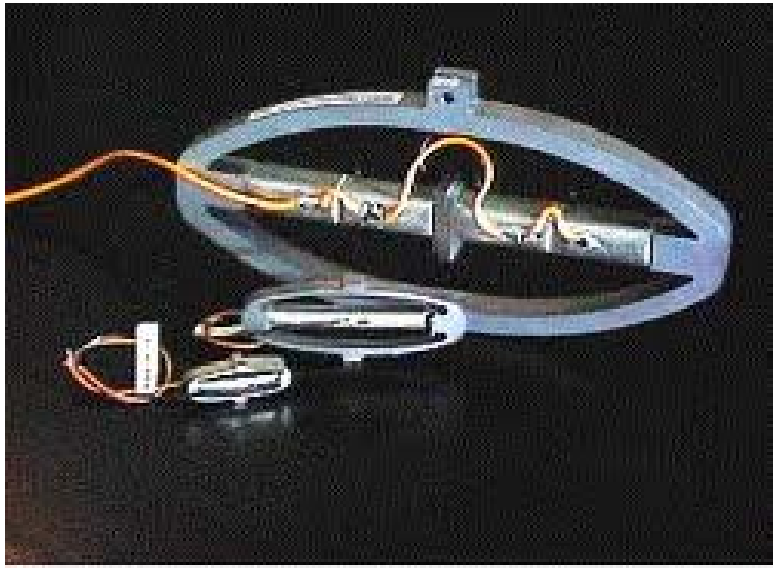
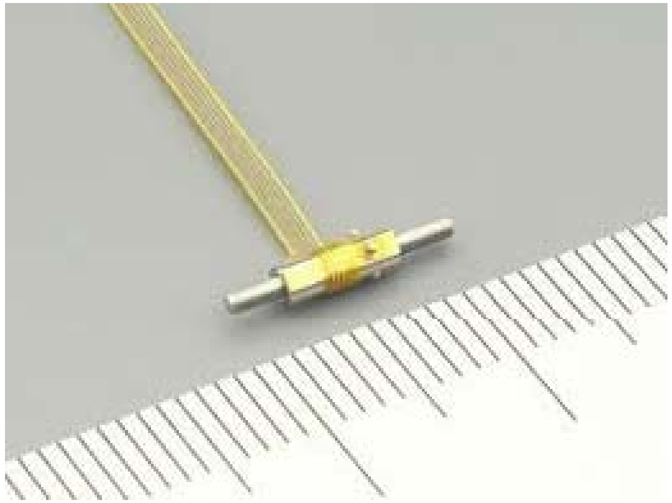


APA230L, APA150M, APA100S

Actuators & Sensors based on HBLS Smart Materials – Device Design



Bishakh Bhattacharya

Department of Mechanical Engineering

Indian Institute of Technology, Kanpur

Topics Covered in the Last Lecture

- HBLS Smart Actuators
- Multilayered Piezoelectric Materials
- Design Issues
- Advanced Devices

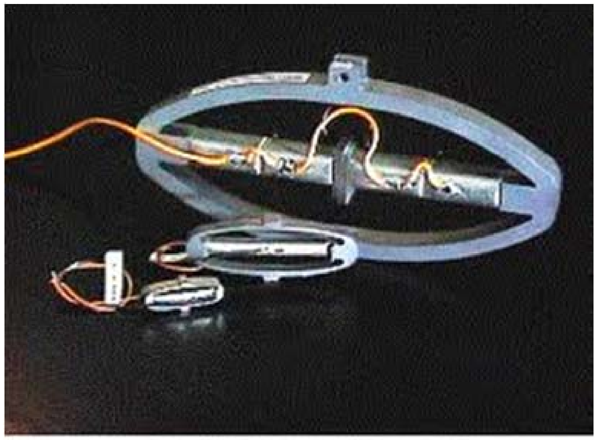
This lecture will cover

- Piezoelectric Inchworm Devices
- Piezoelectric Fuel Injectors
- Ultrasonic Motors

Two Smart actuators

- Thin Disk Buzzer

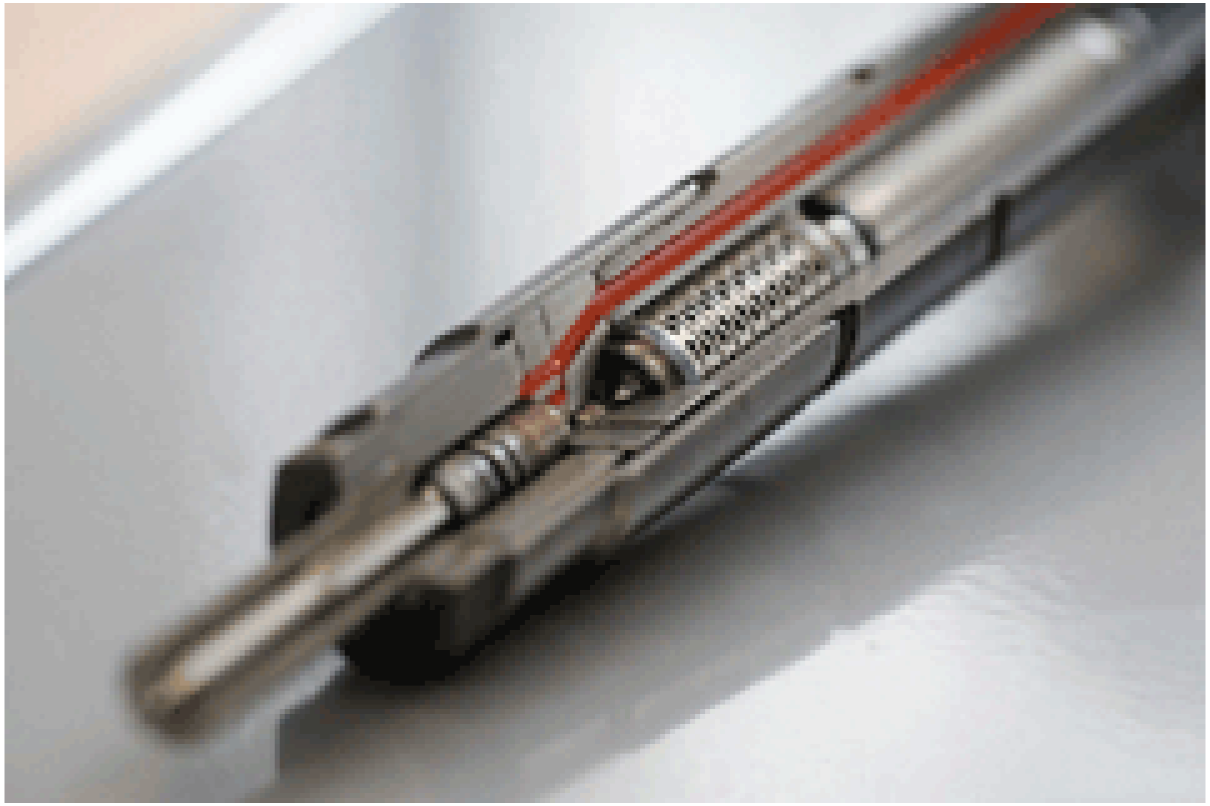
- Amplified Piezo Actuator



APA230L, APA150M, APA100S

Introduction

- Current trend in Automotive Electronics is to use actuators for functions which require faster, more powerful and highly precise motion.
- Initiated application of Piezoelectric Actuators and Rheological Fluids for the control of Fuel Injection and motion control.
- Simple Unimorph/Bimorph/Discs are not popular in the industrial scale due to lack of efficiency, displacement and safety.



Cut-out of a Piezoelectric Fuel Injector from EPCOS

Comparison of Different Actuators

Type	Device	Accuracy	Response
Pneumatic	Motor	Degrees	10 secs
Hydraulic	Motor	Degrees	1 sec
Electro-magnet	Stepper	10 µm	0.1 sec
Piezoelectric	Actuator	0.01µm	0.0001 sec
Magnetostrictive	Actuator	0.01µm	0.0001 sec
Piezoelectric	Ultrasonic	minutes	0.001 sec

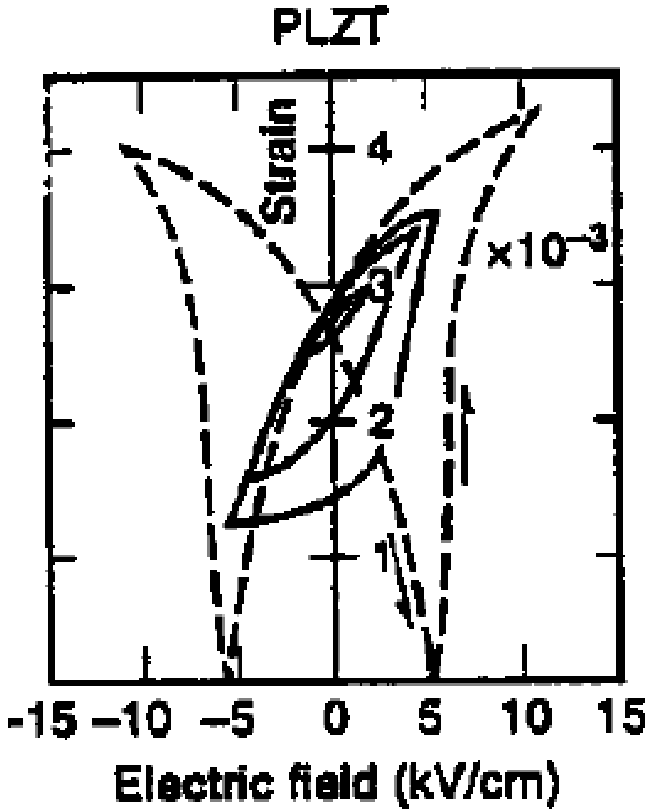
How can we Maximize the Displacement?

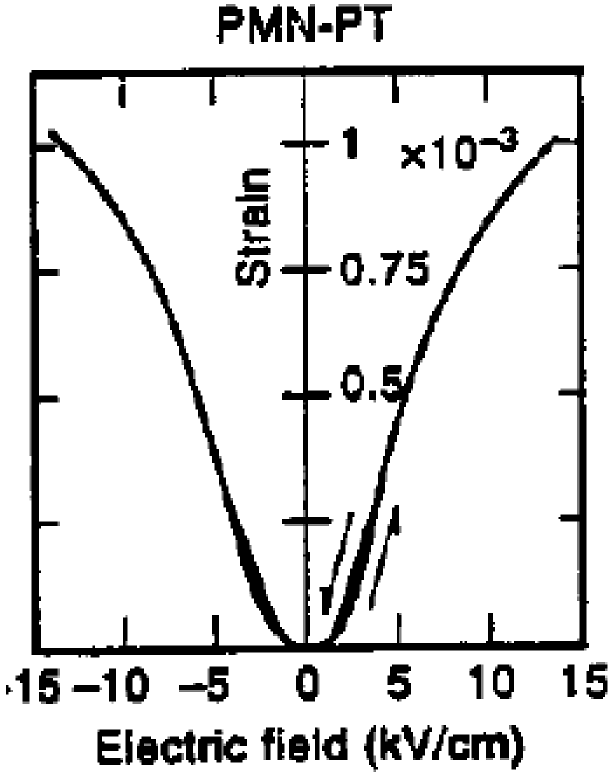
Consider a multilayered piezoelectric stack of length *l* and number of layers *n*, which is subjected to a voltage *V*.

Neglecting elastic deformation, total displacement available from a '*n*' layered stack will be:

$\Delta = (l \times d \times V/(l/n)) = d \times V \times n$

Total displacement is directly proportional to the number of layers n!





A Piezo and an Electrostrictor [Uchino, 2003]

Even more for Electrostrictors

Consider a multilayered electrostrictive stack of length *l* and number of layers *n*, which is subjected to a voltage *V*.

Neglecting elastic deformation, total displacement available from a ‘*n*’ layered strictor will be:

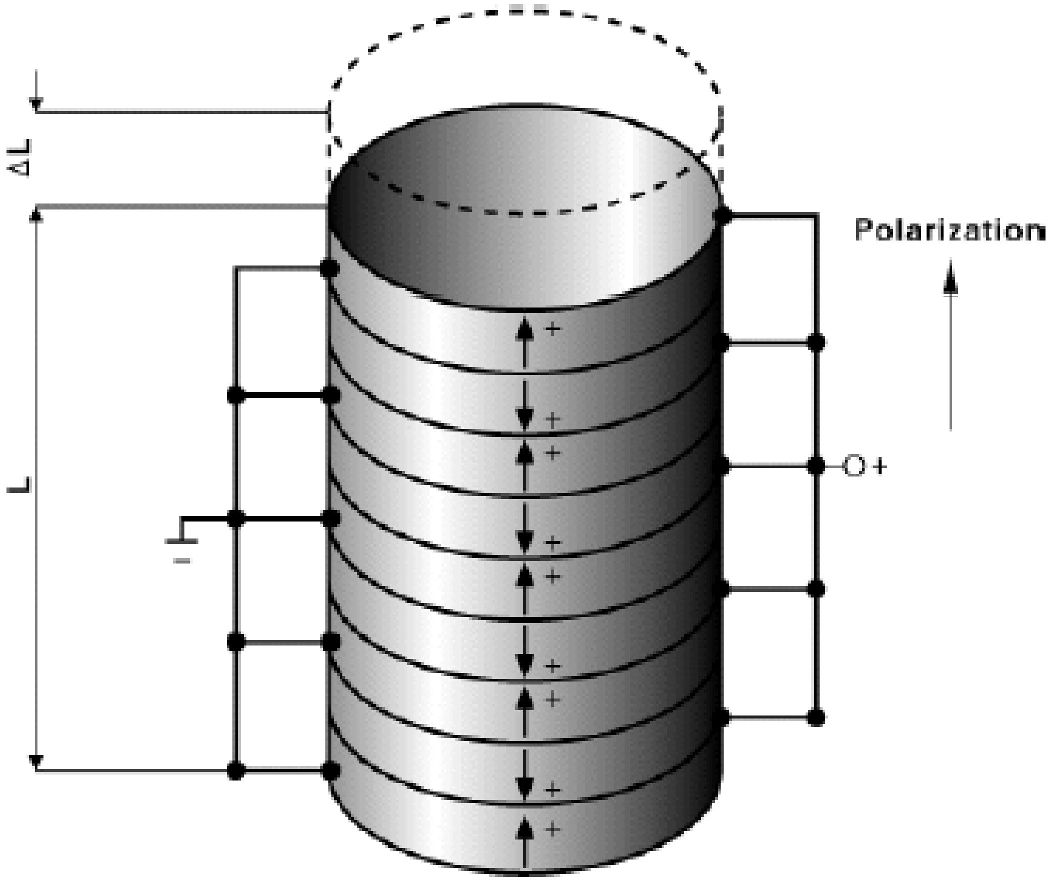
$$\Delta = [\, l \times d\, X\, (V/(l/n))^2 \,] = (d/l)\times V^2 \times n^2$$

Total displacement is directly proportional to the number of layers n^2 !

Multilayer Actuators

- Typical layer thickness is about 50μm
- Typical strain available 0.1%
- Hence, for a 100 mm stack actuator with 2000 piezo-eletcric layers and an applied voltage of about 100V, the displacement will be: $10 \times 10^{-9} \times 100 \times 2000 = 200$ μm
- Blocking force = 100 kgf
- Lifetime = 10^{11} cycles

A Typical Multilayer Configuration



Other important properties

- The resonating frequency of a fixed-free multilayer actuator is given by:

$$f_n = \frac{1}{2l\sqrt{\rho S_{33}^D}}$$

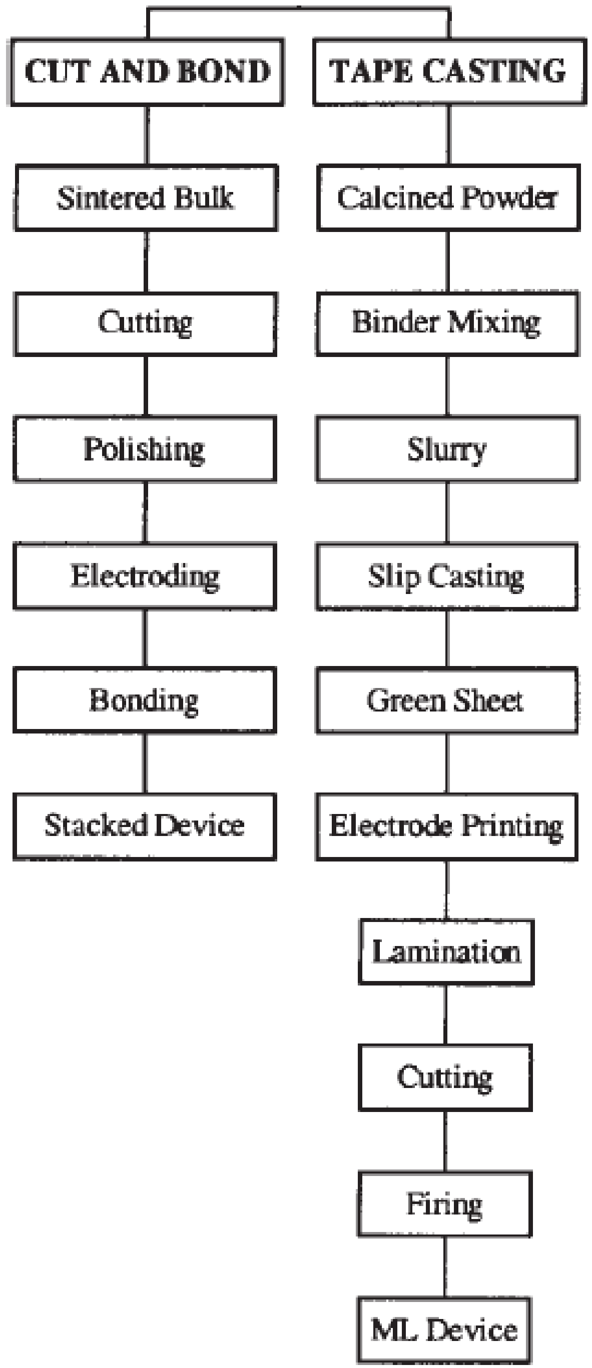
- Where, ρ is the density and S_{33} denotes the compliance modulus
- For example, one 1 cm sample will have resonating frequency about 100 kHz.

Advantages of Multilayered Piezoelectric Actuators

- Requires less voltage
- Produces larger deformation/displacement
- Safer to use
- High Life Cycle
- Lighter and More Compact
- Concurrent engineering – advantages from the development of multi-layered capacitors

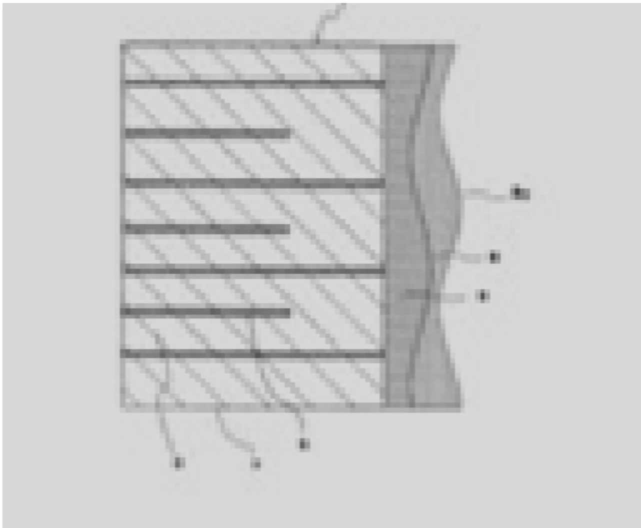
How multilayers are developed?

- Two common techniques – Cut and Bond and Tape-Casting
- In cut and bond technique PZT wafers are cut (typical thickness 0.2mm) and bond with intermittent metal foils. Major draw back is that this is a labor intensive process.
- In tape-casting method, ceramic green sheets are printed with electrodes and cofired. There are various ways of electrically connecting such layers.



Reference:
J. Pritchard, C. R. Bowen,
and F. Lowrie, 2000

Various electrode configurations



Interdigital Configuration

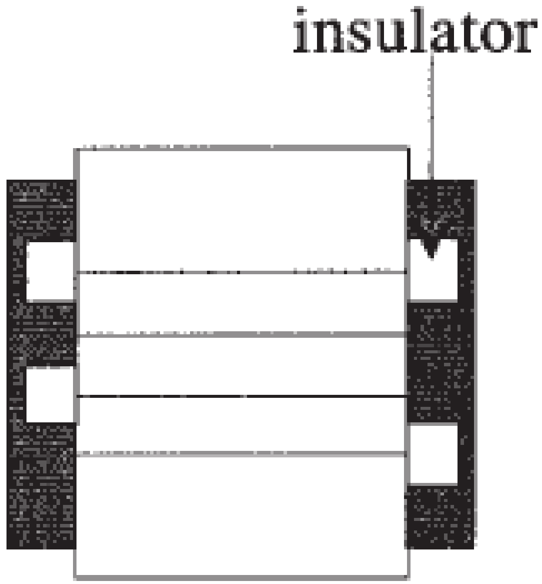
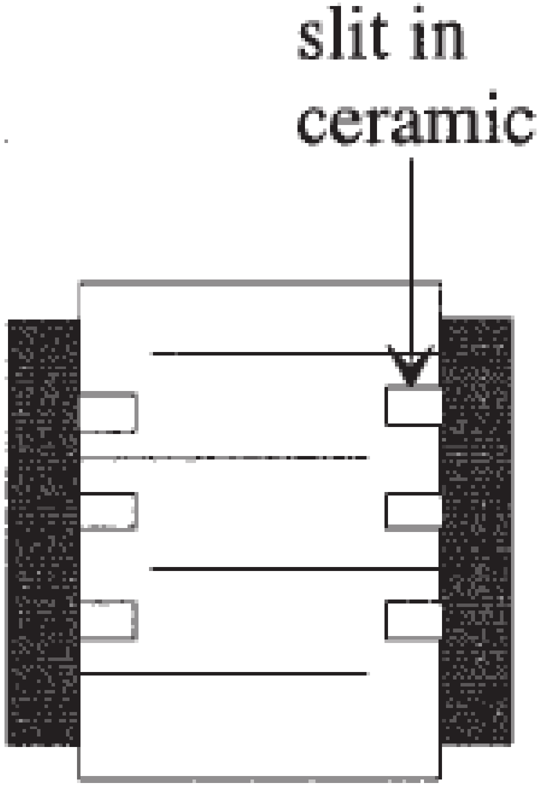
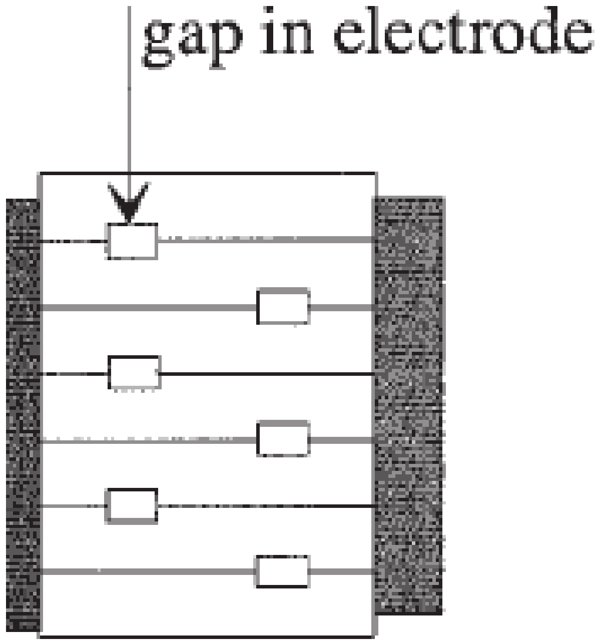


Plate Through Configuration

Some more configurations



Interdigital configuration with slit



Electrode with Gap

Design Issues: Electrode Configuration

- Interdigital Configuration is most common and best suitable for mass production. However, due to non-uniform electric field present towards the edges – stress concentration can occur which may lead to failure.
- All other configurations are developed to make the electric field more uniform and hence reduce the stress concentration.

Design Issues: Inactive Area

- Limited Strain is developed at the edge of the inter-digitated pattern

$$d_{31_{eff}} = \frac{d_{31_{bulk}}}{[1 + \frac{S_e t_e}{S t}]}$$

- Where, d_{31eff} is the effective coupling constant, S and t are the compliance modulus and thickness of piezo while the ones with e-subscript denote that of electrode.

Design Issues: Delamination

- Delamination can occur between the electrodes and the piezo layers due to binder burn-out, inadequate adhesion between the electrode and the ceramics and thermal expansion mismatch during sintering.
- Solution:
  – Control of Organic Binder
  – Decreasing the Metal Powder Surface Area

Design Issues: Effect of Composition

- Increase in Grain size increases piezoelectric effect but reduces the fracture toughness, also increases hysteresis and dielectric loss
- For electrodes – Ag-Pd alloy or Copper-Nickel Alloy are better as they have less thermal mismatch.

Design Issues: Heat Generation

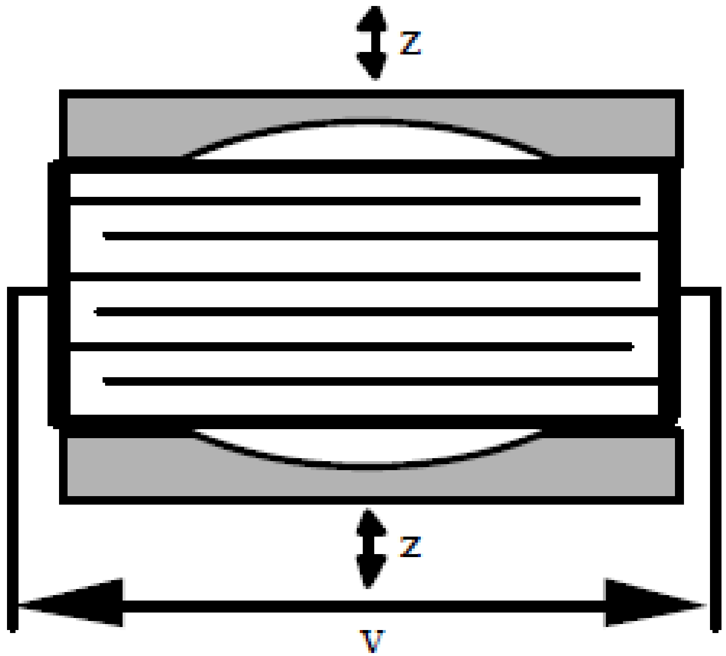
- Heat Generation during operation of such actuator could be expressed as:

$$\Delta T = \frac{U \; f \; v_{actuator}}{k(T)\,A}$$

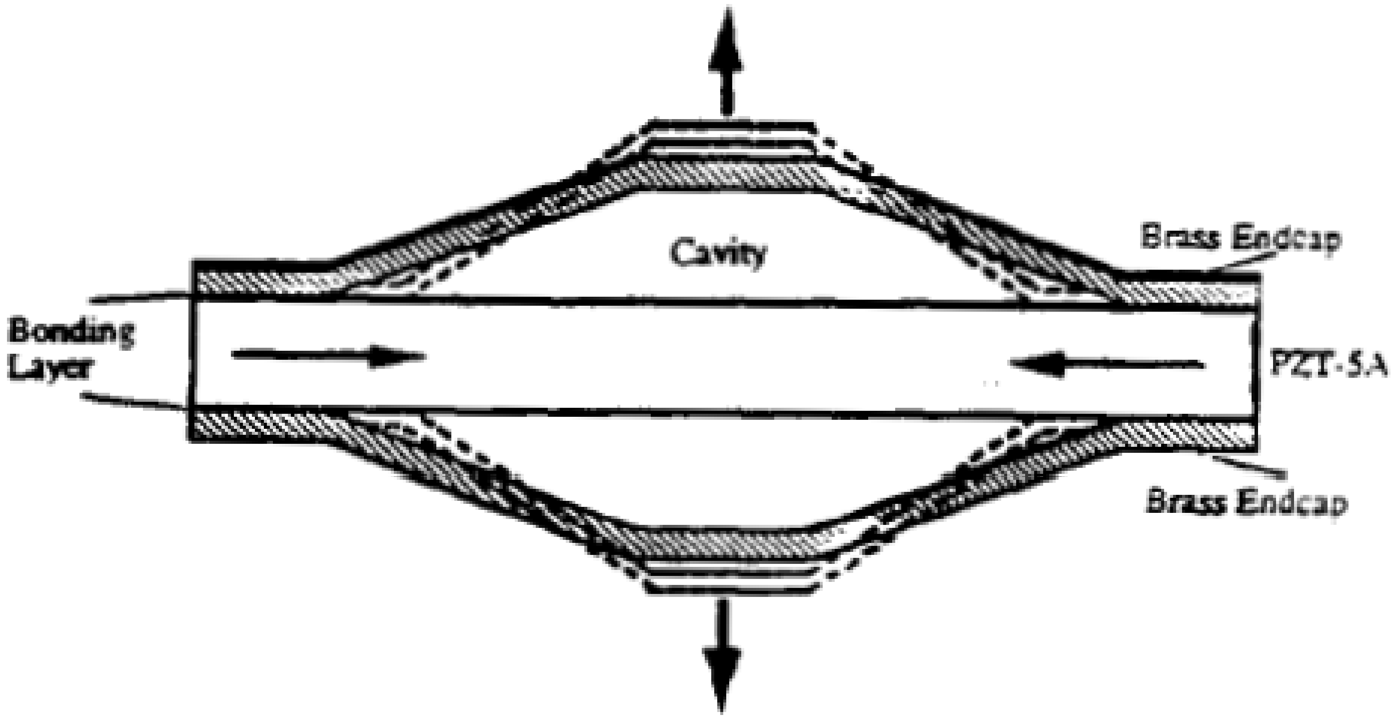
- *ΔT* – change in temperature, *U* dielectric loss per driving cycle per volume fraction, *f* – driving frequency, *v* – actuator volume, *k*- conduction coefficient and *A* – CS area

Further Amplification?

Moonie



Cymbals



A Comparison of Actuators

Device	Driving Voltage (V)	Displacement (μm)	Force (N)	Cost
MLA	100	10	900	High
Bimorph	100	35	1	Low
Rainbow	450	20	3	Medium
Cymbal	100	40	15	Low
Moonie	100	20	3	Medium

Special reference for this lecture

- Micro-mechatronics by Uchino & Giniewicz, Marcel, Dekker
- Kato, Fine Ceramics Technology
- Pritchard, Bowen, Lowrie; Multilayer Actuators: A Review, British Ceramic Transactions, 2001

Acknowledgement: Mr. G. Tripathi of the SMSS Lab for the experiment