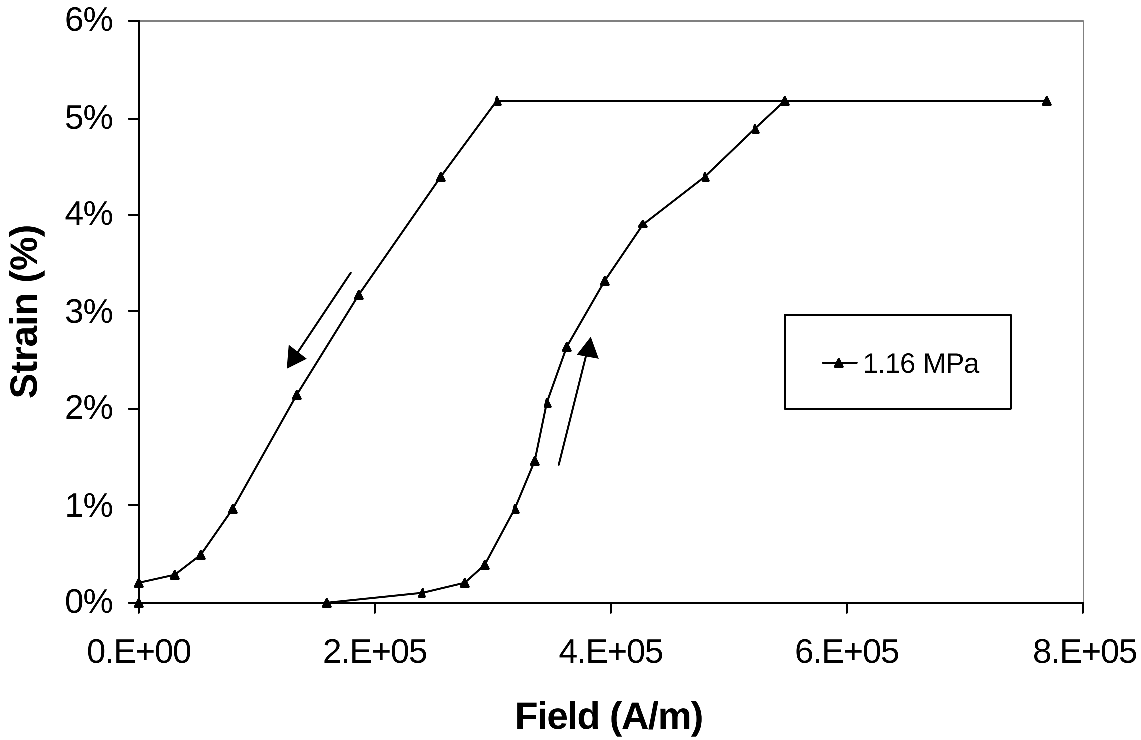
- Program scheduled to start 7/1/00
- Highlights of a previous DARPA program on FSMA Include:
  - Increase of the measured strain from 0.2% to 6.1%
  - Accurate models for mechanical and magneto-mechanical properties

Why do We Care?

- New and unexplored class of actuator materials
- Strain and energy capabilities exceeding those of current magnetic actuators
- Applications in Pumping, valving and “set and forget” position control

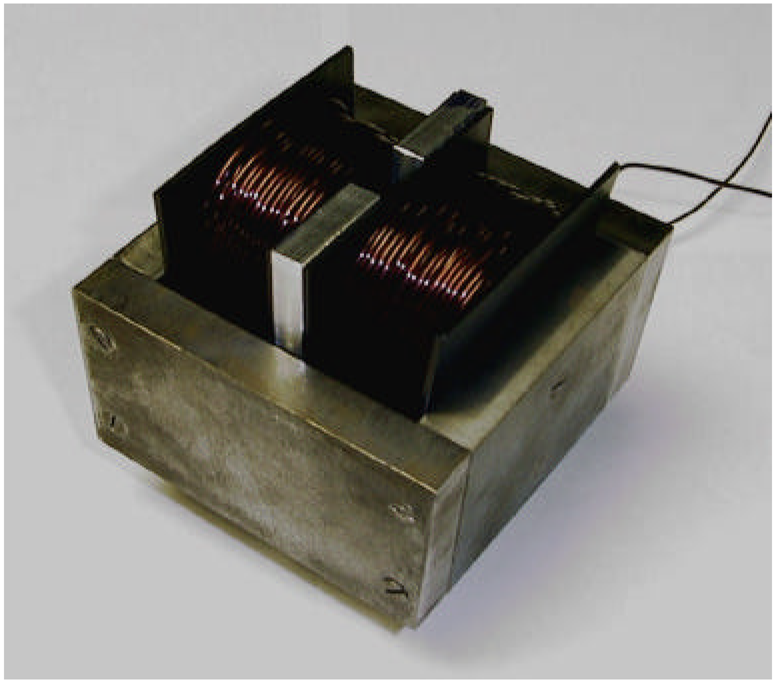


Performance of FSMA



Applications

- **Demonstrate Ni-Mn-Ga actuation in a small, self-contained device.**
- **Create a new actuator designed for FSMA able to create fields of at least 400 kA/m.**
  - Large field compared to other actuators



Design Considerations:

Prototype design

- Start with a high aspect-ratio piece of material to amplify strain into a large deflection
- Must apply a drive field and a perpendicular field or compressive stress ($c/a<1$)
- Design choices quickly reduce to solenoid (axial field) or racetrack (transverse field)
- Iron return path can be modeled as a short in the magnetic circuit for simplicity
- Modeling based on simple magnetic equations along with Maxwell^{tm} FEA analysis

Design Considerations:

Simple magnetic modeling

	General	Transverse	Axial
Reluctance	$R = \frac{length}{mArea}$	$R = \frac{t}{m_o m_r tl}$	$R = \frac{l}{m_o m_r t^2}$
Flux	$\Phi = \frac{MMF}{R}$	$\Phi = \frac{MMFm_o m_r tl}{t}$	$\Phi = \frac{MMFm_o m_r t^2}{l}$
Inductance	$B = \frac{\Phi}{Area}$	$B = \frac{MMFm_o m_r}{t}$	$B = \frac{MMFm_o m_r}{l}$

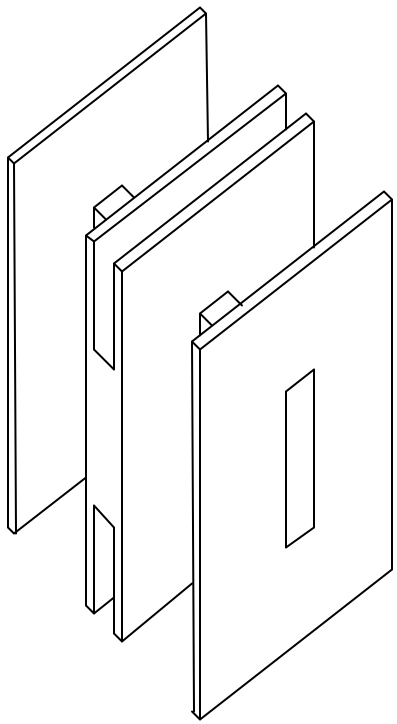
l=sample length
t=sample width

$$\frac{B_{trans}}{B_{axial}} = \frac{l}{t}$$

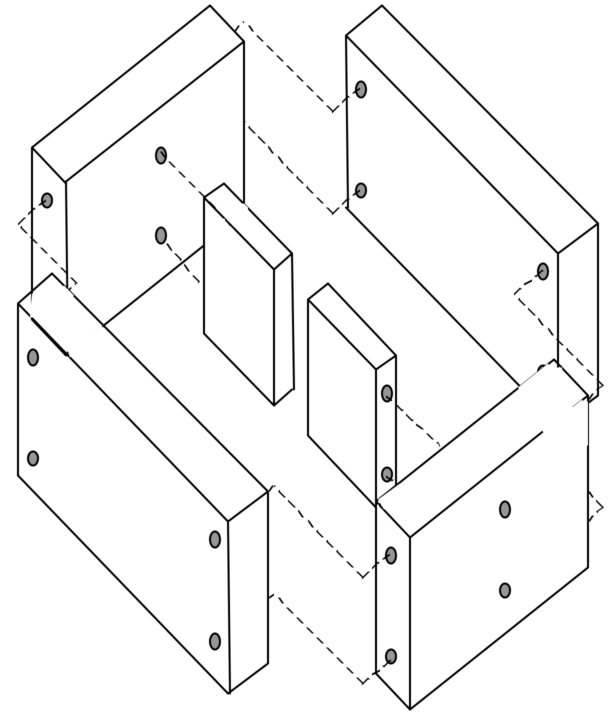
Prototype:

Racetrack design

- Four components:
  - Material
  - Coils
  - Bobbin
  - Return path



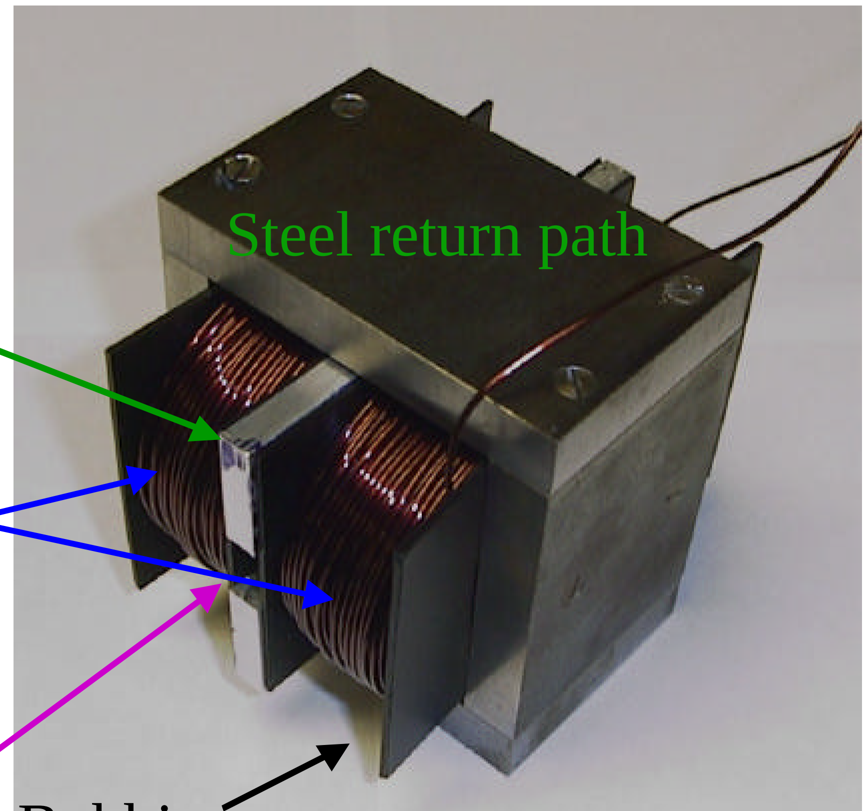
Bobbin



Flux return path

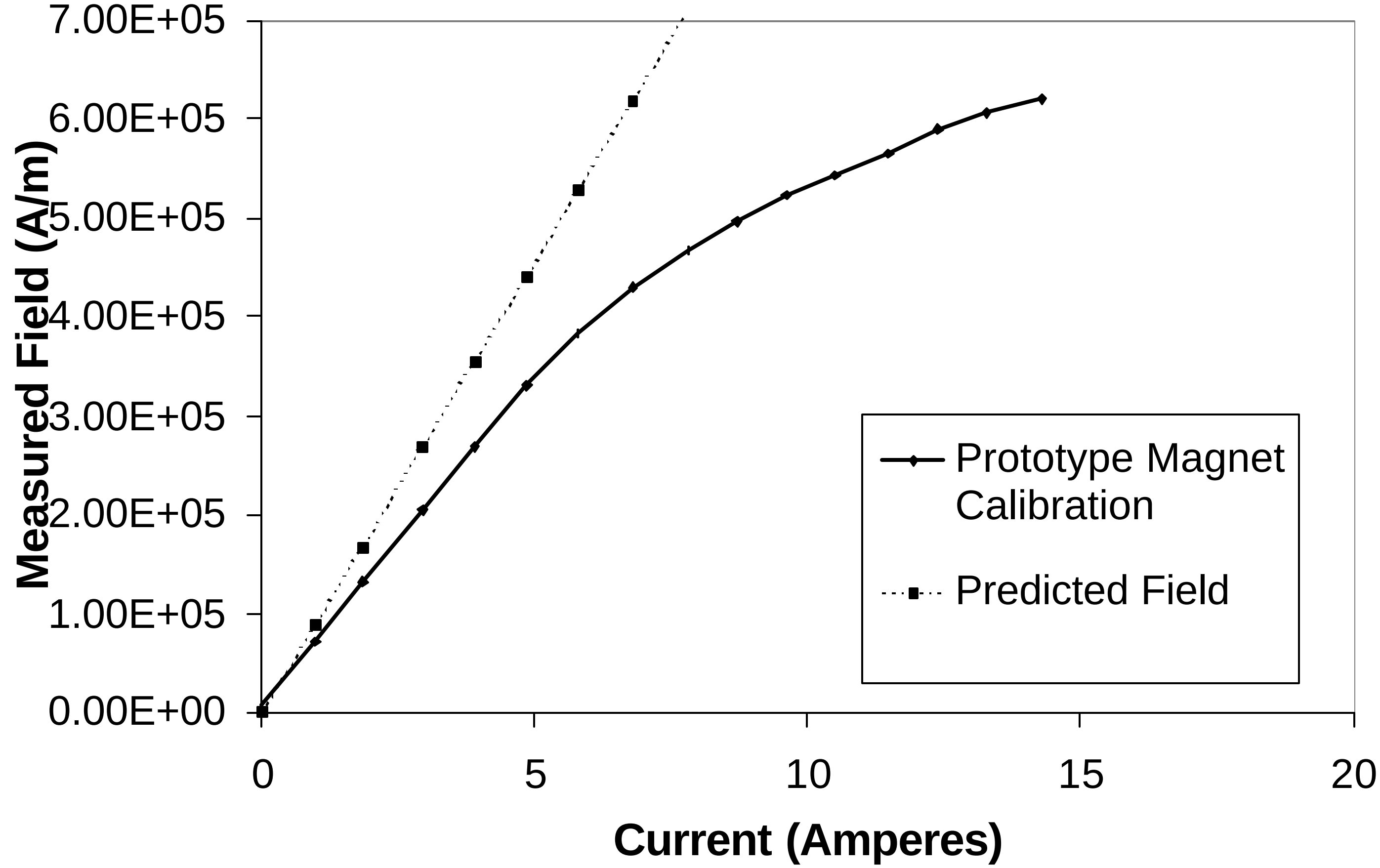
Prototype

- Weighs 3.5 kg
- 50 mm x 8mm x 8mm material cavity (field zone)
- Theoretical maximum deflection of 3mm
- 2Ω coil resistance: 722 turns of #16 copper wire



Results:

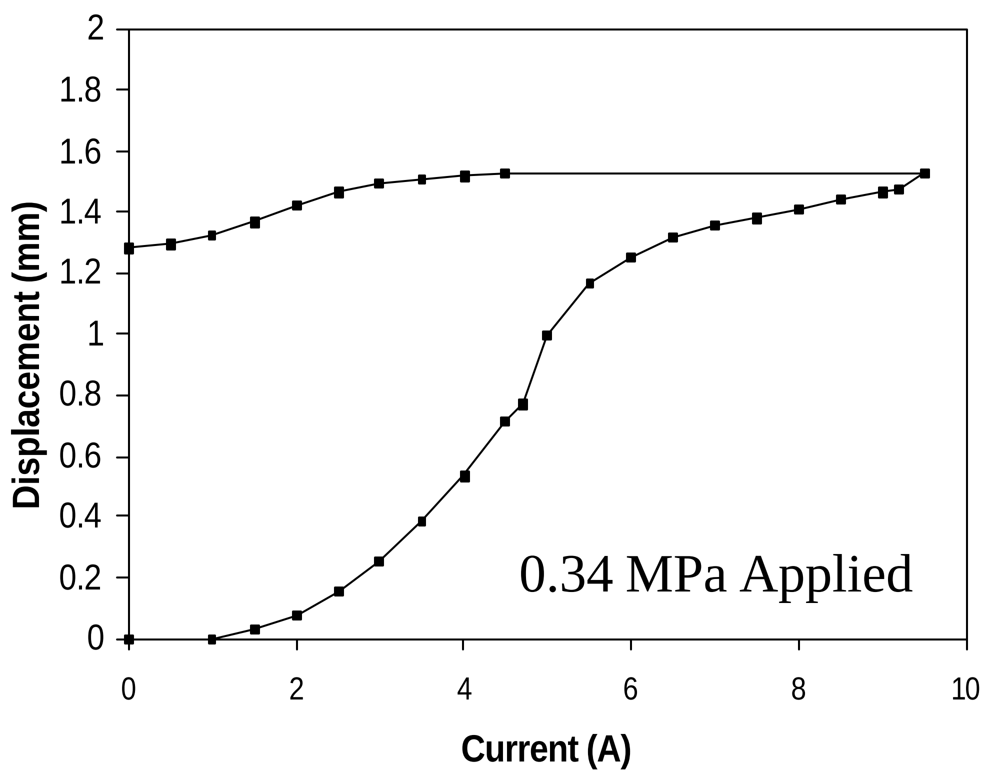
Performance



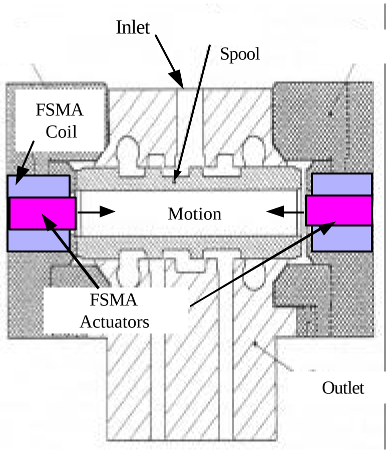
Results:

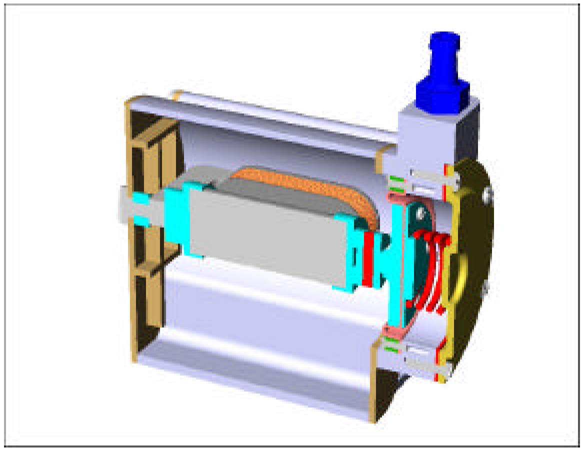
Performance

- Material cavity was loaded with three working pieces of Ni-Mn-Ga for a total material length of 41 mm and cross section of 36 mm^2.
- Maximum deflection 1.6 mm (comparable size of Terfenol reaches 0.06 mm)



Future concepts





- Digital valving
  - FMSA used to throw a valve between on an off positions
- Pumping
  - High stroke and energy density make FSMA suitable for pumping applications

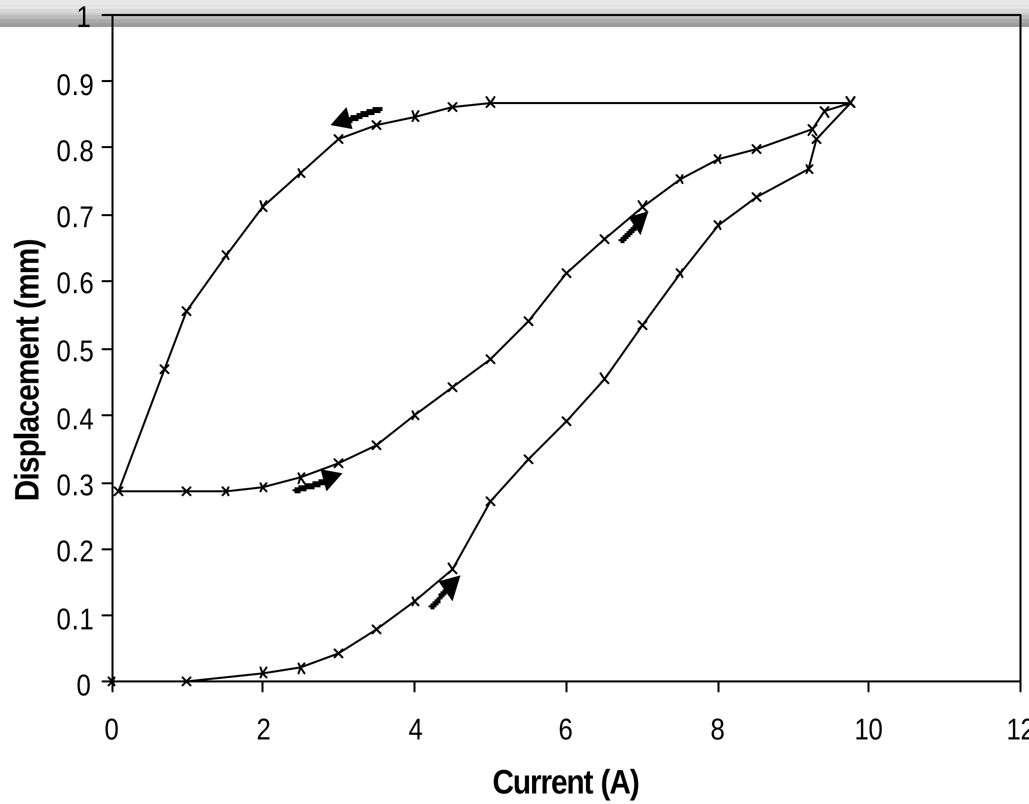
Summary

- The feasibility of developing small electromagnets to drive FSMA has been demonstrated
- Magnetic fields up to 600 kA/m were generated
- This design will be examined for use in valving and pumping devices in the coming program.
- Overall, the program will largely focus on materials development at MIT, Minnesota, and Maryland

Results:

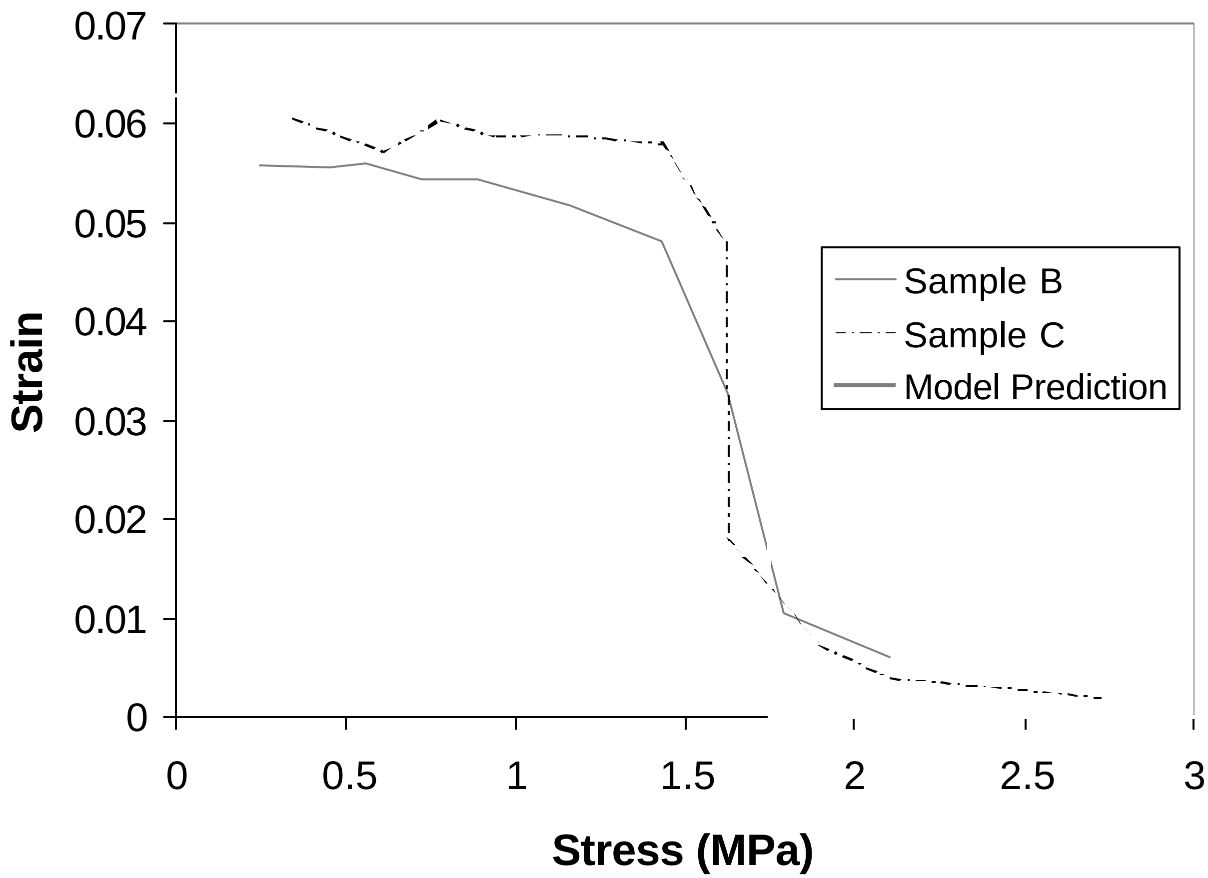
Cyclic Performance

- Constant stress of 0.87 MPa
- Cyclic strain of 0.6 mm
- Actuator type performance



Stress Performance

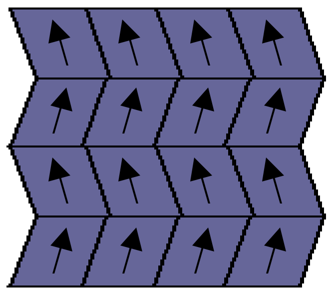
- The blocking stress of the material is about 1.8 MPa
- This stress may change slightly with temperature

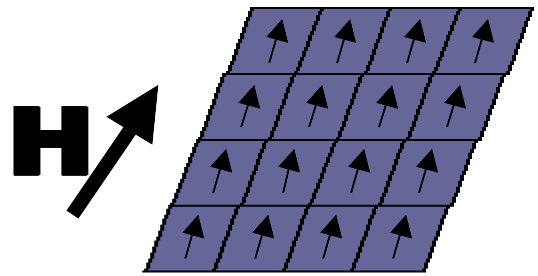


Commercial Actuator Comparison

	PZT 5H	Terfenol D	Nitinol	Ni-Mn-Ga	Fe-Pd
Actuation Mechanism	Piezo-electric	Magneto-strictive	SMA	MASMA	MASMA
Max Strain	0.13%	0.2%	2%-8%	6.1%	0.5%
Modulus (GPa)	60.6	29.7	28m, 90a	.02m, 70a	-
Actuation Specific Energy (J/kg)	6.83	6.42	252-4032	30	160
Temp Range (K)	253 to 473	273 to 523	variable	variable	variable
Cost ($/kg)		1100	40	110	4400
Bandwidth	100 kHz	<10KHz	<5Hz	0-50 Hz	-

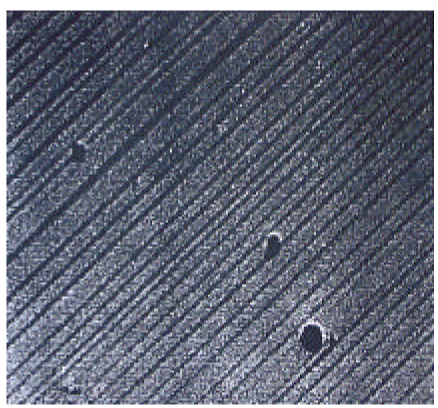
Mechanism of MASMA





Relaxed state twinned to minimize strain

De-twinned by application of magnetic field, e = up to 6%



(From Rob Tickle, et. al. University of Minnesota)