
LUT
University

LUT Material Physics Laboratory

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Field of research - Magnetic Shape Memory (MSM) materials

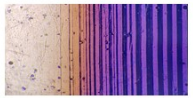
LUT University

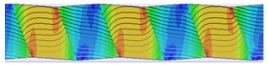
MFG 4.0

Basic research and manufacturing

Research and modelling of the MSM materials

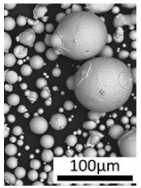
- Actuation speed 6 m/s and acceleration 200 000 g
- Positioning accuracy of few nanometers
- Efficiency up to 95 %

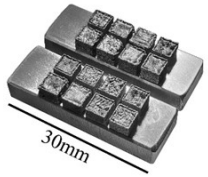




Single crystal growth and processing

Additive manufacturing and 3D printing

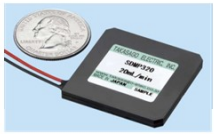




Application research and development

Micropumps and -devices for

- Chemical microreactors
- Environmental diagnostics



Commercial Pump

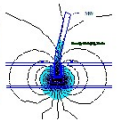
MSM Pump

Fast valves for

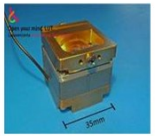
- Digital hydraulics
- Pneumatics

Haptics devices for

- Robotics
- Machines and vehicles

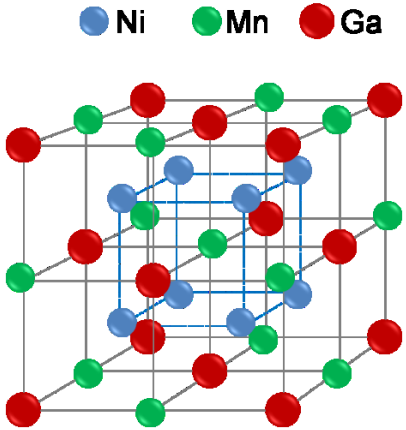


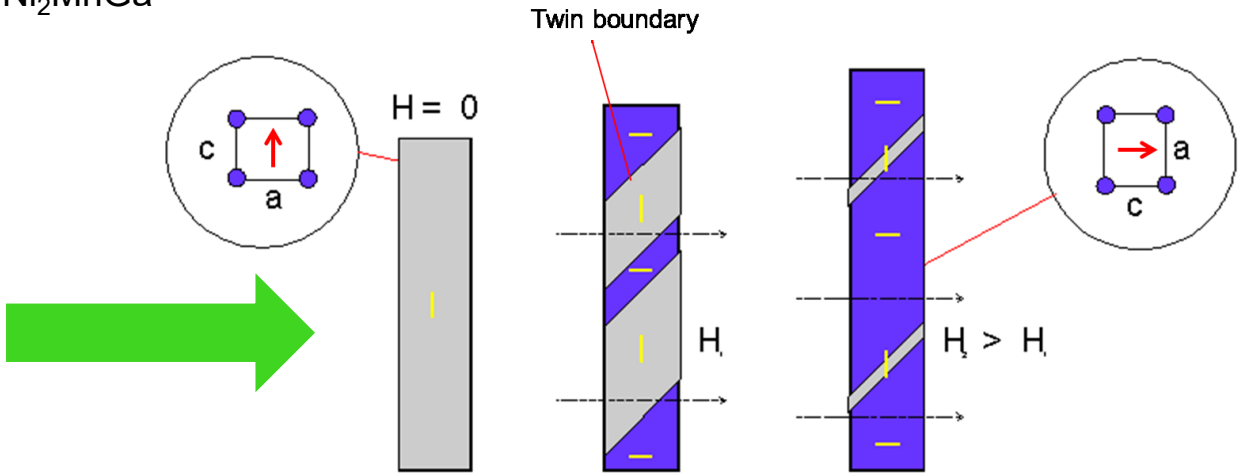
Energy harvesters for converting electricity from mechanical vibrations



Magnetic shape memory effect in Ni-Mn-Ga

Heusler type crystal structure: Ni_2MnGa





T. Graf, C. Felser, Stuart S.P. Parkin. *Simple rules for the understanding of Heusler compounds*, Progress in Solid State Chemistry 39 (2011) pp.1-50

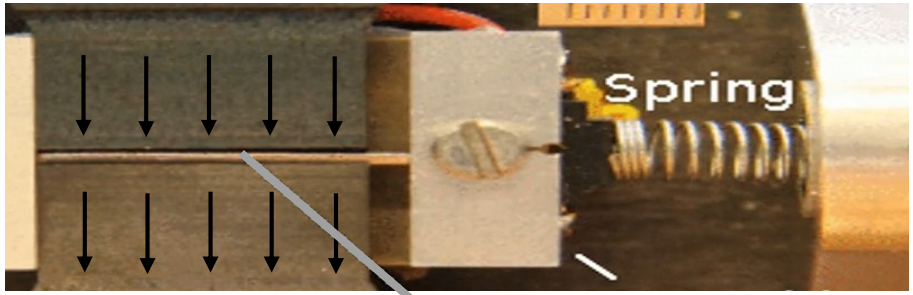
The MSM phenomenon was first demonstrated in Ni-Mn-Ga:

K. Ullakko, et al. Appl. Phys. Lett., Vol. 69 (13), pp. 1966-1968, 1996

MSM materials generate motion

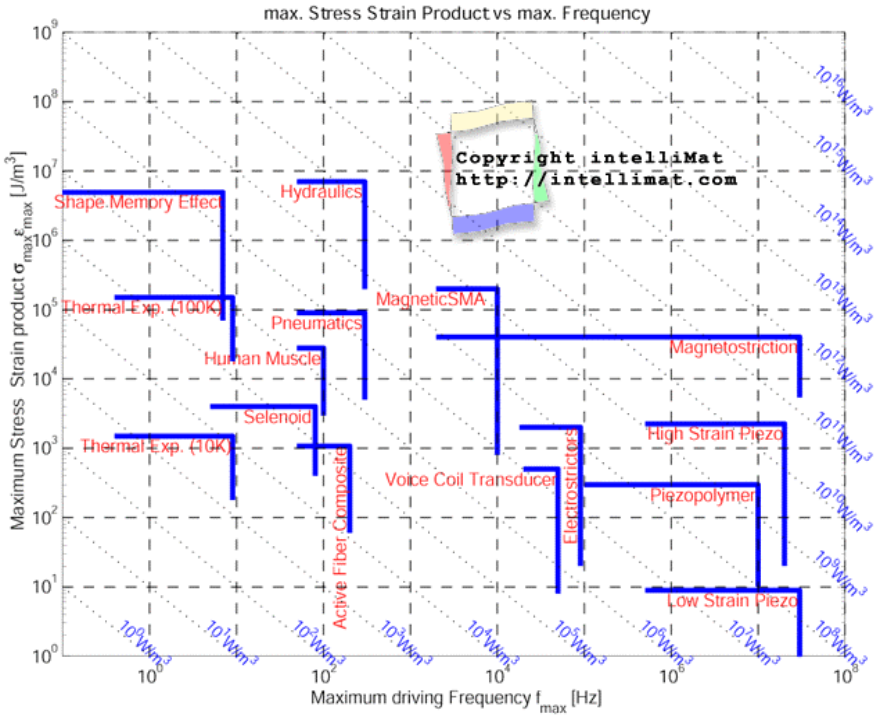
- Magnetic Shape Memory (MSM) materials strain up to 12 % when a magnetic field is applied to them

Alternating magnetic field between 0 – 0.2 T



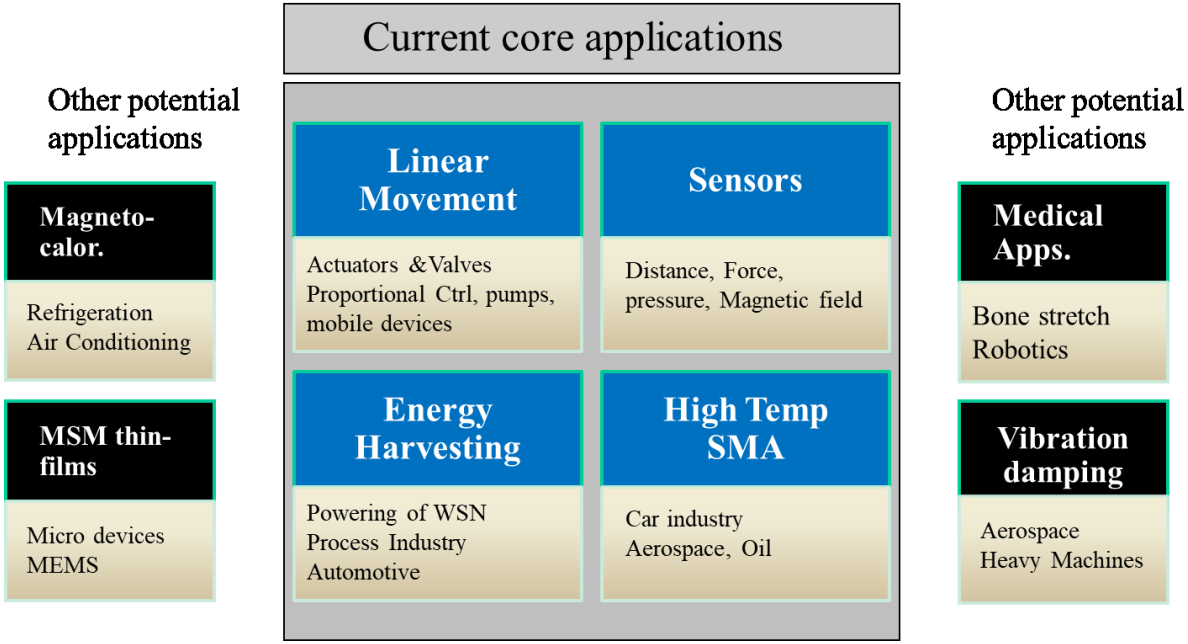
MSM material (Ni-Mn-Ga) 1 x 2 x 20 mm^3

Performance of MSM actuators



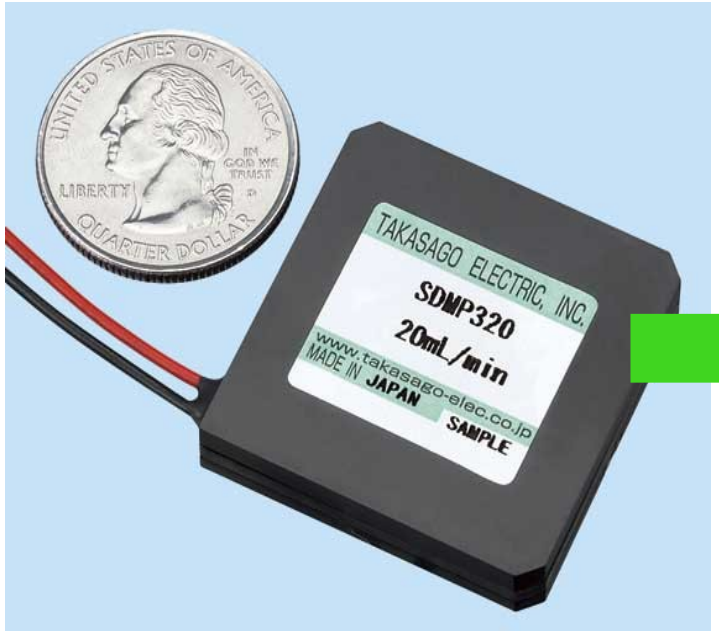
- Magnetic field as low as **8 mT**
- Response time **< 0.5 ms**
- Actuation speed up to **5.5 m/s** and acceleration **700 000 m/s²**
- Positioning accuracy of **few nanometers**
- **Efficiency** over 90 % and strain is stable without energy
- **Wireless** source of energy
- **High fatigue life**, even billions of cycles

Application areas for MSM-based devices

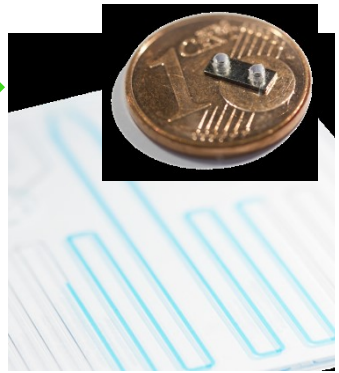


→ Smart material structures to miniaturize and simplify electromechanical devices

MSM micropump

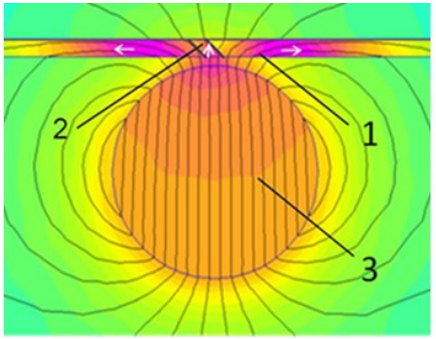


Piezoelectric Pump **20 mL/min**



MSM Pump **13 mL/min**

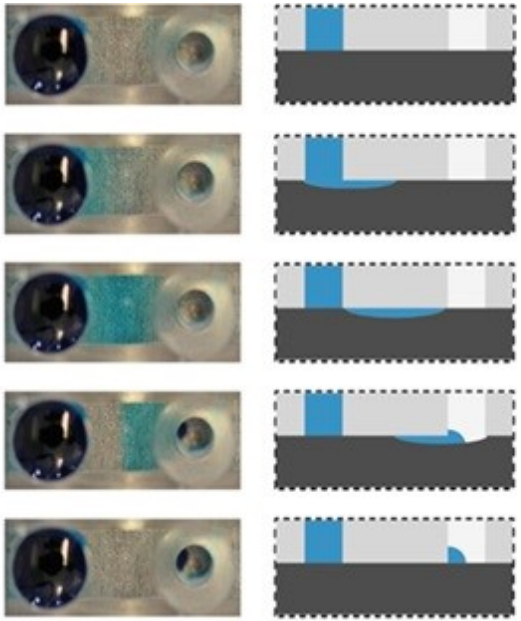
Local actuation – bidirectional magnetic field



1) **MSM element**
2) **Shrinkage**
3) **Diametrically magnetized cylindrical magnet**

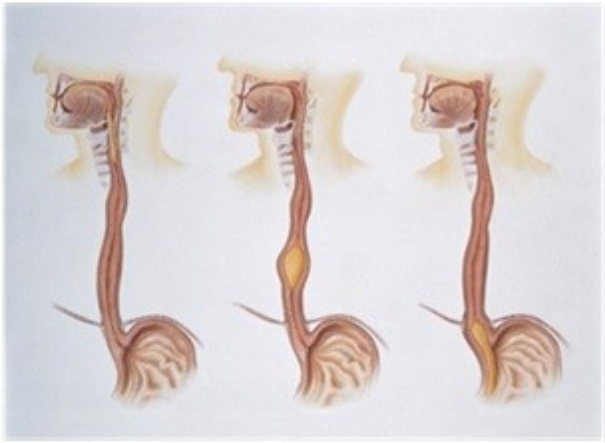
K. Ullakko, et al., Smart Mater. Struct. 21 (2012) 115020

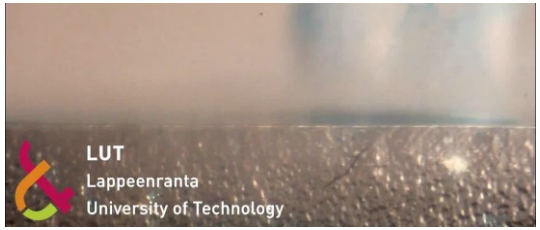
MSM micropump

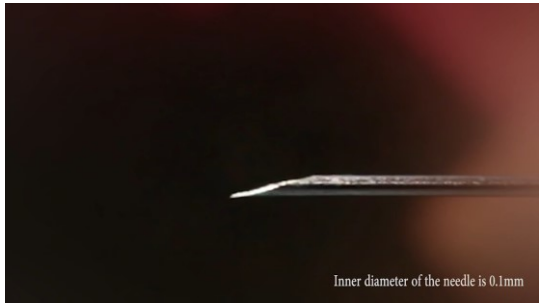


MSM micropump uses localized straining to transport fluid from an inlet to the outlet

Principle is similar to swallowing:

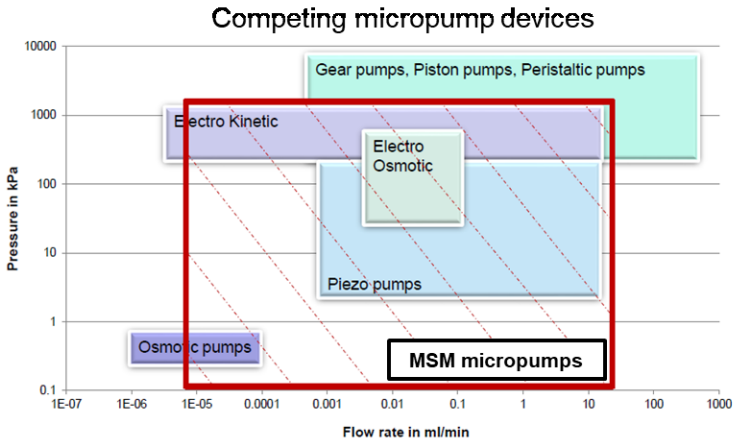






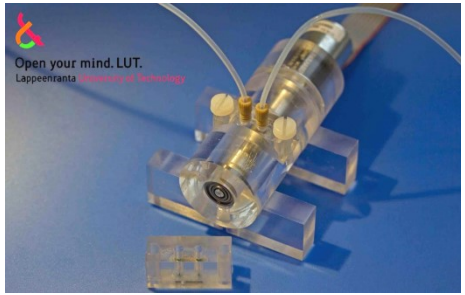
Characteristics of the MSM micropump

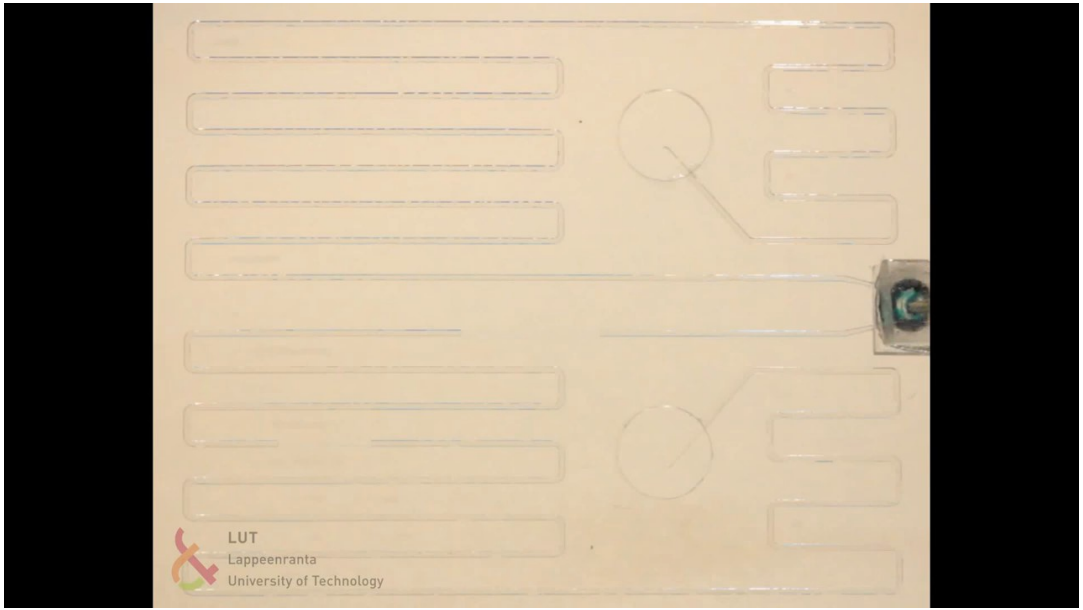
Quantitative		Qualitative
• Volume per cycle (resolution)	80-150 nL (scalable)	• Multifunctional – valve and pump
• Flow rate	0-30 mL/s at 0-300 Hz	• Simple design
• Repeatability	1%	• Scalable
• Differential pressure	5-8 bars	• Integrable
• Power consumption	<1 mJ/cycle	• Contact-free
• Working temperature	~RT ±10° (Type-I twins)	• Discrete resolution
• Fatigue	Millions of cycles	• Pumps gas and viscous liquids



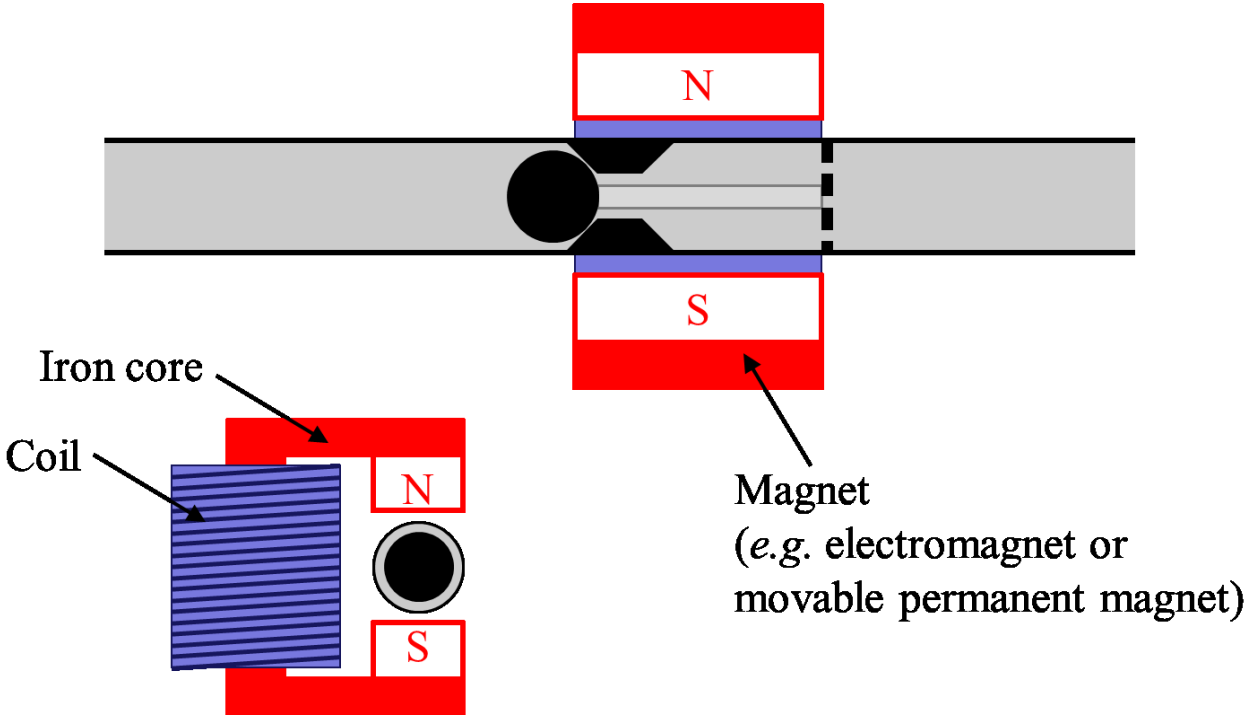
Application areas of the MSM micropump

- ◊ Bioanalytics
- ◊ Gene technology
- ◊ Synthetic biology
- ◊ Medical applications
- ◊ Chemical microreactors
- ◊ Environmental analytics

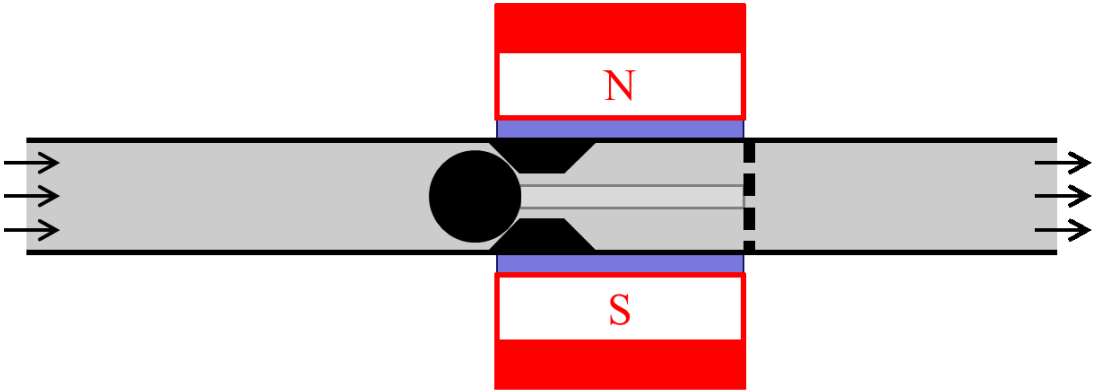




MSM-based hermetically sealed valve

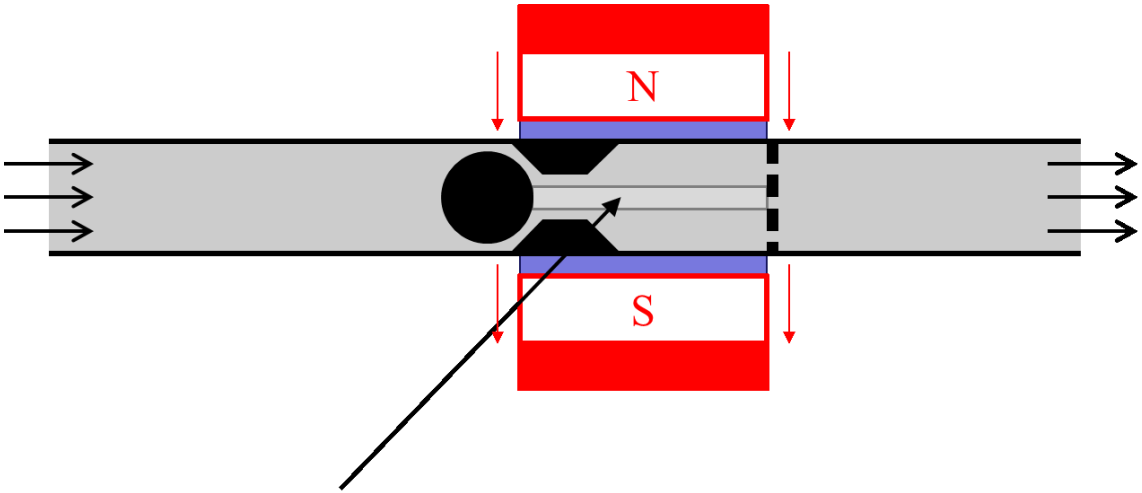


MSM-based hermetically sealed valve



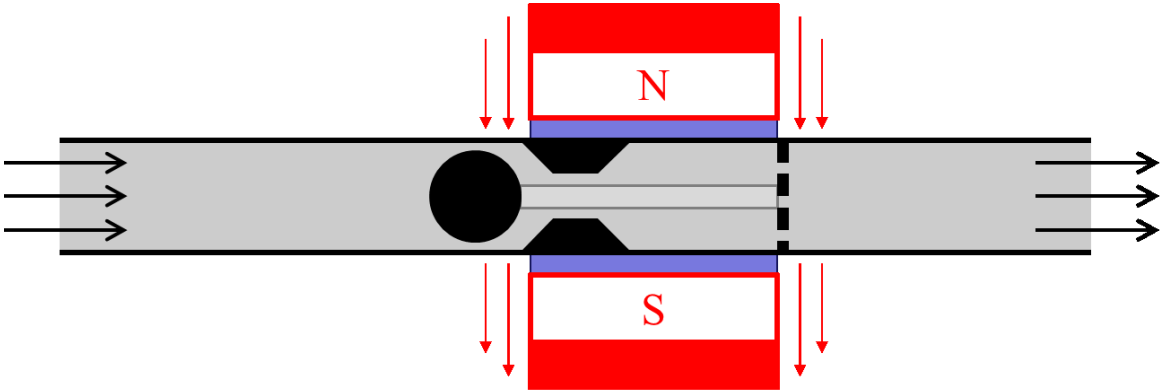
Field off:
Small flow (or none)

MSM-based hermetically sealed valve



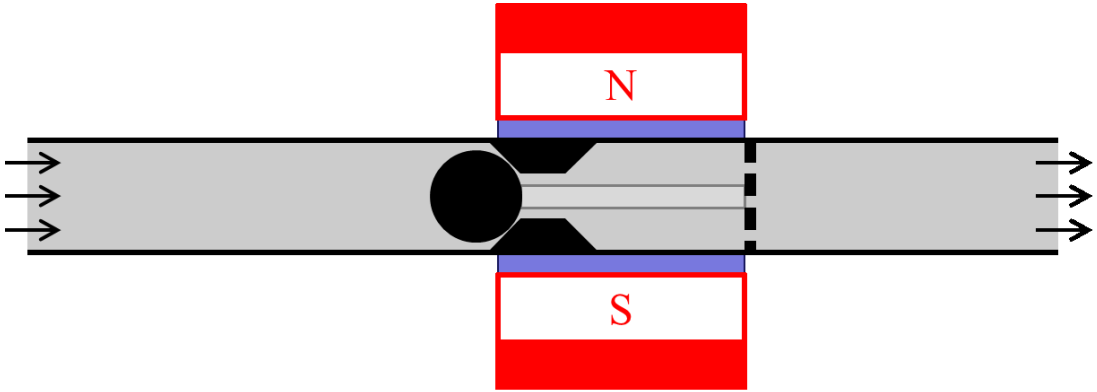
Low field:
MSM begins to elongate
→ Flow increases

MSM-based hermetically sealed valve



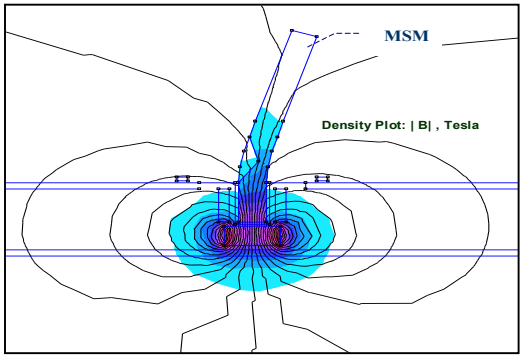
High field:
MSM elongates to maximum
→ Maximum flow

MSM-based hermetically sealed valve

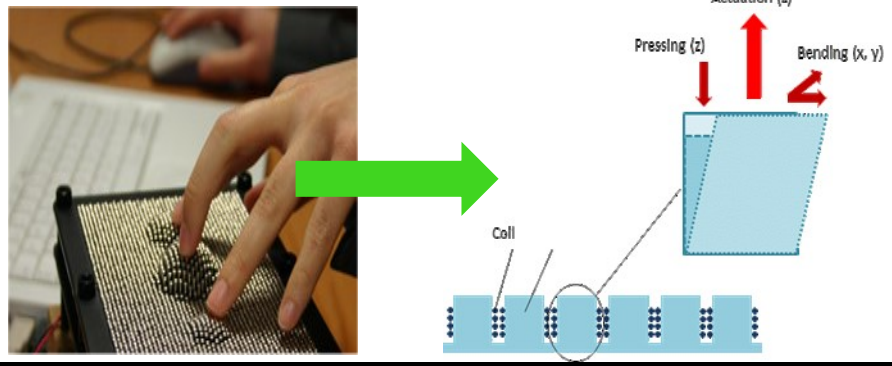


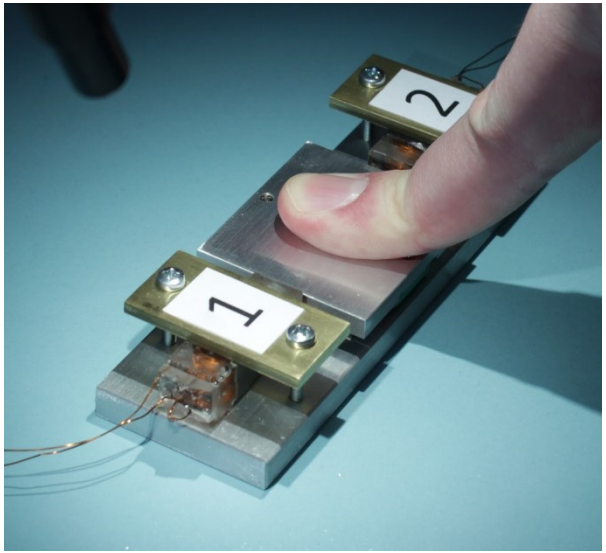
Field off:
Valve closes again due to flow/pressure

MSM haptic devices – act as sensors and actuators



Calculated magnetic field distribution in an MSM joystick



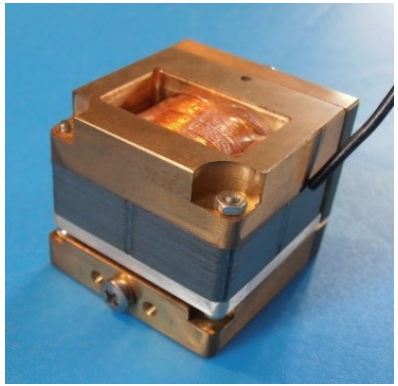


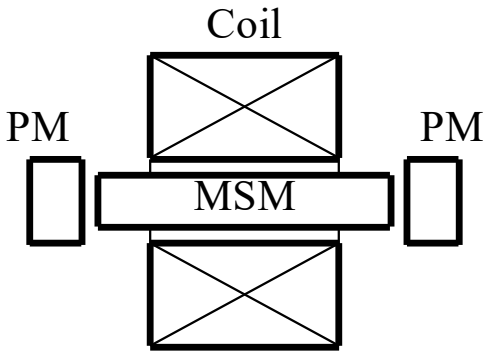
A. Saren, et al., (2018), Highly Perceivable Tactile Feedback by Magnetic Shape Memory Technology. 16th International Conference on New Actuators.

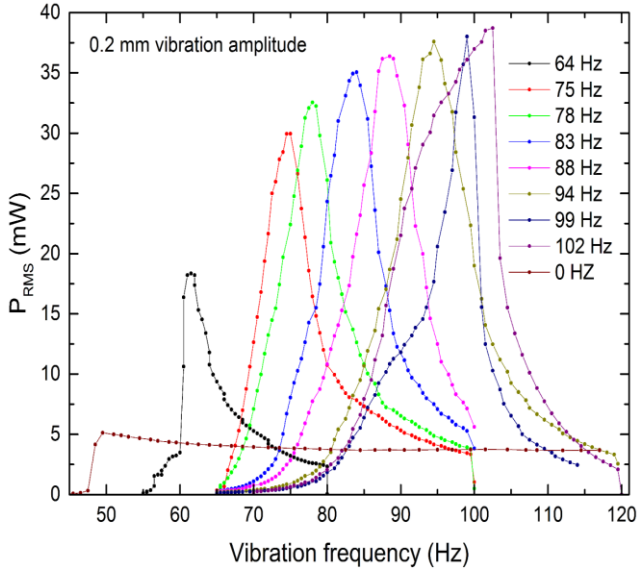
MSM-based Vibration Energy Harvester

- Permanent magnets produce magnetic flux in MSM element
- Permeability of MSM element changes when it is elongated or compressed, changing the magnetic flux

→ Changing magnetic flux within pickup coil → Electrical current





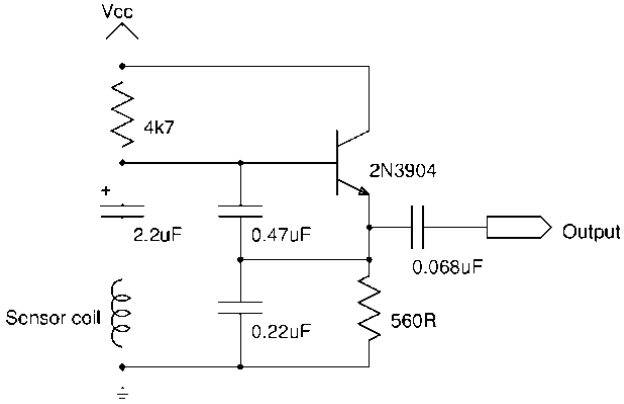


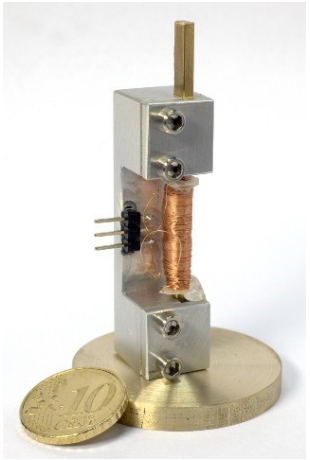
Magnetization change can be use also for displacement measurement/sensor

MSM Displacement sensor

- High resolution MSM displacement sensor
  - Based on proportional change of permeability
  - MSM element placed inside a coil
  - Coil is a part of an oscillating circuit
  - As the MSM length changes the frequency of oscillation changes as well
  - Sensitivity below 1 um

- Other sensors proposed
  - Force and pressure
  - Strain gauge
  - Speed sensors
  - Magnetic field

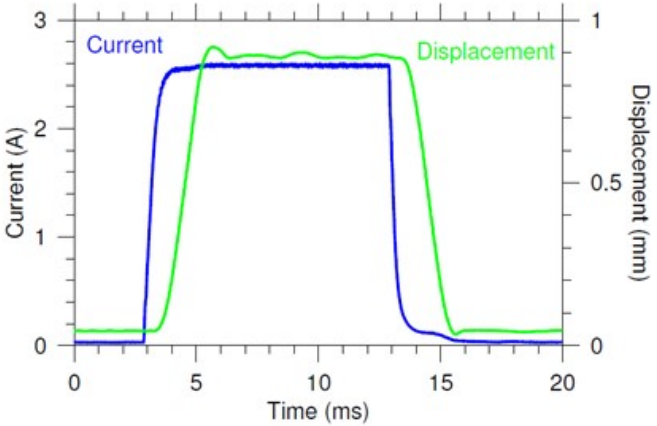




MSM Spring actuator

An example actuator specifications:

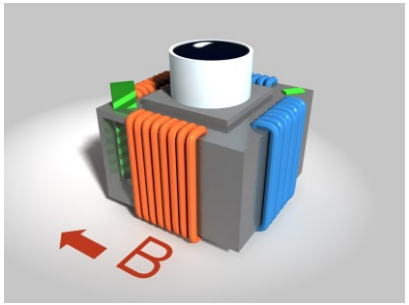
- Element size 20×2.5×1.0 mm^3
- Maximum stroke 0.9 mm
- Maximum output force 5 N
- Fatigue life >200 million cycles
- Rise time 1 ms (see Fig)

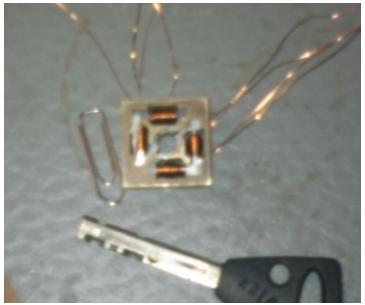


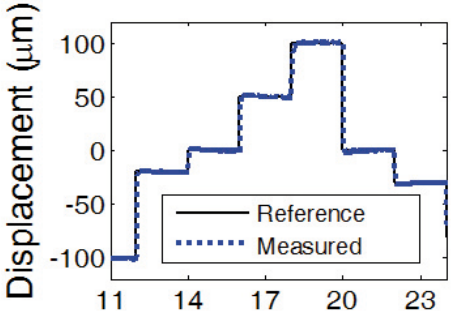
Adaptamat

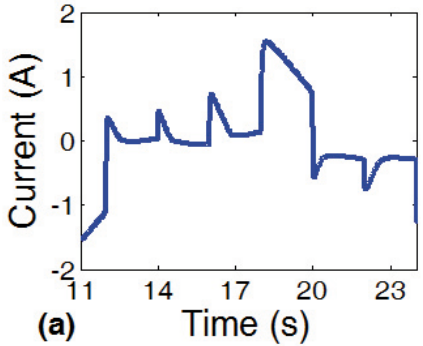
MSM Push-push actuator

- Antagonist set-up, two actuators working against each other (push-push actuator)
- Actuator consumes power only when a movement is made
- Partial/proportional movements within the range of elongation are possible

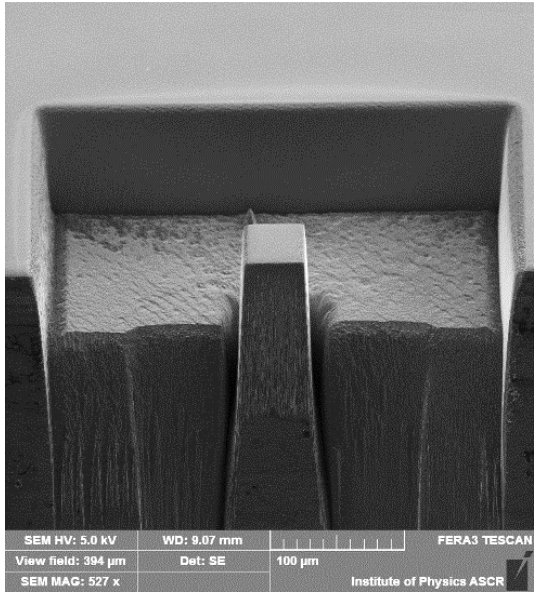


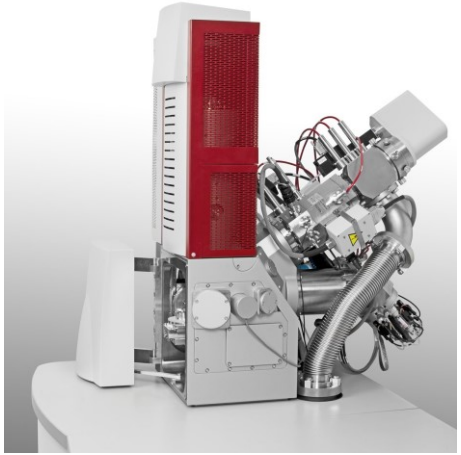




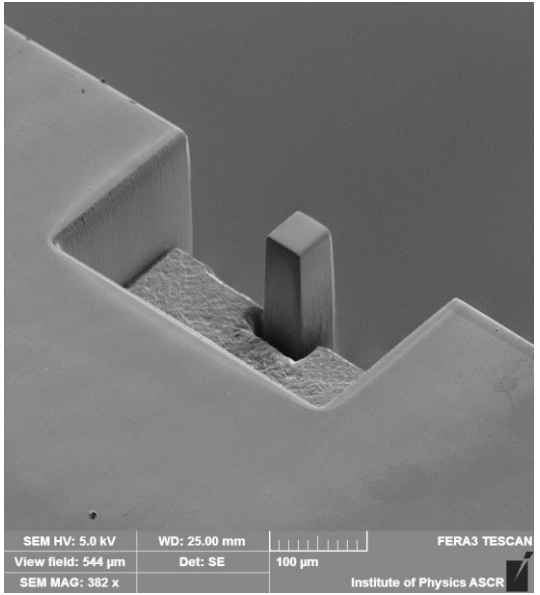


MSM micropillars by focused ion beam milling

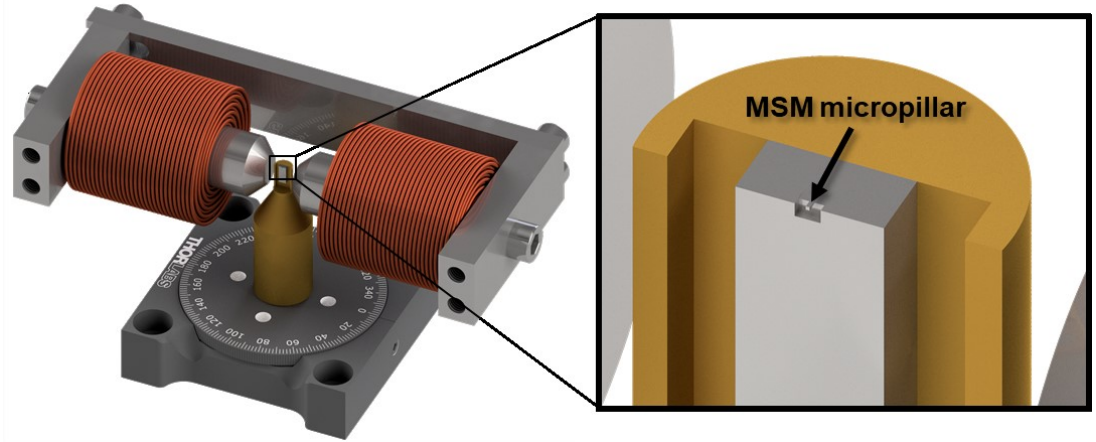


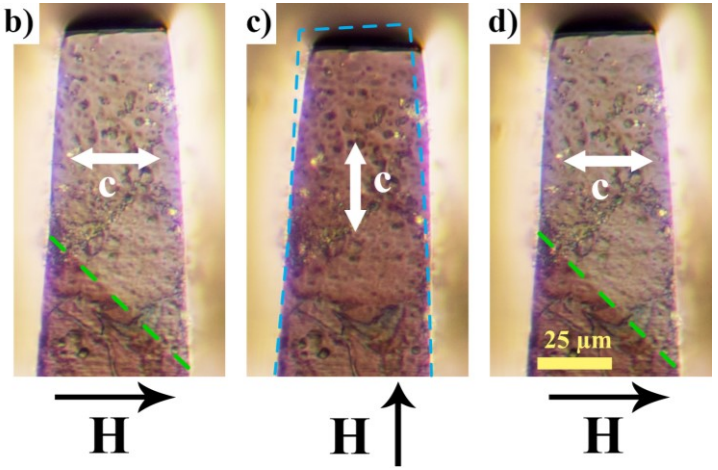


TESCAN FERA3
with ECR-generated
Xe plasma FIB milling



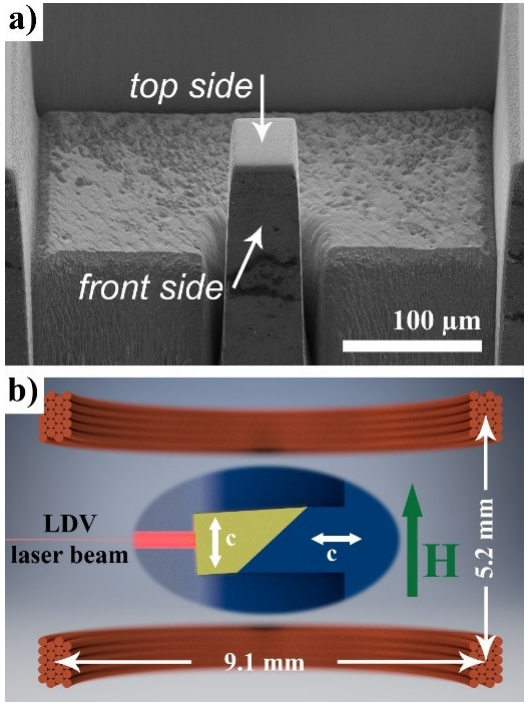
6% magnetic-field-induced strain in micropillar

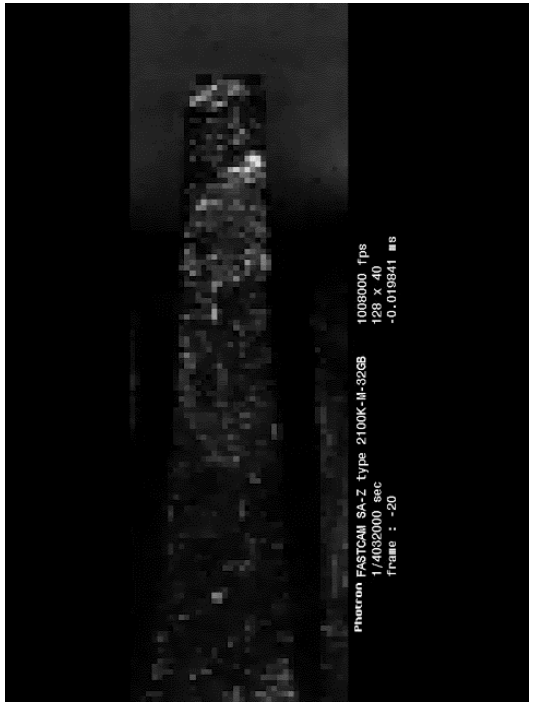




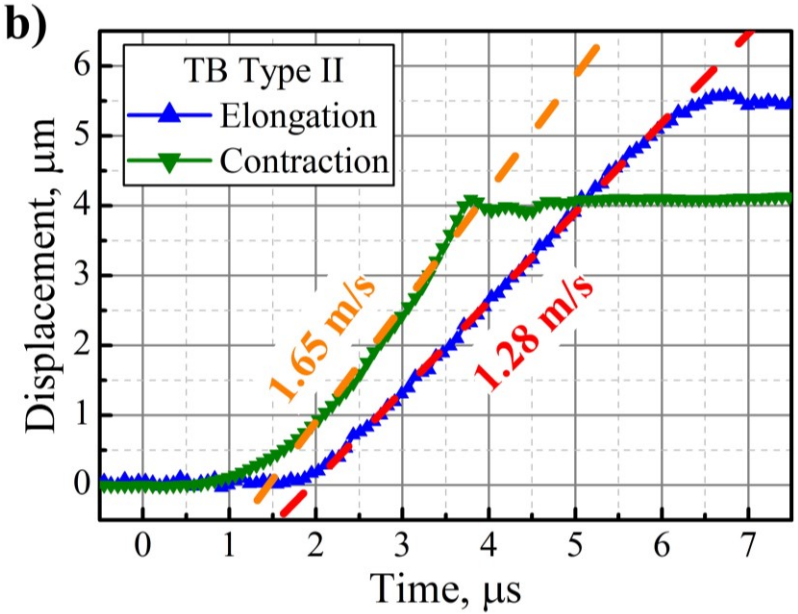
Musiienko, Denys, et al. "Giant magnetic-field-induced strain in Ni-Mn-Ga micropillars." Scripta Materialia 150 (2018): 173-176.

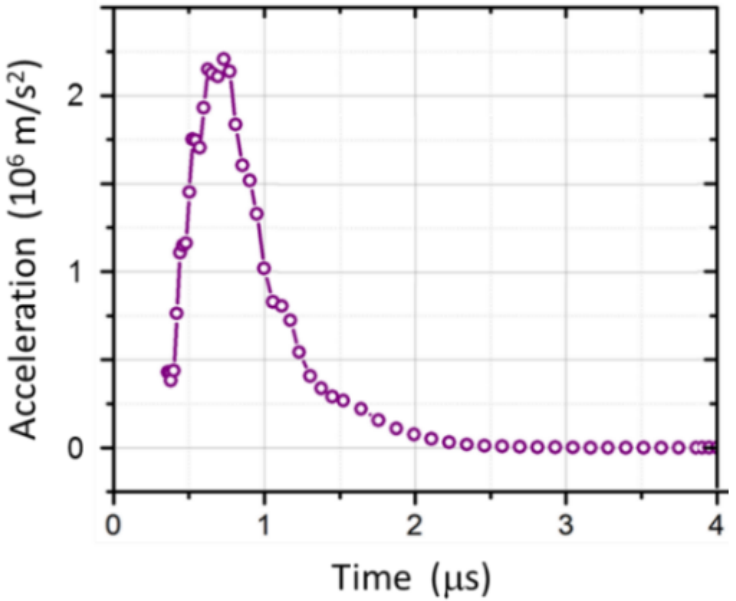
Ultrafast actuation of MSM micropillar





Ultrafast actuation of MSM micropillar



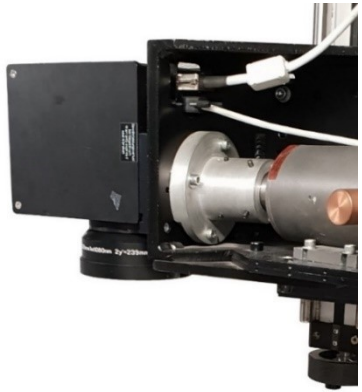


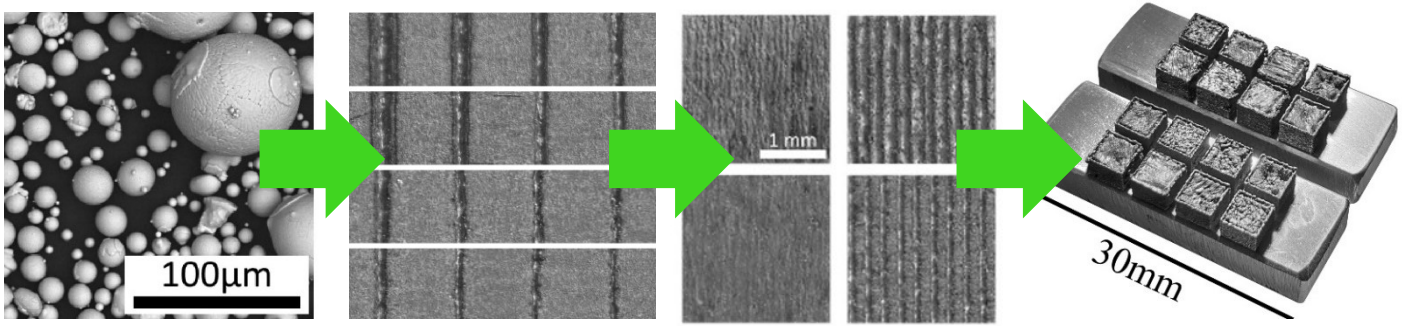
Additive manufacturing at MPL

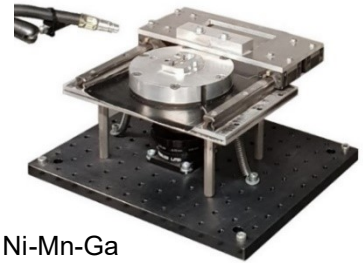
Laser powder bed fusion (L-PBF) of Ni-Mn-Ga and other active ferromagnetic alloys

- Process optimization
- Post processing and heat treatment
- Compositional, crystallographic and magnetic characterization

→ Collaboration with **Laboratory of Laser Processing**







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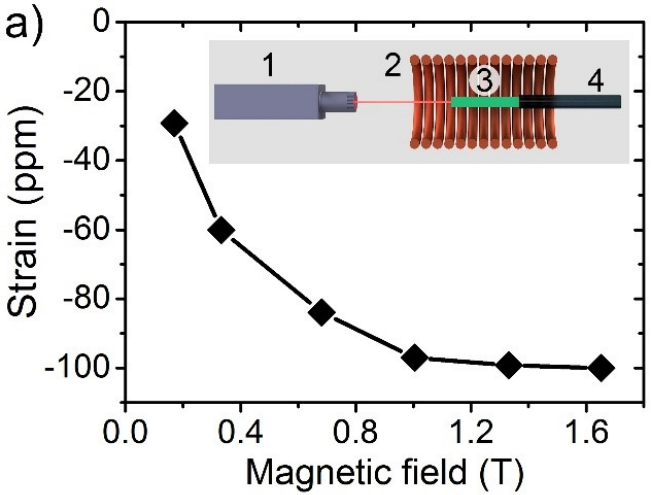
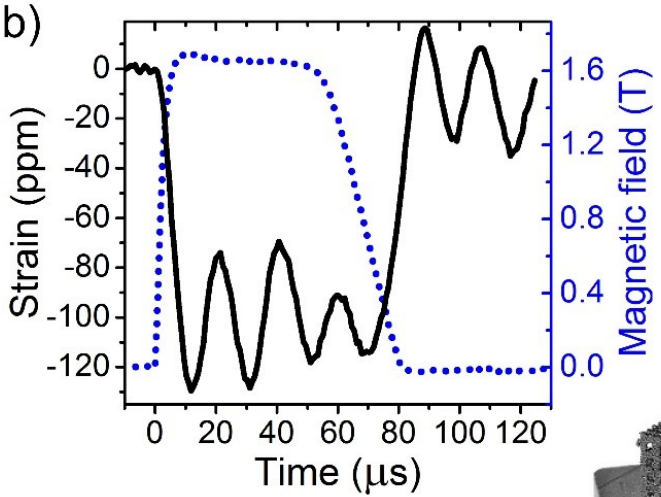
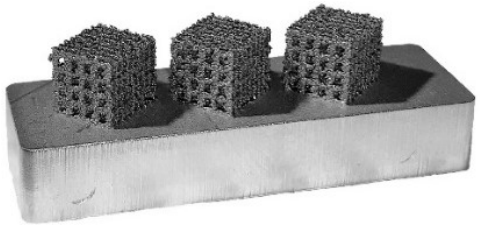
Additive manufacturing at MPL







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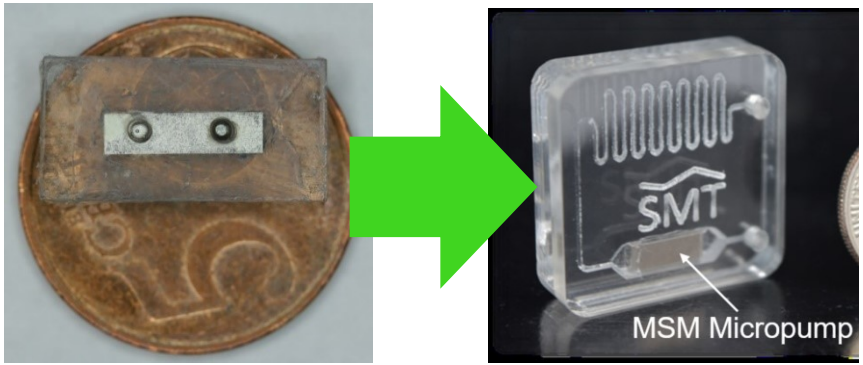
Additive manufacturing at MPL

Digital Light Printing (DLP) based vat photopolymerization process

- MSM micropump and microfluidics related casings
- In-house developed tools and research equipment
- Rapid prototyping



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