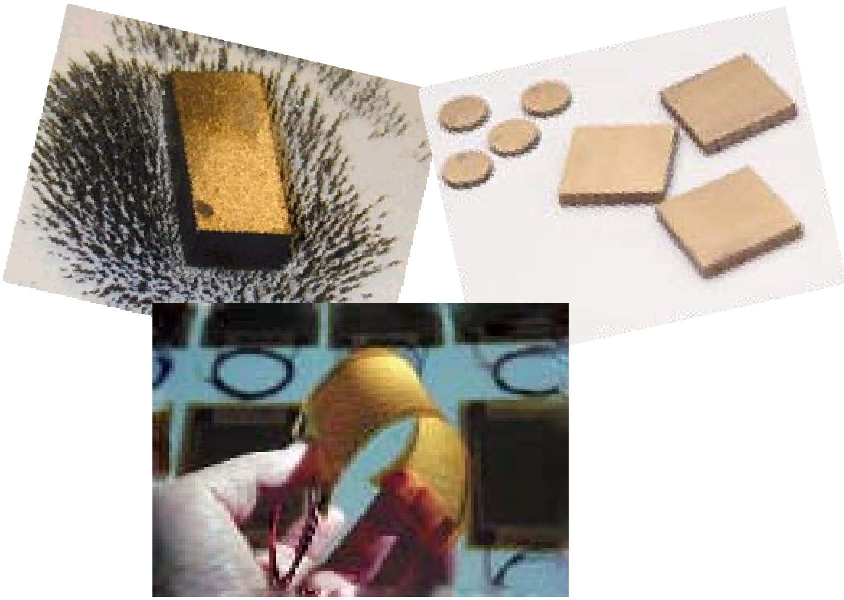
# Module 1: Overview of Smart Materials



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# Lecture #1: Introduction to Smart Material

- What is a Smart Material?
- Applications of Smart Material
- Smart systems using Smart Materials
- Smart Actuators
- Direct and Reverse Effects
- Piezoelectric Materials

# Features of Smart Materials

- These materials are a part of a group of materials broadly known as Functional Materials.

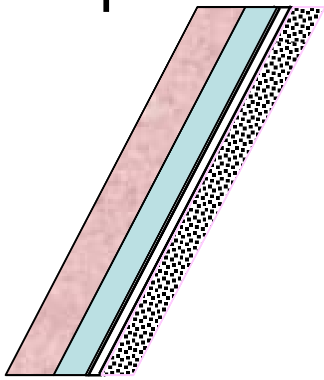
- The basic energy forms that gets interchanged are: thermal energy, electric energy, magnetic energy, sound energy & mechanical energy

- Analogous to Biological Materials: adaptivity, cellular function, self sensing, actuation & control

- Smart sensors & actuators are highly embeddable

# Smartness in a scale of intelligence

- Stupid – Dumb – Foolish – Trivial – Sensible – Smart/Clever – Intelligent – Wise
- Present smart materials are in the range from highly sensible to poorly intelligent level
- Passive smartness to Active Smartness; eg. of passive smartness - multiphase rocket nozzle of Space Shuttle
- Porous Tungsten with silver coating, Graphite, Ceramic Layer, Steel
- Passive smartness is in open-loop!



# Traditional vs. Smart Structure

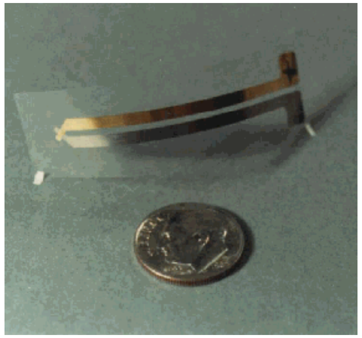
**Traditional structures**

- Designed for certain performance requirements eg. load, speed, life span
- Unable to modify its specifications if there is a change of environment

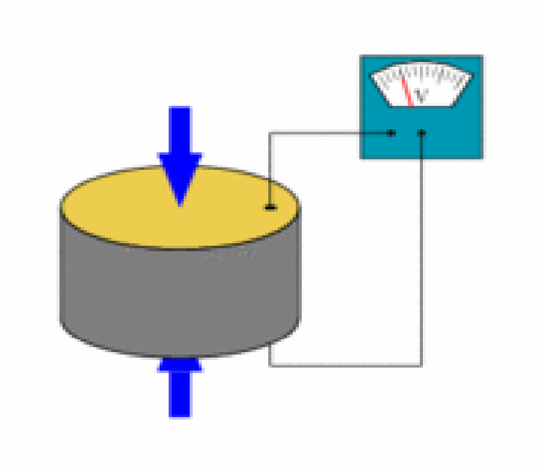
**Smart Structures**

- Can accommodate unpredictable environments
- Can meet exacting performance requirement
- Offer more efficient solutions for a wide range of applications

# Smart Materials



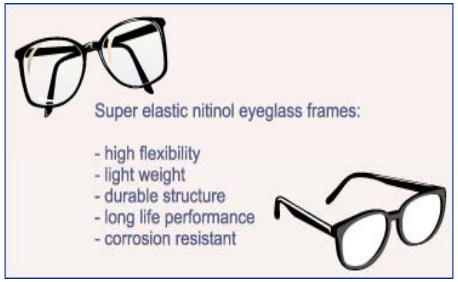
■ Piezoelectric film, PVDF



Piezoceramic, PZT

■SMA, Nitinol


MS Material, Terfenol-D




■SMA, Nitinol

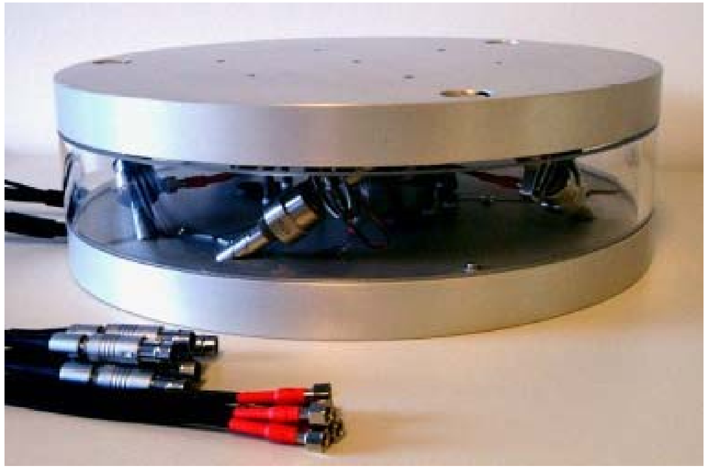
# Why smart sensors and actuators ?

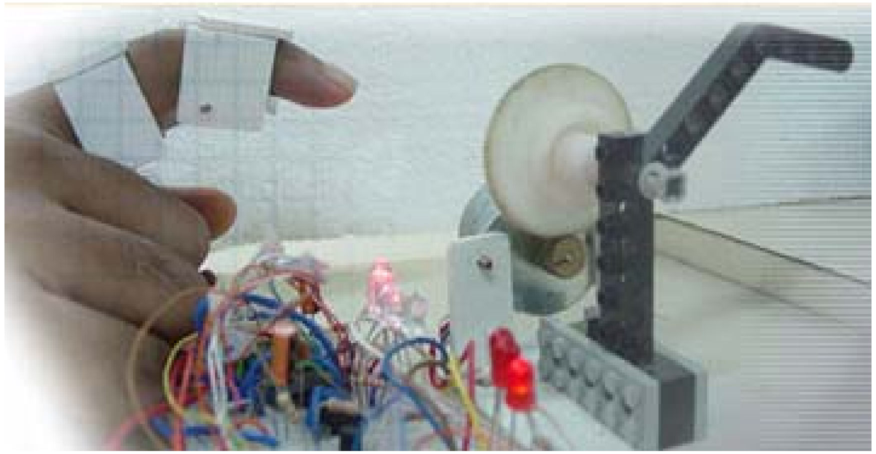
- Real time response
- Exploit functional properties
- Better embeddability
- Minimal effect on structural properties
- Reduction in weight
- Less power consumption
- Better reliability

# Impetus to growth of smart structures

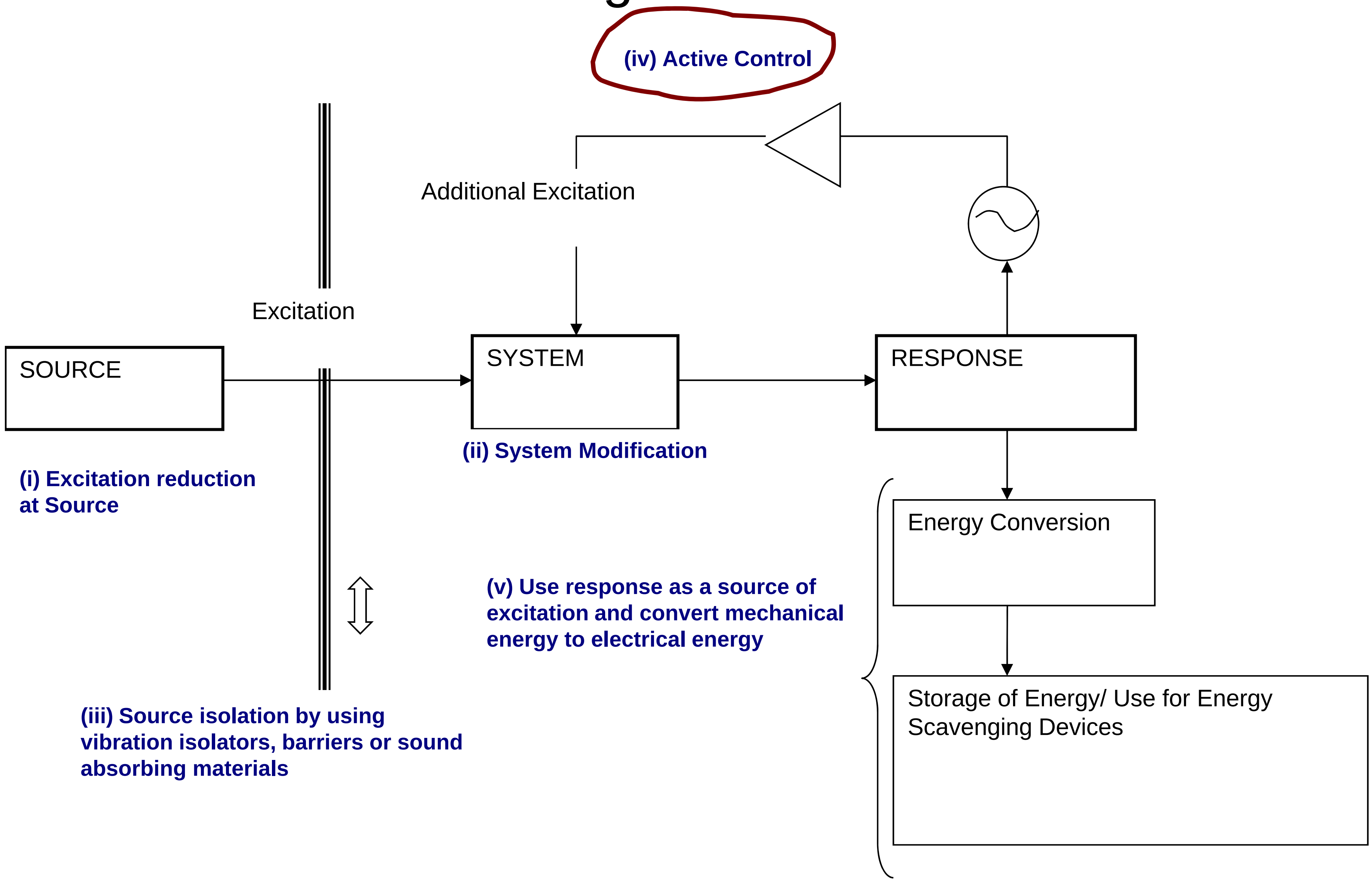
- Recent advances in materials
- Improved sensor and actuator technologies
- Real-time information processing
- Tape casting and screen printing technologies
- Integration and miniaturization

# A Range of Applications





# Different Strategies for Vibration Control



# Intelligent Product: A Mobile Charger

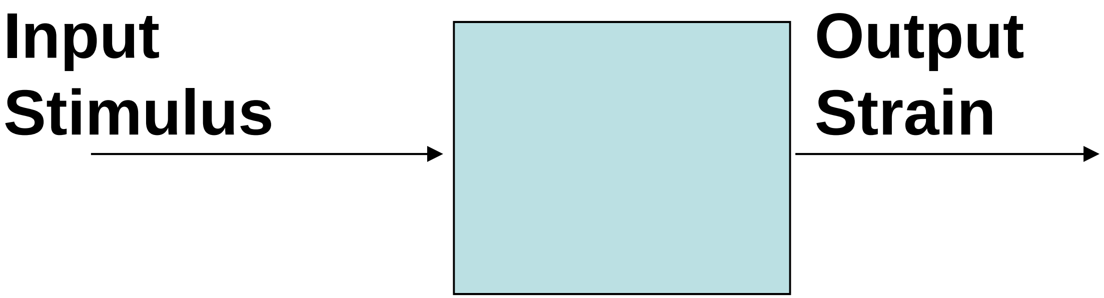
# Smart Materials for Sensing & Actuation

| Output / Input | Current/ Charge | Magne- tization | Strain | Temperature | Light |
|---|---|---|---|---|---|
| Electric Field | Cond- uctivity Permitti- vity | Electro- magnetic Effect | Reverse Piezo- electricity | Ohmic Resistance | Electro- Optic effect |
| Magnetic Field | Eddy Current Effect | Perme- ability | Joule Effect Magneto- striction | Magneto caloric Effect | Magnet o-Optic effect |
| Stress | Direct Piezo- Electric Effect | Villary Effect | Elastic Modulus | Thermo-Mechanical Effect | Photo- elastic Effect |
| Heat | Pyro- electric Effect | Thermo- Magne- tization | Thermal Expansion Phase Transition | Specific Heat | Thermo- Lumin- ecence |
| Light | Photo- Voltaic Effect | Photo- Magne- tization | Photo- striction | Photo- Thermal effect | Refract- ive index |

# Smart Materials as Sensors & Actuators


**Direct Effect**

**Output –**
**Electric Potential**




**Reverse Effect**

**Input:**

**Electric/Magnetic**
**/ Thermal**

# Smart Actuators

| Input Parameter | Actuator Type/ Devices |
|---|---|
| Electric Field | Piezoelectric/ Electrostrictive |
| | Electrostatic (MEMS) |
| | Electro- Rheological Fluid |
| Magnetic Field | Magnetostrictive |
| | Magneto-Rheological Fluid |
| Chemical | Mechano-chemical |
| Heat | Shape Memory Alloy |
| | Shape Memory Polymer |
| Light | Photostrictive |

# Traditional VS New Actuators

| Drive | Device | Displacement | Accuracy | Torque/Generative Force | Response Time |
|---|---|---|---|---|---|
| Air Pressure | Motor | Rotation | degrees | 50 Nm | 10 sec |
| | Cylinder | 100mm | 100$\mu$m | $10^{-1}$ N/mm$^2$ | 10 sec |
| Oil Pressure | Motor | Rotation | degrees | 1000 Nm | 1 sec |
| | Cylinder | 1000mm | 10$\mu$m | 100 N/mm$^2$ | 1 sec |
| Electricity | AC Servo | Rotation | minutes | 30 Nm | 100 msec |
| | DC Servo | Rotation | minutes | 200 Nm | 10 msec |
| | Linear Stepper | 1000mm | 10$\mu$m | 300 N | 100 msec |
| | Voice-Coil | 1mm | 0.1$\mu$m | 300 N | 1 msec |
| | Piezoelectric | 100$\mu$m | 0.01$\mu$m | 30 N/mm$^2$ | 0.1 msec |
| | Magnetostrictive | 100$\mu$m | 0.01$\mu$m | 100 N/mm$^2$ | 0.1 msec |
| | Ultrasonic Motor | Rotation | minutes | 1 Nm | 1 msec |

# Direct Effect

- All Piezoelectric Materials and PVDF
- Magnetostrictive Materials
- Optical Fibre

# Converse/Reverse Effect

- Ferroelectrics Perovskites, Piezoceramics, PVDF respond to electric field by change in shape
- Terfenol-D, Amorphous Met-Glasses show a similar effect with the change in magnetic field
- Shape Memory Alloy respond in a similar manner but with the change in Thermal Field
- Electro/Magneto Rheological Fluids respond to electric/magnetic field by changing its’ viscosity

# Properties of a few Smart Materials

| Props. | PZT | PVDF | T-D | NiTiNOL |
|---|---|---|---|---|
| Free strain(ppm) | 1000 | 700 | 2000 | 20000 |
| E. Mod.<br>(GPa) | 62 | 2.1 | 48 | 27– M<br>89 - A |
| Band | .1Hz-GHz | .1Hz-GHz | .1Hz-MHz | 0-10 Hz |

# References


- Gauenzi, P., Smart Structures, Wiley, 2009
- Cady, W. G., Piezoelectricity, Dover Publication, 1950
- Crawley, E. F., Intelligent Structures for Aerospace: a technology overview and assessment, AIAA, 33 (8), 1994, pp. 1689-1699

# END OF LECTURE 1