Actuator 3 – Piezoelectric and shape memory alloy technology

ME490A

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Adapted from a presentation by Dr. Kee Moon


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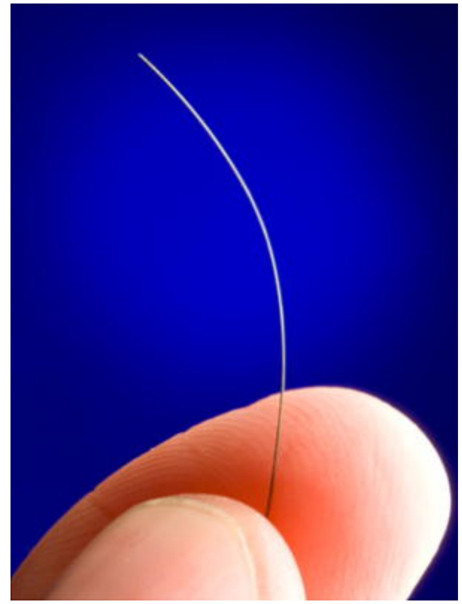
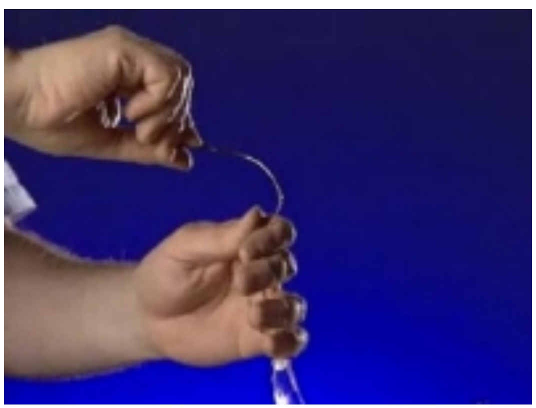
Linear
Motor
Products



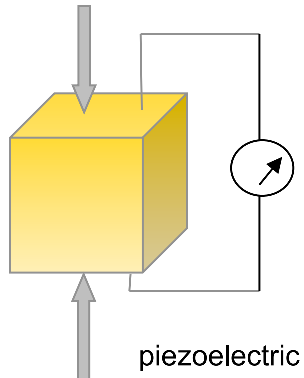



A
B

Piezoelectric property

Direct piezoelectric effect: Certain materials produce electric charges on their surfaces as a consequence of applying mechanical stress. The induced charges are proportional to the mechanical stress.

converse piezoelectric effect: Materials showing this phenomenon also conversely have a geometric strain proportional to an applied electric field.



piezoelectric effect
(sensor application)

Piezoelectricity is extensively utilized in the fabrication of various devices such as transducers and actuators.

Piezoelectric property

Piezoelectric Strain Constant d
The magnitude of the induced strain x by an external electric field E is represented by this figure of merit (an important figure of merit for actuator applications):
$x = d E$.

Piezoelectric Voltage Constant g
The induced electric field E is related to an external stress X through the piezoelectric voltage constant g (an important figure of merit for sensor applications):
$E = g X$.

Electromechanical Coupling Factor k
k2 = (Stored mechanical energy / Input electrical energy)
or
k2 = (Stored electrical energy / Input mechanical energy)

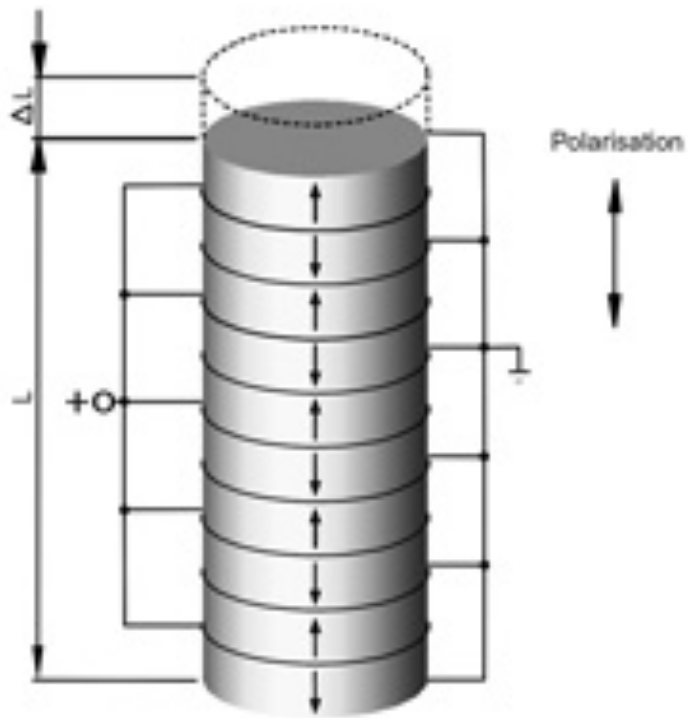
Single Crystals vs Polycrystalline Materials

Polycrystalline Materials: Piezoelectric Pb(Ti,Zr)O3 solid solutions [PZT] ceramics have been widely used because of their superior piezoelectric properties.

Though, the PZT films may bring dielectric constant up to around 600 by using PZT powder, it also raises its acoustic impedance; Meanwhile, due to the porosity of the PZT materials, the electromechanical coupling coefficient is *kt* ~ 0.3, which is not high enough to provide a high acoustic performance.

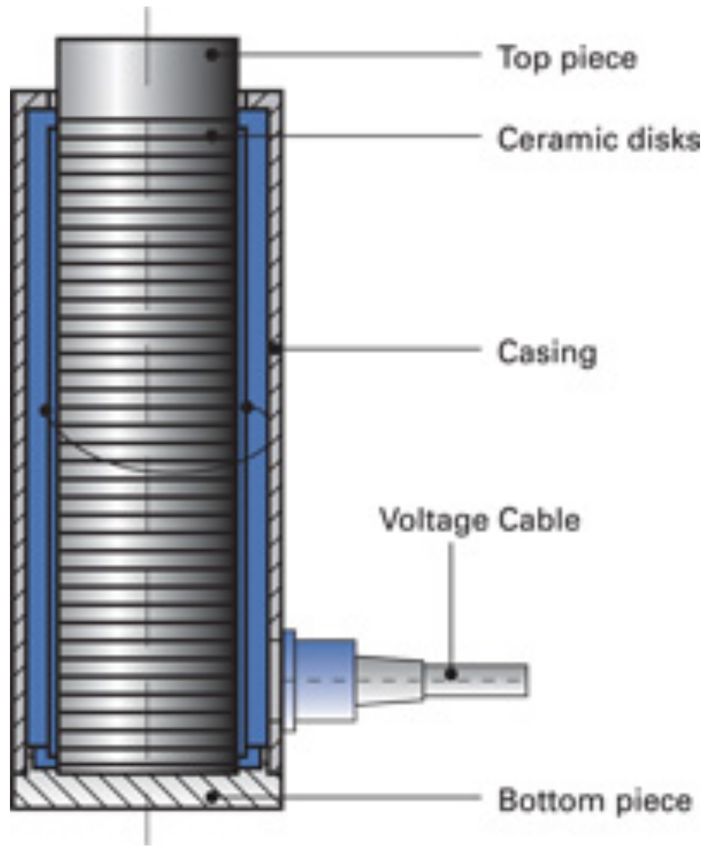
Mechanical Quality Factor QM
The mechanical quality factor, QM, is a parameter that characterizes the sharpness of the electromechanical resonance spectrum.

PIEZO ACTUATORS



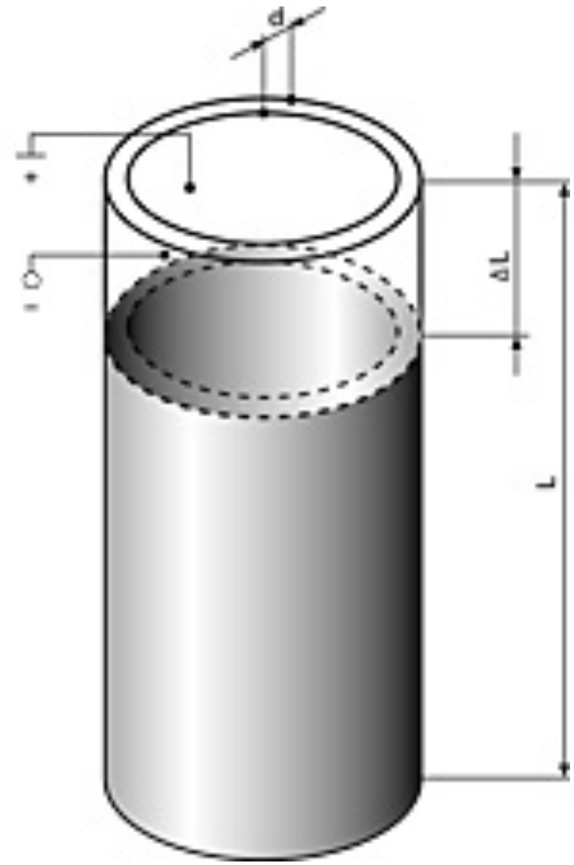
Electrical design of a stack translator.

PIEZO ACTUATORS



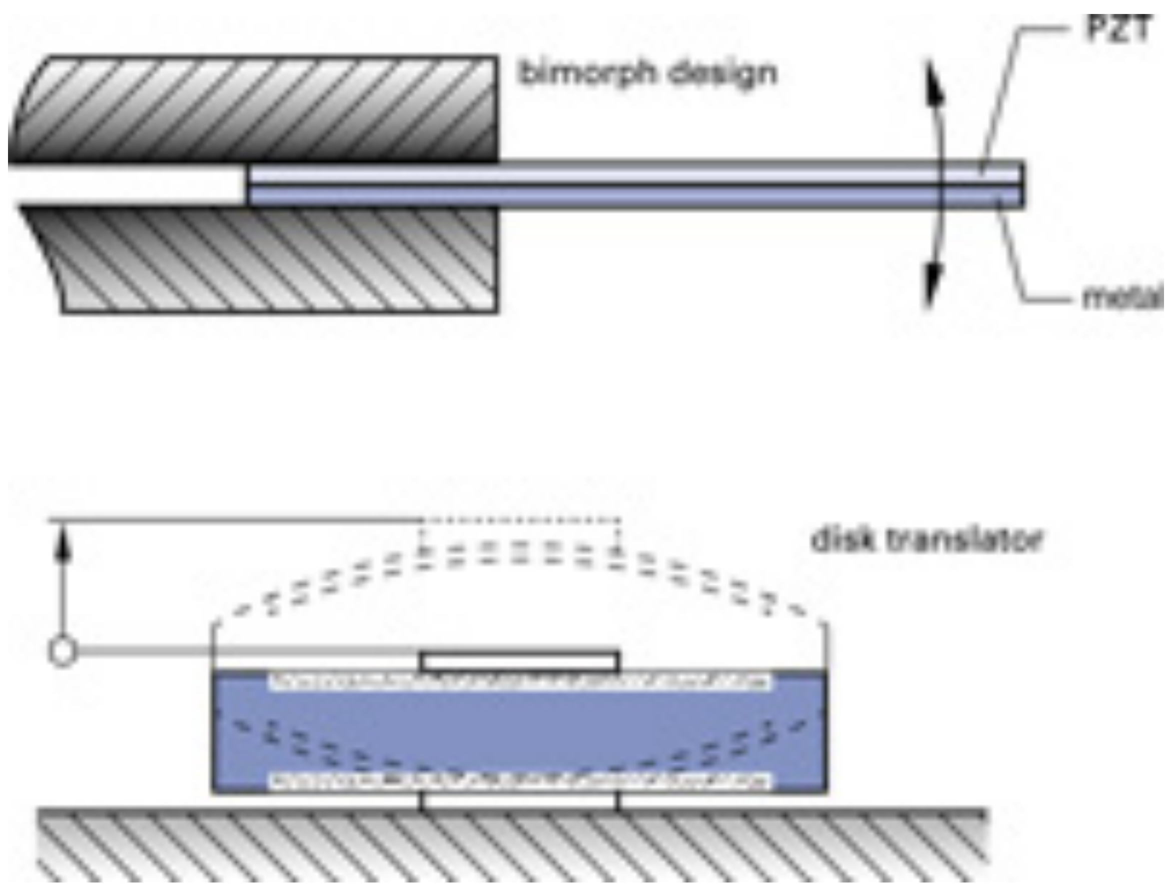
Mechanical design of a stack translator.

PIEZO ACTUATORS



Tube actuator design.

PIEZO ACTUATORS



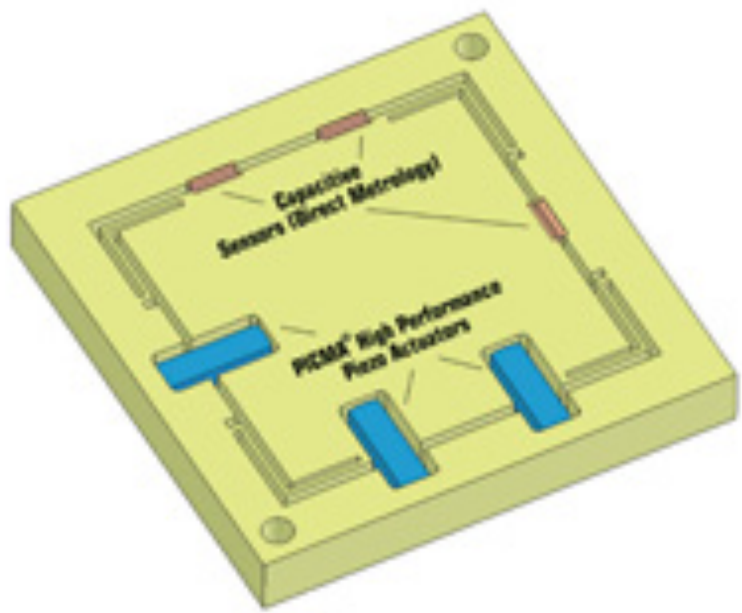
Bimorph design (strip and disk translator).

PIEZO ACTUATORS

Parallel and Serial Kinematics / Metrology

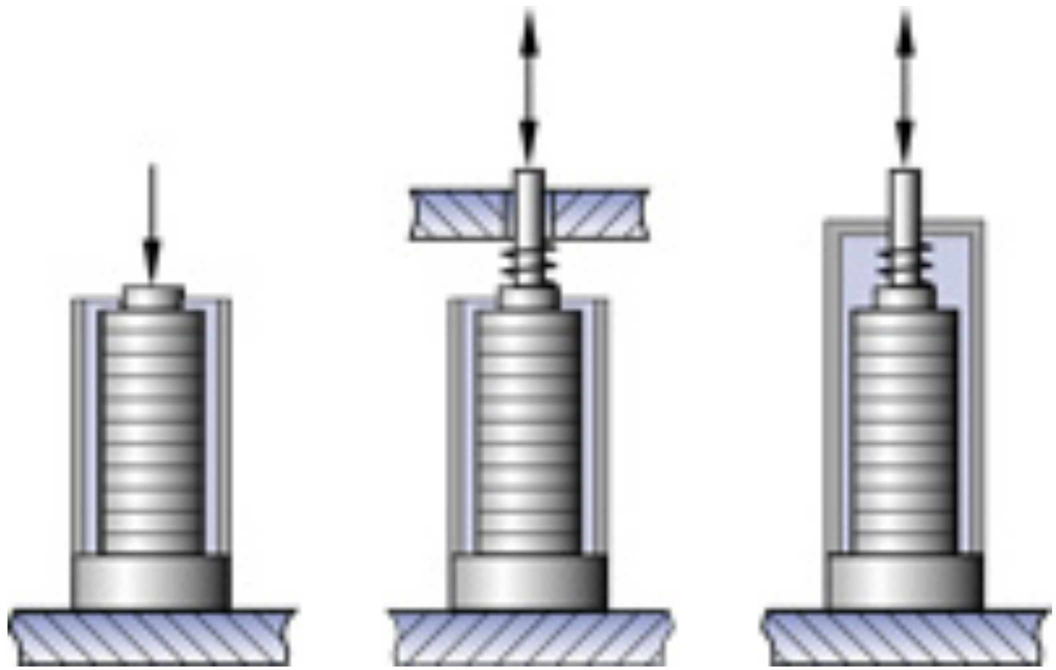
-Direct and Indirect Metrology

-Parallel and Serial Kinematics



PIEZO ACTUATORS

Mounting Guidelines for Piezo Translators



No pulling force without preload.

PMN-PT

Commercial
PMN-PT bulk

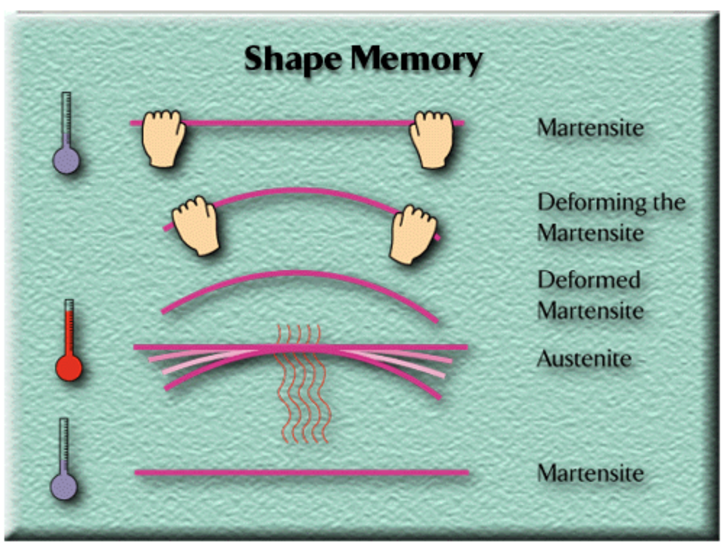
PMN-PT provides a means of
advancing the performance of
high
frequency transducers far
beyond the capability of
conventional
ceramic devices

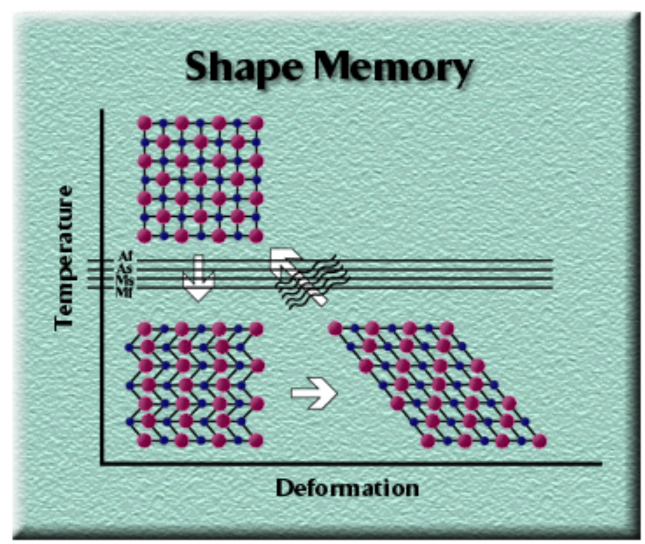
SMA wire "Muscle Wire" actuation

- SMA wire (Shape Memory Alloy Wire) or "Muscle wire" is an alloy made in a wire form using approximately 50% titanium and 50% nickel.
- This alloy is drawn down to small wire diameter sizes to be used for actuation designs.

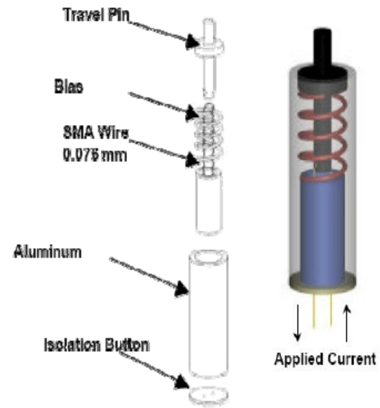
Thermal shape memory actuation

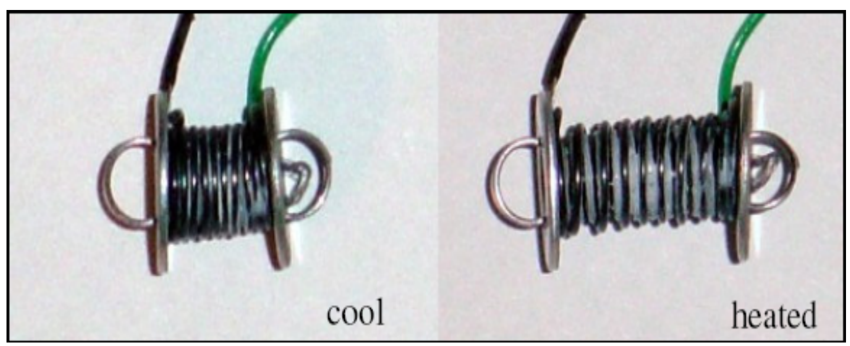
- SMA (Shape Memory Alloy Wire) is an alloy that "remembers" its shape
- The transformation from austenite to martensite (cooling) and the reverse cycle from martensite to austenite (heating) does not occur at the same temperature.





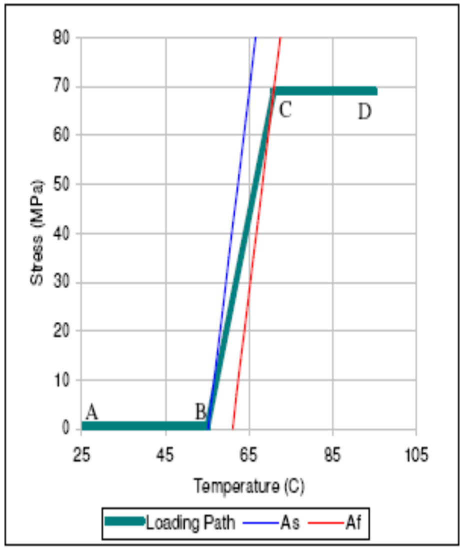
Thermal shape memory actuation examples





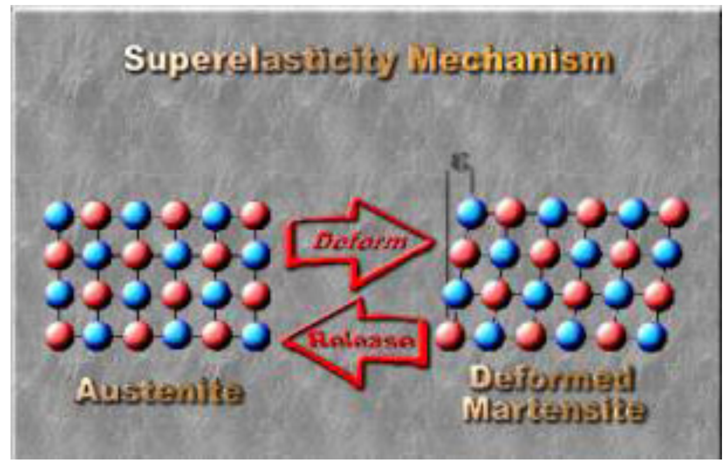
Nitinol "Muscle Wire"

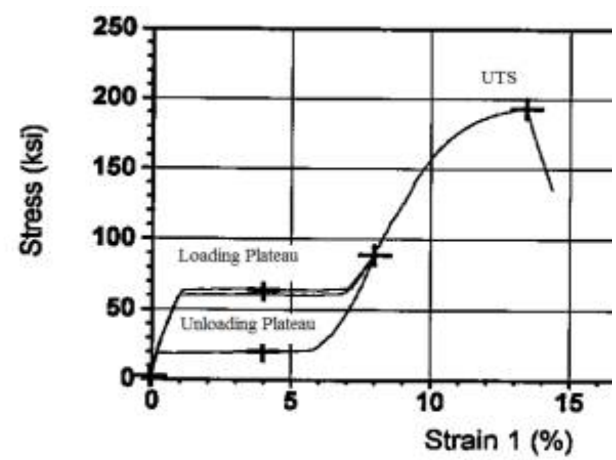
- Nitinol is ageneric trade name for NiTi alloys, which stands for Nickel (Ni), Titanium (Ti) and discovered in the early 1960s.
- NiTi alloys after an apparent deformation in the martensitic phase have the ability to recover their original shape upon heating through the phase transformation temperature range above the Austenite finish (Af) temperature temperature. (~60 degree C)
- http://www.nitinol.info/pages/technology.html



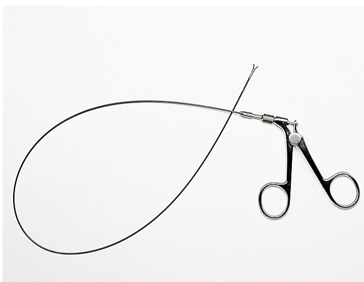
What is superelasticity?

- Also termed “pseudoelasticity”, superelasticity describes a nonlinear recoverable deformation behavior of NiTi alloys at temperatures above the Af temperature
- Arises from the stress-induced martensitic transformation on loading and the spontaneous reversion of the transformation upon unloading.
- A transformation-induced strain up to 6% is recoverable.
- Cold worked NiTi alloys exhibit extended linear elasticity where a strain as high as 3.5% is recoverable with minimal plastic deformation.





Superelasticity = Flexibility



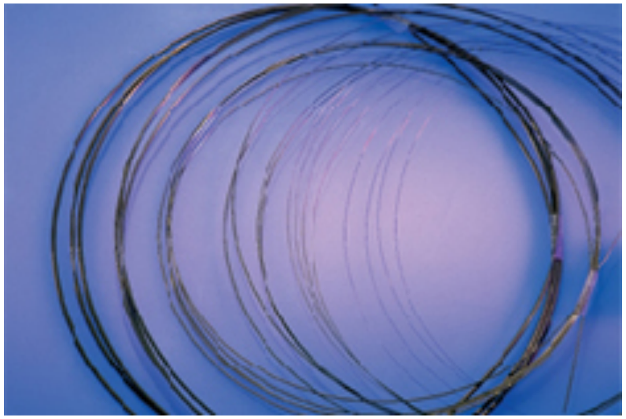
Grasper w
ith flexible
Nitinol tub
e

Nitinol eye
glass
frames

Nitinol wires

Round wire
OD: 0.001" to 0.250"
Condition: Straight or As drawn
Surface options: Bright polished, Black oxide, Etched, Sand blasted, Ground

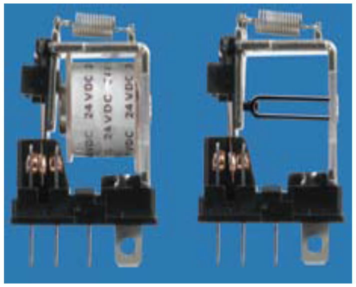
Rectangular wire
Thickness: 0.004" to 0.080"
Condition: Straight or As drawn
Surface options: Bright polished, Black oxide, Etched



Nitinol applications

PROPERTY	CONSUMER APPLICATIONS	MEDICAL APPLICATIONS
Thermal Shape Memory	Actuators	Heart Valve Tools
Flexibility & Kink Resistance	Fishing Lures *Eyeglass Frames* Cell Phone Antennas	Guidewires Endodontic Files *MIS Instruments*
Elastic Springback	Cell Phone Antennas	*Homer Mammalok®* Needles
Constancy of Stress	Brassiere Wire Eyeglass Frames	*Archwire* Stents MIS Instruments
Elastic Deployment		Septal Defect Device *Hingeless Instruments* *Baskets*
Thermal Deployment		Stents Simon Blood Filter®
Biomechanical Compatibility		Bone Anchors Staples, Spacers
Dynamic Interference (Stress Hysteresis)		Stents Filters
Biocompatibility		Implants
MRI Compatibility		Open MRI Instruments Needles

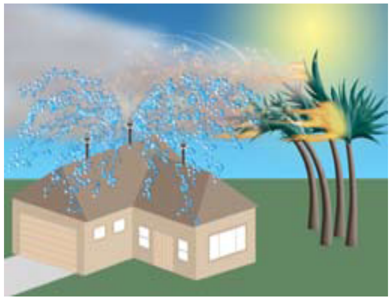
Device examples



Muscle Wire replaces
wound coils in
relays & solenoids.

Wire when heated moves
arrow
with gear. Linear motion is
translated to rotary motion.

Device examples (continued)

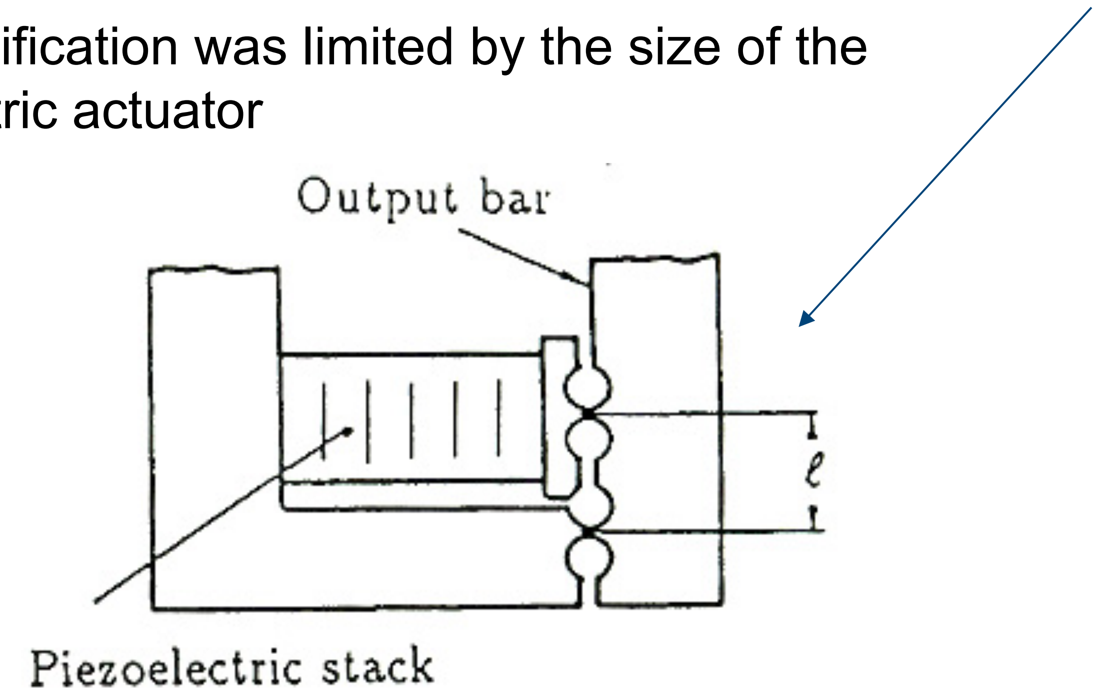


Heated air from fire
activates water valve
which sets off sprinkler
system that waters
the roof.

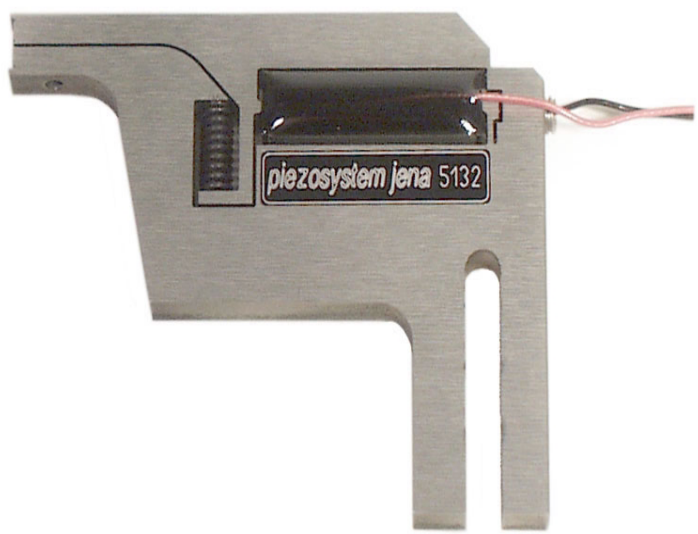
Engine air louver system opens
& closes
louvers open when heat from
the car
engine activates the muscle
wire.

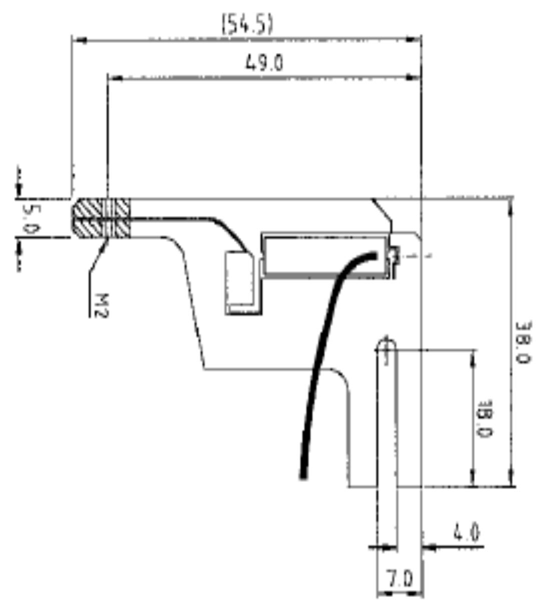
Magnifying Mechanism for Piezos

- Need accurate magnification
- However, space restriction, l
  - Usually amplification from flexure pivoted mechanical lever
  - The magnification was limited by the size of the piezoelectric actuator



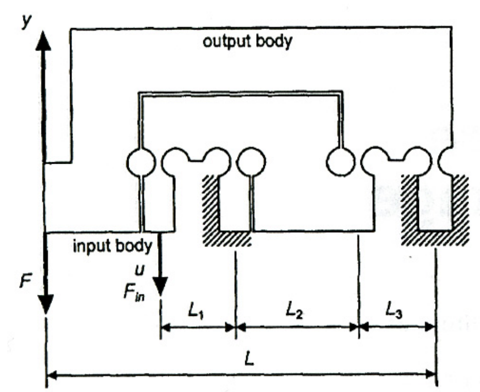
Other examples: a compact piezoelectric gripper (tweezers)

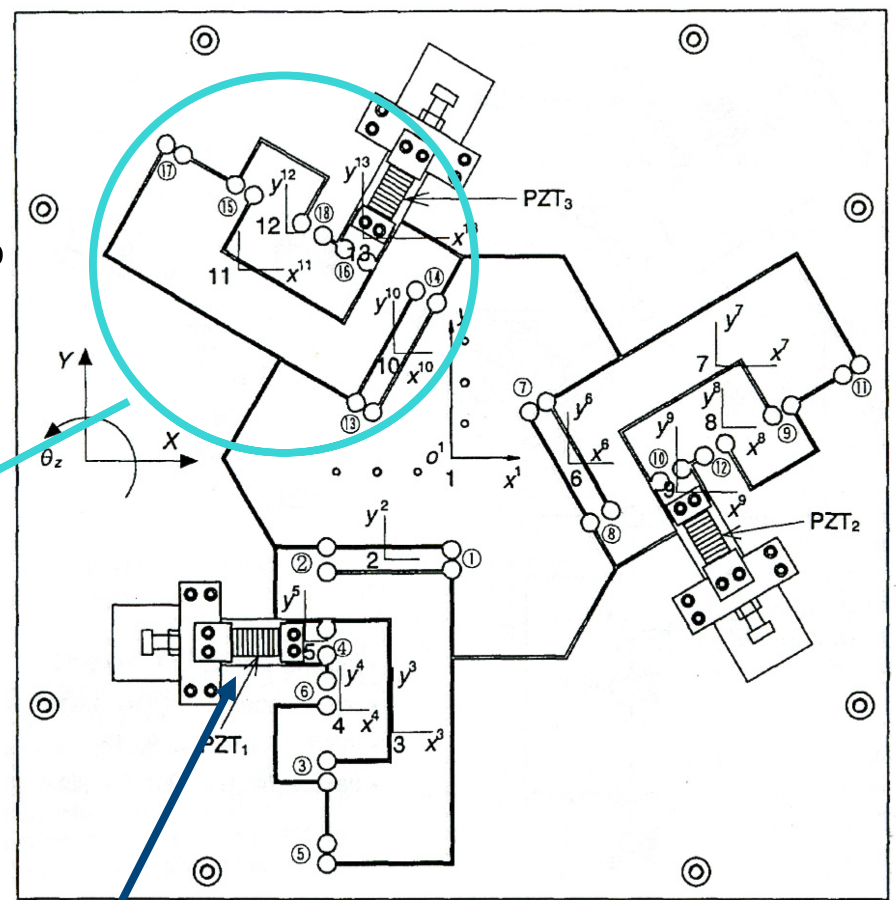




Flexure Hinge for XYθ Wafer Stage

- Components
  - 3 piezoelectric actuators
  - 1 monolithic mechanism
    - 3 double compound mechanical lever hinges to amplify motion
    - Symmetric structure for temperature tolerance



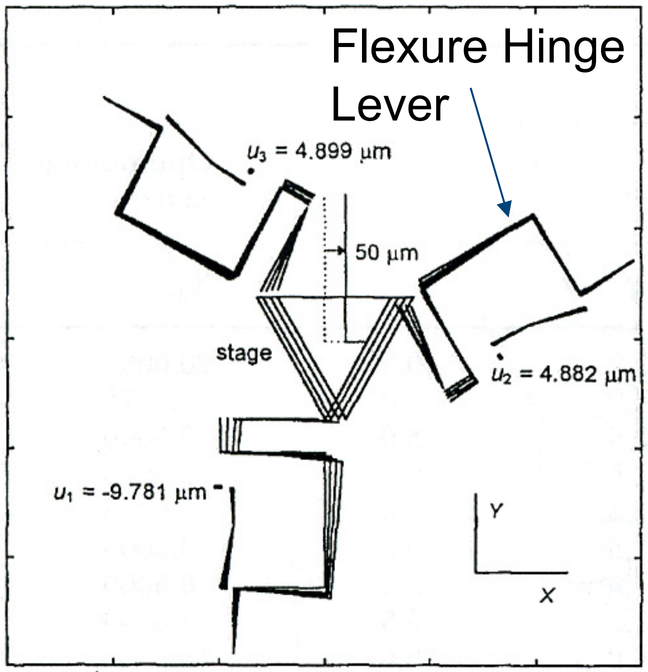


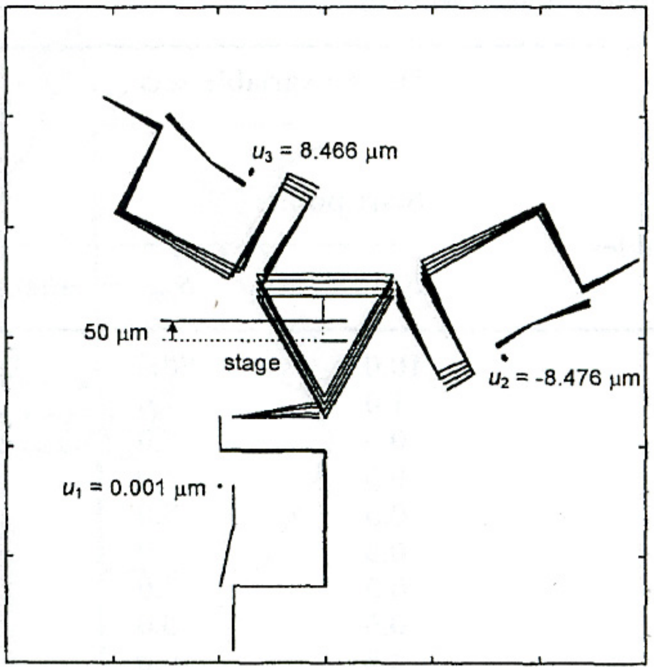
Piezoelectric Actuator

Displacements are usually less than 10μm

Flexure Hinge for XYθ Wafer Stage

- Fine positioning
  - Parallel linkage was originally used
    - Problem: The yaw motion had a limit of 36 arcsec
  - With the proposed Flexure Hinge for XYθ Wafer Stage
    - Yaw motion of 322.8 arcsec





Application: HexFlex Nanomanipulator