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Smart Materials in Nanoscience and Nanotechnology - An overview

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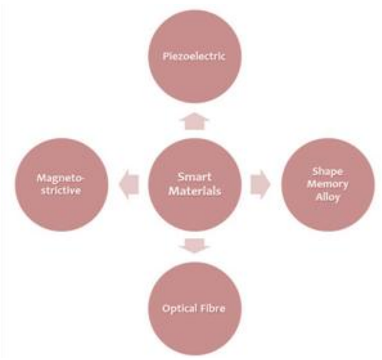
GRAPHICAL ABSTRACT



ABSTRACT

Design of new materials with a multi-functional capability has become a key research focus in all materials science and engineering discipline in the recent past. A "smart material" is one having a structure at the nano-structural level that responds in a particular and controlled way to influences upon it. These range from magnetically-changed materials, to "memory" molecules that return to their original form, to materials that generate an electric charge when pressed, twisted, or warped. In some extent, a structure made by this material or more than one type of this material incorporated with an appropriated sensor system has been well defined as a "smart structure", that can be used for the implementation of a damage and performance detection strategy for aerospace, civil and mechanical engineering and other applications. Since the last decade, an increasing interest in the development of miniaturized structures and systems, particularly on micro and nano-electromechanical systems (MEMs and NEMs), and integrated biosensor systems has evolved a new page in the area of smart materials and nanotechnology.

Keywords: *Smart Material, functional materials, MEMS, NEMS, titanates, Shape memory alloys.*

1. INTRODUCTION

Smart materials are demarcated as materials with properties engineered to change in a precise manner under the impact of external inducements in response to their environment. These external influences include thermal, mechanical, optical, magnetic fields, electric charge, force, moisture, pH. Recent examples of smart materials include self-healing polymers that release healing agents upon structural damage, electronic paper displays, whose ink appears or disappears depending on electrical charge, and meta-materials that serve as an "invisibility cloak" to make objects invisible at a particular wavelength, smart materials may have a wide range of potential applications in medicine, and many of them, including thermoresponsive hydrogels, switchable surfaces, and photoresponsive materials, have already been explored in this capacity. Smart materials are mainly classified into the following types,

a. Piezoelectric
b. Shape Memory Alloy
c. Optical fibre
d. Magnetostrictive

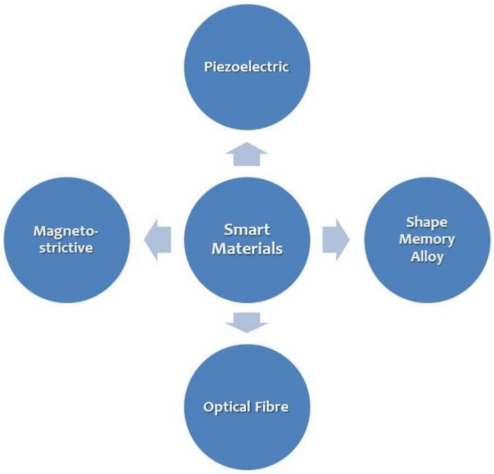


Fig. 1 Classification of Smart Materials

Piezoelectric:

Piezoelectric materials are used for both sensing and actuating devices which exhibit an electrical polarization with an applied mechanical stress (direct effect), or a dimensional change with an applied electric field (converse effect). When subjected to an electric charge or a variation in voltage, piezoelectric material will undergo some mechanical change, and vice versa. These events are called the direct and converse effects. Lead zirconate titanate ($PbZr_{1-x}Ti_xO_3$) is the chief piezoelectric material as it may be doped to produce an n-type or p-type material with a range of dielectric constants to meet the requirements of numerous applications. Lead Metaniobate ($PbNb_2O_6$), Barium Titanate ($BaTiO_3$) and Lead Titanate ($PbTiO_3$) are other types of piezoelectric materials.

Shape memory alloys:

Shape memory alloys are subjected to a mechanical load below a certain temperature these special materials will undergo phase transformations which will produce shape changes i.e., plastically deformed beyond their elastic limit but then are capable of retrieval their original shape if they are then heated above a certain temperature. Nickel-titanium is the best common Shape memory alloy with best shape memory properties having relatively low transformation temperatures, cannot match the outstanding shape memory capabilities of Ni-Ti. Cu-Zn-Al and Cu-Al-Ni are the common ternary Cu-based systems which can achieve commonly a shape memory strain of 4 to 5% (compared to about 8% for Ni-Ti) and have a broader range of transformation temperatures Iron-based alloys like Fe-Mn, Fe-Mn-Si, Fe-Pt, Fe-Ni, Fe-Ni-Co and Fe-Pd exhibit shape memory but these are not capable of regaining their shape to the same extent as nickel-titanium and copper-based alloys.

Magnetostrictive:

When an external magnetic field is applied, magnetostrictive material will undergo an induced mechanical strain i.e., change in shape which is used in actuators contrary to this effect is called piezomagnetism which is used in sensors, where a magnetic field is produced/altered upon application of a mechanical strain. Ferromagnetic materials like Fe, Ni, Co etc. can exhibit magnetostriction to some extent and rare earth elements have exhibited considerably higher magnetostriction which limits to lower than room temperature. Nickel-based alloys and particulate composites are common magnetostrictive materials which contains magnetostrictive particles.

Optical Fibres:

Optical Fibres are excellent sensors which use intensity, phase, frequency or polarization of modulation to measure strain, temperature, electrical/magnetic fields, pressure and other measurable quantities. The reaction for the incitement, advantages and disadvantages of various smart materials are tabulated in table 1.

Table 1: Different Smart materials

S. No.	Material	Stimulus	Response	Advantages	Limitations
1	Piezoelectric Material	Stress, Electric field	Electric charge, Mechanical strain	High bandwidth, Frequencies and Low power Actuation	Limited Strains, Auxiliary Equipment needed, Low material tensile Strength, Typically brittle materials, Limited temperature range
2	Shape Memory Alloy	Thermal field	Original Memorized shape	High energy density, material strength, Elasticity and Large forces	Low bandwidth, Low frequencies, High hysteresis, Limited temperature range
3	Optical Fiber	Temperature, pressure, Mechanical strain	Change in Opto-electronic signals	High elastic strain limits, fracture toughness, flexibility in bending, sensitivity to strain	-
4	Magneto-Strictive material	Magnetic field	Mechanical strain	High frequencies, temperature range and Contact-less control via magnetic field	Generation of magnetic field equipment intensive, Limited strains, Low material tensile strength, Typically brittle materials

Nanoscience and Nanotechnology:

Today Nanoscience and Nanotechnology offer an incredible potential for the conceptual design and the practical realization of radically new smart materials that can help solve some of the global challenges. Nanotechnology is rapidly entering the world of smart materials and taking them to the next level. These new materials may incorporate nanosensors, nanocomputers and nanomachines into their structure. This will enable them to respond directly to their environment rather than make simple changes caused by the environment.

Applications of smart nanomaterials:

Smart materials are having prospective applications in medicine and many of them, including thermoresponsive hydrogels switchable surfaces, and photo-responsive materials. Another prominent motivation of the quest for synthetic materials with dynamically controlled properties is their potential use as dynamic blueprints in time-resolved self-assembly.

In the future scientists may be able to produce nanoparticles that can be incorporated in paints to efficiently capture solar light and convert it into electric energy at a low cost; or nanomaterials that can allow the design of new batteries with high power content and light weight. Nanoelectronic devices like nanocomputers that can be incorporated in textiles and clothing and provide new functions like a change in hardness as a consequence of an impact. Probably, the field where smart nanomaterials are going to have the largest impact is in healthcare and medicine. Implants and prostheses made from materials that can modify their surfaces and bio-functionality to increase biocompatibility; or specific functionalized nanoparticles that are able to deliver drugs and antibiotics in specific areas of a living organism; or synthetic "cells" that can produce protein drugs when triggered with light.

Despite this encouraging progress, the implementation of switchable properties will continue to be one of the central obstacles in nanomaterial science in the decades to come. Ultimately, imparting dynamic properties to nanomaterials will result in systems where the materials themselves will be the actual active device.

a. Energy generation and conservation with highly efficient batteries and energy generating materials
b. Security and Terrorism Defence with smart materials that can detect toxins and either render them neutral, warn people nearby or protect them from it.
c. Healthcare, with smart materials that respond to injuries by delivering drugs and antibiotics or by hardening to produce a cast on a broken limb.
d. Implants and prostheses made from materials that modify surfaces and bio-functionality to increase biocompatibility
e. Smart textiles that can change colour, such as camouflage materials that change colour and pattern depending upon the appearance of the surrounding environment. These materials may even project an image of what is behind the person in order to render them invisible.

Conclusion

Smart materials have already been used and are now an intrinsic part of our society. Nanoscience and nanotechnology is essential for the development for smart materials, acting as a tool which can change the properties of structures and involved in development of smart materials. Nanoscience and nanotechnology today offer an incredible potential for the intangible design and the practical realization of fundamentally new smart materials that can help solve some of the potential global societal challenges. Nanotechnology and smart materials are crucial for future technology developments and it will directly and indirectly impact our everyday life sooner or later. Though some people argue that smart materials are from nature and they can survive themselves and nanoscience and nanotechnology is not necessary for development for smart materials. Nanotechnology and Smart Materials provides together provides plethora of advantages where engineers and scientists working on nanoscience and nanotechnology and smart materials all around the world freely get together and discuss.

References

[1] Langer, R.; Tirrell, D. A. Designing Materials for Biology and Medicine. Nature 2004, 428, 487–492.

[2] Hoffman, A. S. "Intelligent" Polymers in Medicine and Biotechnology. Artif Organs 1995, 19, 458–467.

[3] White, S. R.; Sottos, N. R.; Geubelle, P. H.; Moore, J. S.; Kessler, M. R.; Sriram, S. R.; Brown, E. N.; Viswanathan, S. Autonomic Healing of Polymer Composites. Nature 2001, 409, 794–797.

[4] Cho, S. H.; Andersson, H. M.; White, S. R.; Sottos, N. R.; Braun, P. V. Polydimethylsiloxane-Based Self Healing Materials. Adv. Mater. 2006, 18, 997–1000.

[5] Comiskey, B.; Albert, J. D.; Yoshizawa, H.; Jacobson, J. An Electrophoretic Ink for All-Printed Reflective Electronic Displays. Nature 1998, 394, 235–255.

[6] Mullins, J. Now You See Me. The New Scientist 2007, 193, 38–41.

[7] Schurig, D.; Mock, J. J.; Justice, B. J.; Cummer, S. A.; Pendry, J. B.; Starr, A. F.; Smith, D. R. Metamaterial Electromagnetic Cloak at Microwave Frequencies. Science 2006, 314, 977–980.

[8] Yang, J.; Yamato, M.; Kohno, C.; Nishimoto, A.; Sekine, H.; Fukai, F.; Okano, T. Cell Sheet Engineering: Recreating Tissues Without Biodegradable Scaffolds. Biomaterials 2005, 26, 6415–6422.

[9] Lahann, J.; Langer, R. Smart Materials With Dynamically Controllable Surfaces. MRS Bull. 2005, 30, 185–188.

[10] Lendlein, A.; Jiang, H.; Ju¨ nger, O.; Langer, R. Light-Induced Shape Memory Polymers. Nature 2005, 434, 879–882.

[11] Metals Handbook, 10th Edition, Vol. 2: Properties and Selection: Nonferrous Alloys and Special-Purpose Materials, ASM International, 1990; DTIC Doc. AD-D450 152