Introduction to Smart Materials

Dr.Fatimah J. AL-Hasani

What are smart materials?

Smart materials:

are those that exhibit coupling between multiple physical domains. Common examples of these materials include those that can convert electrical signals into mechanical deformation and can convert mechanical deformation into an electrical output. Others that are materials that convert thermal energy to mechanical strain, and even those that couple the motion of chemical species within the material to mechanical output or electrical signals.

Smart Materials

- Smart materials are materials that possess the ability to change their physical properties in a specific manner in response to specific stimulus or their environment. Physical properties could be shape, viscosity, stiffness, color, dimension, etc.

- Smart means programmed by **human intellect** manipulating: composition, processing, modifying tiny structures or molecules Introduction of intentional defects that adapt to levels of **stimuli** in a controlled way. This means that **actual people** need to solve the problem, then engineer the materials to respond as needed. Materials include many diverse fibers, yarns, fabrics, pigments, finishes, etc. These can be individual attributes and as combinations of all the above.

Stimuli could be:

- Stress/Strain
- Pressure
- Water
- Wind
- Temperature
- Electric current
- Magnetic fields
- Nuclear radiation
- Light
- pH
- Moisture
- Emotions . . . Yes, emotions - And more
-

the term smart based on their interesting material properties. Some of these materials exhibit a volume change when subjected to an external stimulus such as an electric potential; others shrink, expand, or move when heated or cooled. Still other types of smart materials produce electrical signals when bent or stretched. Other names for these types of materials are intelligent materials, adaptive materials, and even structronic materials

SMART MATERIAL PROPERTIES

Smart materials are, first and foremost, materials, and it is useful to step back and examine the properties of smart materials compared to those of conventional Two properties that are commonly used to compare engineering materials are density and elastic modulus. The density of a material is the mass normalized to the volume, and in SI units it is defined in terms of kg/m3. The elastic modulus of a material is a material property that relates the applied loads on a solid material to the resulting deformation. it is only important to note that for the same applied load, materials with a higher elastic modulus will undergo less deformation than will materials with a lower elastic modulus. Thus, materials with a higher elastic modulus will be stiffer than “soft” materials that have a low elastic modulus.

The universe of materials spans a wide range of density and modulus values. The density of all materials generally varies over approximately three orders of magnitude. Low values for materials are approximately 0.01 kg/m3 for foams, and high values can reach ≈ 20 kg/m3 for some metals and ceramics. In contrast, the variation in elastic modulus for materials spans approximately seven orders of magnitude, from approximately 1 kPa for soft foams and elastomeric materials to almost 1000 GPa for certain ceramics

The smart materials generally fall in the middle of the range of density and modulus values. Piezoelectric materials and shape memory alloys have modulus values on the order of 10 to 100 GPa with a density that is typically in the range 7000 to 8000 kg/m3. Piezoelectric polymers are softer materials whose elastic modulus is on the order of 1 to 3 GPa, with a density of approximately 1000 to 2000 kg/m3. Electroactive polymers are generally the softest and least dense materials. Electroactive polymers have moduli that span a wide range— from approximately 1 MPa to greater than 500 MPa—and density values that range from 1000 to 3000 kg/m3.

Classification of Smart Materials

- **Passive Smart Materials** - Lack the inherent capability to transduce energy in response to stimuli. These act as sensors not as actuators or transducers. Example – fiber optic cable.
- **Active Smart Materials** – possess the capability of modifying their geometric, and material properties under the application of stimulus (input) of electric, thermal, or magnetic fields, thereby acquiring an inherent capacity to transduce energy. Can be used as force transducers and actuators Examples: Piezo-electric, magnetostrictive materials, shape memory alloys, Electrorheological fluid

There are different types of smart materials. Each type exhibits different characteristics that can be changed. Some examples include:

1- **Piezoelectric**: These are materials (mainly crystals) that produce electric voltage when stress is applied. Conversely, applying a voltage across a piezoelectric material causes a change in the shape. Piezoelectric

materials are lightweight and compact. They are used in microelectronics, optics, biology, medicine, and mechanical engineering. Piezoelectric devices can act as transducers between electric potential and frequency.

2- **Electrostrictive:** Electrostriction is present in dielectric materials such as lead magnesium niobate (PMN). Both piezoelectric and electrostrictive materials belong to the same ferroelectric family. But electrostrictive materials may be more reliable than piezoelectric materials due to some physical properties.

3- **Magnetostrictive:** These are the magnetic analogue of electrostrictive materials. They are ferromagnetic materials that change in shape when magnetic field is applied. They can convert magnetic energy to kinetic

energy. They are used in constructing sensors and actuators.

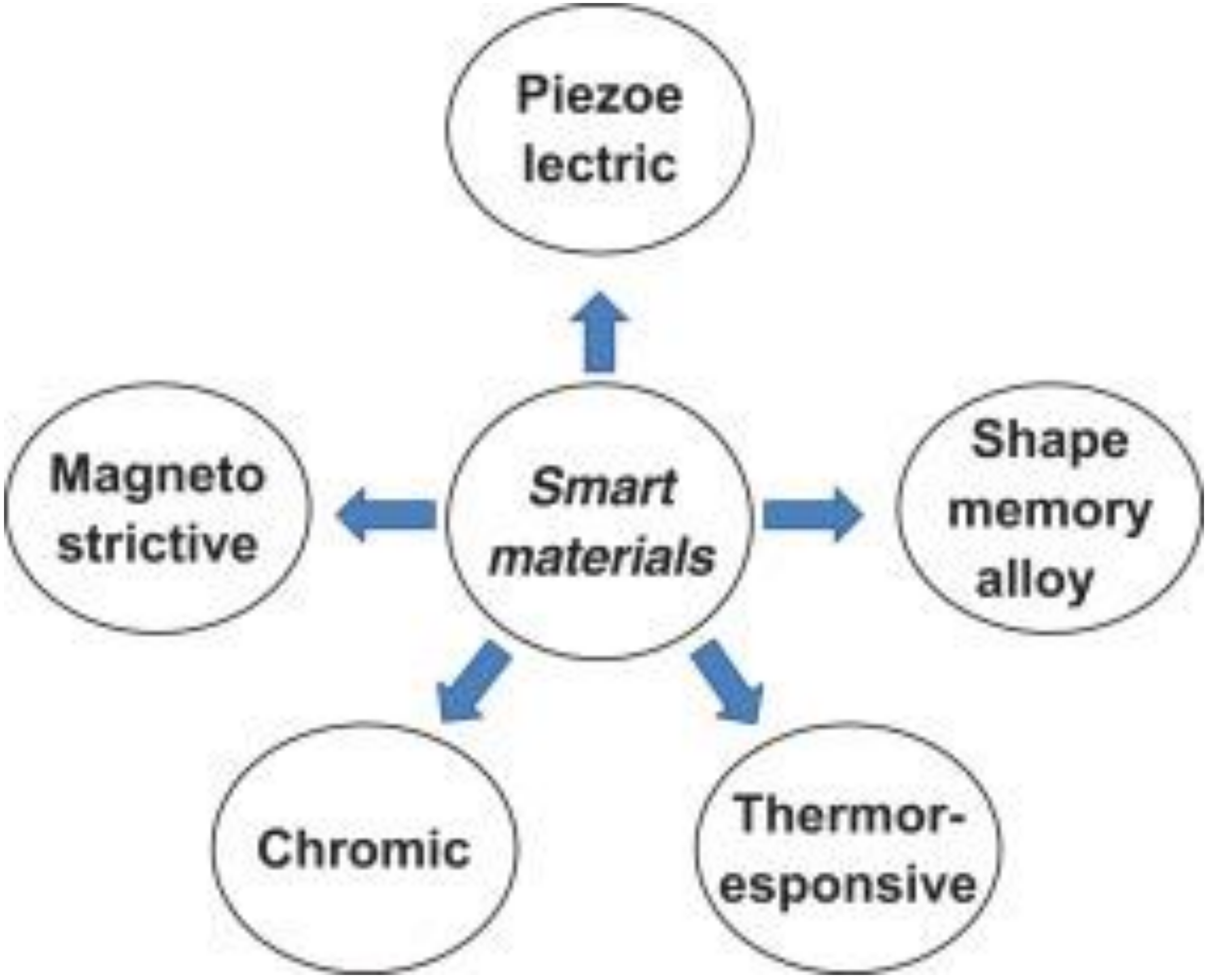
3- Shape memory alloys (SMA): This is the class of adaptive materials that are thermally activated and can transform thermal energy into mechanical work. They are unique metallic alloys. These materials exhibit high power volume ratio. They are recognized for their unusual thermo mechanical properties, memory form effect, and damping capacity. A typical example is nickel-titanium alloy (NiTi). Some of the applications of SMA take advantage of their superelasticity [3]. This property enables the smart material to go back to its original dimension after stress-induced changes.

4- Optical fibers: These are dielectric structures designed to guide light. They possess lightweight, geometrical flexibility, and low attenuation. They have high bandwidth and are immune to electromagnetic interference. The emergence of optical communication has led to the development of embedded optical sensors. Optically

smart structures can automatically change color to match their background.

Smart materials are either active or passive. Active materials have the inherent ability to transduce energy, while passive do not. Examples of active smart materials are piezoelectric materials, while fiber optic is passive. Passive

materials can be used as sensors but not as actuators [4].



Piezoe lectric

Magneto strictive

Smart materials

Shape memory alloy

Chromic

Thermor-esponsive

Applications of Smart Materials

Smart materials find a wide range of applications due to their varied response to external stimuli. The different areas of application can be in our day to day life, aerospace, civil engineering applications and mechatronics to name a few. The scope of application of smart material includes solving engineering problems with unfeasible efficiency and provides an opportunity for creation of new products that generate revenue. Important feature related to smart materials and structures is that they encompass all fields of science and engineering. As far as the technical applications of smart materials is concerned, it involves composite materials embedded with fiber optics, actuators, sensors, MicroElectro Mechanical Systems (MEMSs), vibration control, sound control, shape control, product health or lifetime monitoring, cure monitoring, intelligent processing, active and passive controls, self-repair (healing), artificial organs, novel indicating devices, designed magnets, damping aeroelastic stability and stress distributions. Smart structures are found in automobiles, space systems, fixe-and rotary-wing. aircrafts, naval vessels, civil structures, machine tools, recreation and medical devices.