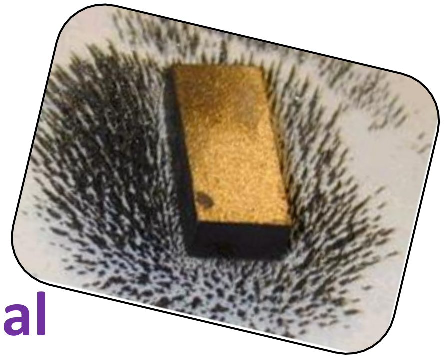
Smart Materials – I

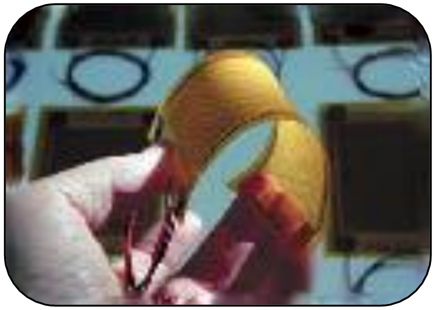
(*Introduction*)

Smart Materials Structures and Systems
Laboratory
IIT Kanpur

Contents

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





Features of Smart Materials

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

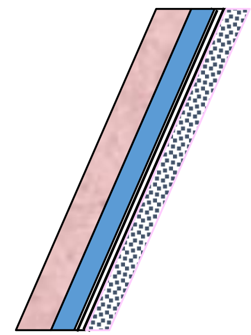
- The basic **energy** forms that gets **interchanged** are: thermal energy, electric energy, magnetic energy, sound energy & mechanical energy.

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

- Smart sensors & actuators are **highly embeddable**.

Smartness in a scale of intelligence

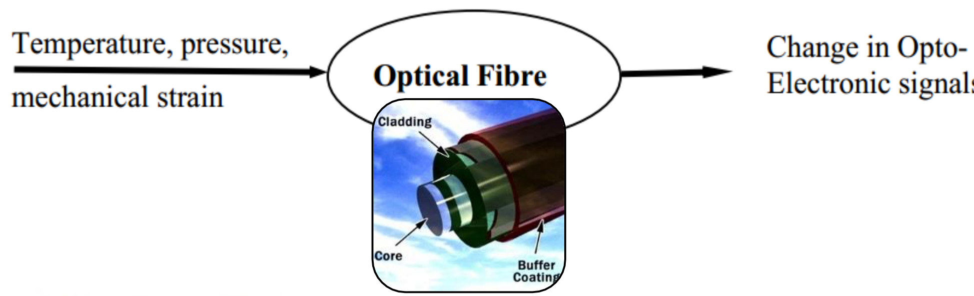
- Stupid – Dumb – Foolish – Trivial – Sensible – Smart/Clever – Intelligent – Wise.
- Present smart materials are in the range from highly sensible to poorly intelligent level.
- Passive smartness to Active Smartness; eg. of passive smartness - multiphase rocket nozzle of Space Shuttle.
- Porous Tungsten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



Passive Smartness

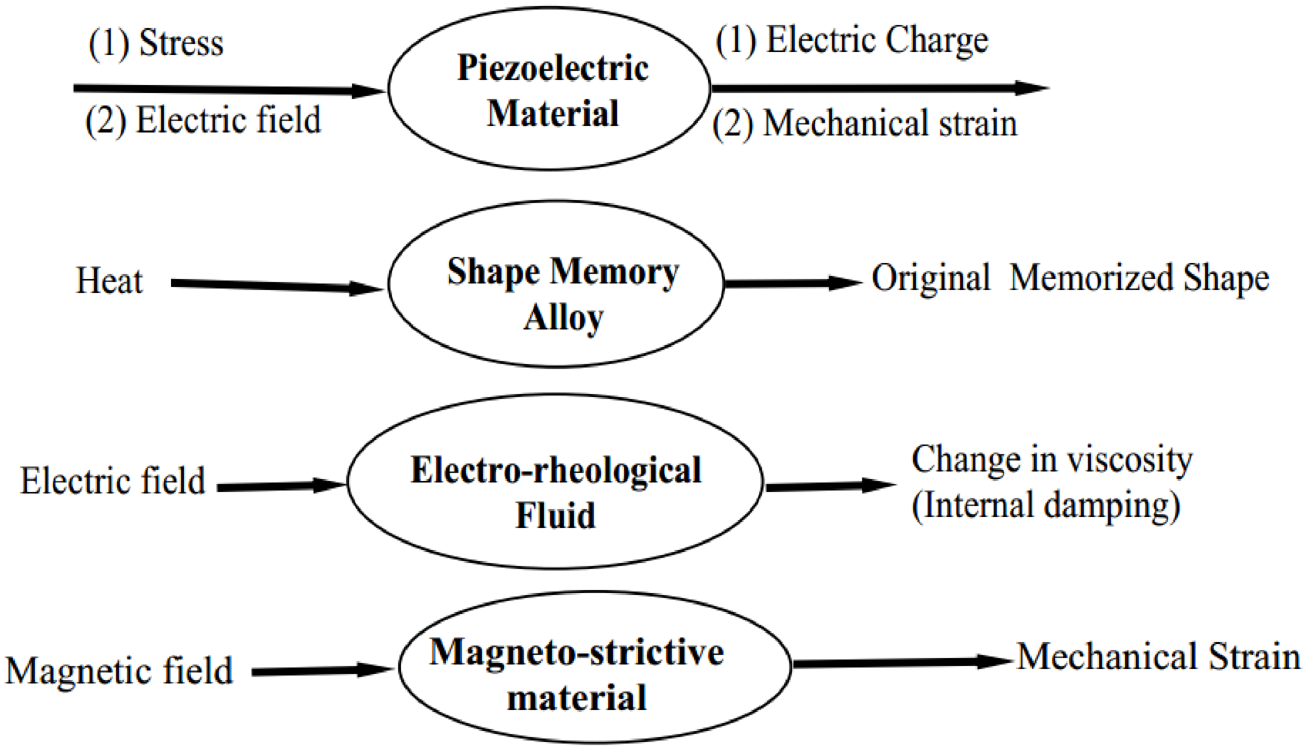
- ❑ Lack the inherent capacity to transduce energy.
- ❑ Can act as only sensors but not as actuator.

Other example: Optical fiber cable



Active Smartness

- ❑ Possess capacity to modify their geometric or material properties.
- ❑ Thus, inherent capacity to transduce energy.
- ❑ Can acts as both sensors and actuators.



Reference: http://ssdl.iitd.ac.in/vssdl/smart.pdf

Traditional v/s Smart System

Traditional system

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

Smart System

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

Smart Materials

A **smart material** are those which posses ability to change their physical properties in a specific manner in response to specific stimulus input.

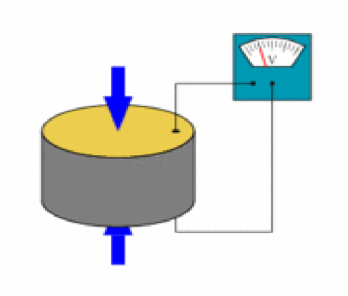
Commonly used smart materials are:-

1. **Piezoelectric -** Generate an electric charge in response to applied mechanical stress and vice versa.

2. **Magnetostrictive** – Change in dimension of ferromagnetic material in magnetic field and vice versa.

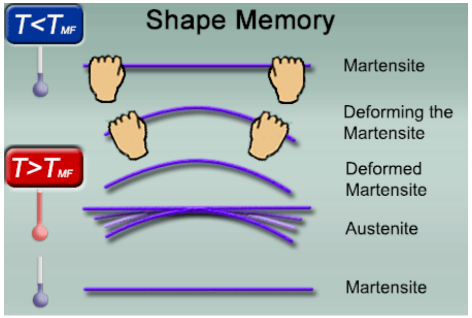
3. **Phase-Transition dependent -** "Remembers" its original shape and after being deformed returns to its original shape when heated.

4. **Electro/Magneto Rheological Materials –** Change in viscosity in response to electric/magnetic field.



Piezoelectricity

Terfenol-D



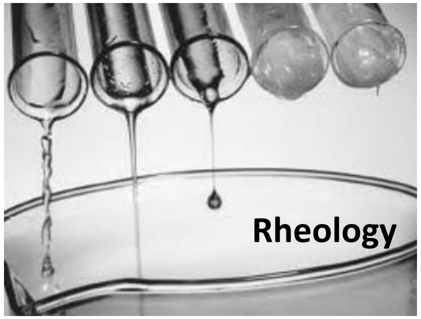
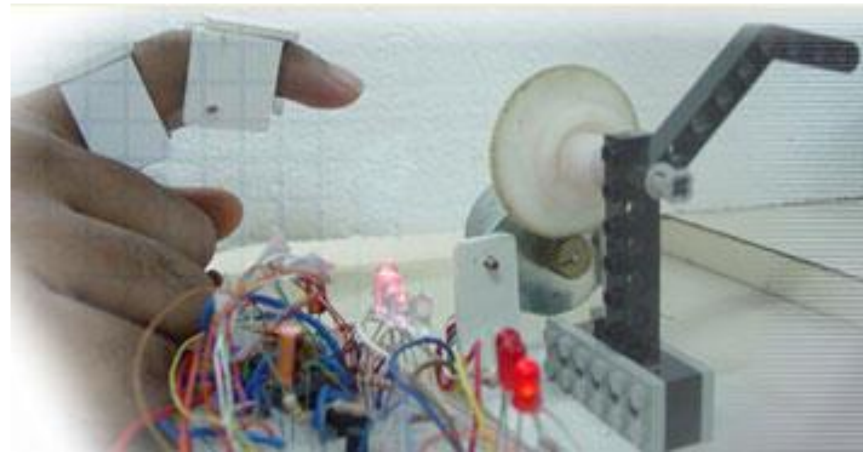


Image: Wikipedia

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

A Range of Applications



Smart Materials for Sensing & Actuation

Output / Input	***Current/ Charge***	***Magnetization***	***Strain***	***Temperature***	***Light***
Electric Field	Conductivity Permittivity	Electro-magnetic Effect	Reverse Piezo electricity	Ohmic Resistance	Electro-Optic effect
Magnetic Field	Eddy Current Effect	Permeability	Joule - Effect Magnetostriction	Magneto caloric Effect	Magneto-Optic effect
Stress	Direct Piezo-electric Effect	Villary Effect	Elastic Modulus	Thermo-Mechanical Effect	Photo-elastic Effect
Heat	Pyro-electric Effect	Thermo-Magnetization	Thermal-Expansion Phase Transition	Specific Heat	Thermo-Luminescence
Light	Photo-Voltaic Effect	Photo-Magnetization	Photostriction	Photo-Thermal effect	Refractive index

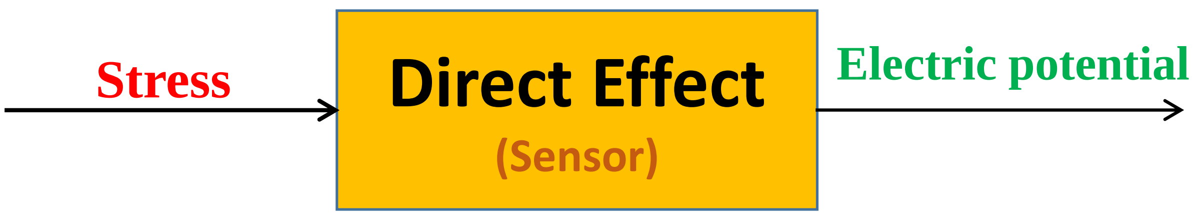
Smart Materials as Sensors & Actuators

Stress → **Direct Effect** (Sensor) → Electric potential

Electric/ Magnetic/ Thermal Stimulus → **Reverse Effect** (Actuator) → Strain

Direct Effect

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



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 it's viscosity.

Electric/ Magnetic/ Thermal Stimulus → **Reverse Effect** (Actuator) → Strain

Traditional v/s New Actuators

Drive	Device	Displacement	Accuracy	Torque/Generative Force	Response Time
Air Pressure	Motor	Rotation	degrees	50 Nm	10 sec
	Cylinder	100mm	100μm	10^{-1} N/mm^2	10 sec
Oil Pressure	Motor	Rotation	degrees	1000 Nm	1 sec
	Cylinder	1000mm	10μm	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	10μm	300 N	100 msec
	Voice-Coil	1mm	0.1μm	300 N	1 msec
Smart materials	Piezoelectric	100μm	0.01μm	30 N/mm^2	0.1 msec
	Magnetostrictive	100μm	0.01μm	100 N/mm^2	0.1 msec
	Ultrasonic Motor	Rotation	minutes	1 Nm	1 msec

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

Properties of a few Smart Materials

Properties	PZT	PVDF	Terfenol-D	NiTiNOL
Free strain(ppm)	1000	700	2000	20000
Elastic Modulus (GPa)	62	2.1	48	27-Martensite 89 - Austenite
Band	0.1Hz - 1 GHz	0.1Hz - 1GHz	0.1Hz - 1 MHz	0 - 10 Hz

In the **next lecture**, we will learn about

- ✓ Piezoelectric materials
- ✓ Constitutive Equations
- ✓ Piezoelectric Polymer
- ✓ Piezoelectric Composites

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