Smart materials: development of new sensory experiences through stimuli responsive materials

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Smart materials: development of new sensory experiences through stimuli responsive materials

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Smart materials are materials that change properties according to stimuli, adapting to their environment. This aspect make them particularly interesting, to help to increase the performance of the objects, and to enable new functionalities and new ways to interact with users.

Some smart materials can affect the perception we have of the objects. The existing smart materials have an action mostly on the visual and the tactile aspects. The most popular variations are based on color changing materials, such as thermo/photo-chromic materials or thermo/photo-luminescent ones and shape changing materials, such as shape memory alloys.

These new materials will allow designers to introduce new sensory experiences in their products. But for that, they need to know what differentiate these materials from common ones, which kinds of smart material exist, and have some clues about how they can be used. This paper present a classification of smart materials, as well as some of the applications of color and shape changing materials.

Keywords*: smart materials, sensory experience, stimuli-responsive, industrial design*

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Introduction

Smart materials have the unique ability to respond to stimuli and adapt to their environment. Through this particularity, they offer brand new possibilities for designers, especially when it comes to the interaction between the user and the product. To be able important to take advantage of their unique properties and create new experiences for the user, knowing which smart materials exists and how they work is really important. In this paper, the different types of smart materials will be presented, with a focus on materials that affect the user senses and their applications.

I. What are smart materials?

1. General description

Smart materials are materials that change properties according to stimuli: under a certain input, they produce a predictable and repeatable response, or output.

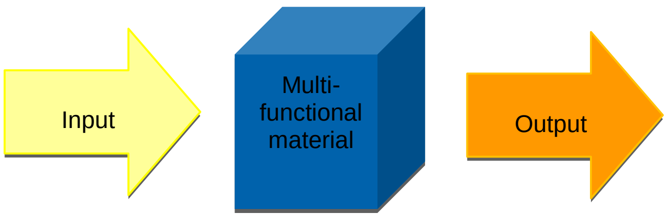

Figure 1 Basic functioning of smart materials

The input can be either specifics wavelengths of light, temperature changes, movement, deformation, pressure, chemical concentration, electric field or magnetic field, while the output produced can be changes in color, light, temperature, deformation, stress, stiffness or viscosity, electric field, magnetic field or electrical resistance.

Most of these smart materials have five characteristics in common: the immediacy, the transiency, the self-actuation, the directness and the selectivity. The immediacy means these materials react as soon as the stimuli appear, i.e. they have an immediate response. The transiency is related to the fact that they react to more than one environmental state, and have different properties depending on these various environmental states. As for the self-actuation, it means the special properties are internal of the materials, and are not produced be some external actions on the materials. Directness represent the fact the response of the material is local, and the output is produced at the point the input was given. Last of all, the selectivity qualify the predictable and repeatable characteristic of the response, so a single environmental state can only lead to a unique and constant response of the material. (Addington, Schodek, 2005)

2. Classification

Although they have these common characteristics, there are many types of smart materials, and each type will have a different interest for designers and users. To better understand the range of potential uses, a classification is needed.

A possible way to sort these materials is to separate them by input and output. For example, the following graphic (fig. 2) links the input, on the left part, with the output, on the right part, for each material. This allow a user to know which materials are adapted to a predefined input or to a desired output.

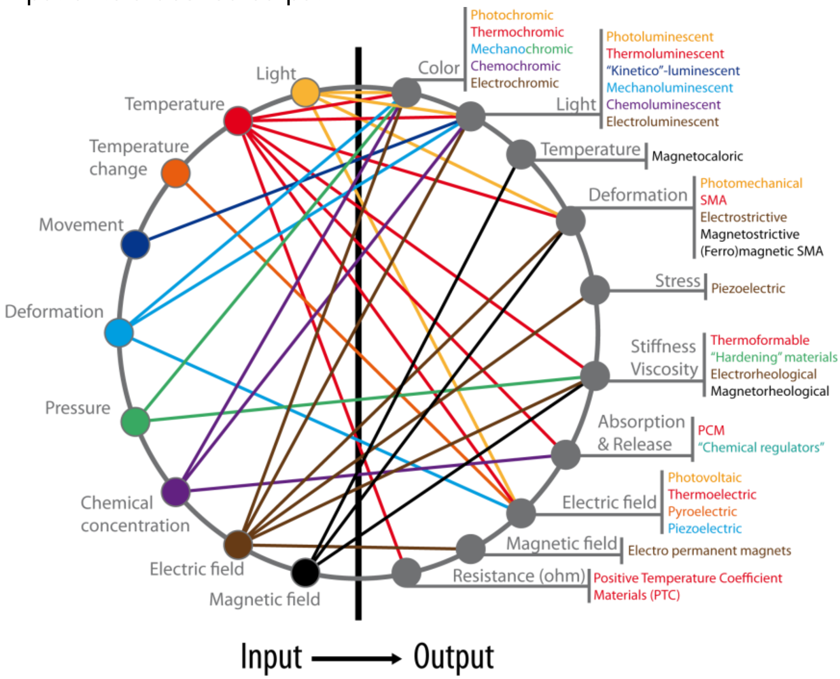

Figure 2: One possible classification of smart materials

Also, some of these materials are reversible: that means they can react to an input creating an output, but also react to the former output and having an effect on the input. For example, a piezoelectric material will respond to electricity by generating a deformation, and will respond to a deformation producing electricity. Therefore these reversible smart materials can be used in a different way than the other ones, which are monodirectional.

Table 1: Smart materials having a reversible effect

Type	Input		Output
Piezoelectric	Deformation	⟺	Electricity
Pyroelectric	Temperature difference	⟺	Electricity
Thermoelectric	Temperature difference	⟺	Electricity
Electrostrictive	Electricity	⟺	Deformation
Magnetostrictive	Magnetic fiels	⟺	Deformation

2. Smart materials vs. common materials

The varying properties of smart materials make them fundamentally different from common materials. Indeed, common materials are inert, and are most often used as a medium to give fixed properties to an object. In the case of smart materials, these properties become variables: the material will respond by itself to a particular event in his environment, and at the same time give information, interact with and/or entertain the user. By taking advantage of the novel versatility of these materials, designers can imagine a new relation between the user and the object. As stated by Passaro et al. (2013), the sensory properties of a product is essential in the user's evaluation and attachment toward it. Therefore, making the product's sensory properties reactive present a great advantage to boost the interactions between user and product.

Another advantage of smart materials over common ones is that their response is immediate and simple, while through common materials a complex system would be required to give the same response, often with a larger delay.

II. Smart materials that directly affect senses

If we focus on making the sensorial properties of an object variable and interactive, several classes of materials become more interesting than others. It is especially the case for color changing, light-emitting and shape changing materials, which variations affect directly the perceptions of the user.

1. Color changing and light-emitting materials

These materials have a direct effect on the visual appearance of an object, and present a large variety of possible inputs, therefore they also can be used in a wide variety of applications. For both color changing and light-emitting materials, possible inputs are light (photochromic, photoluminescent), change in temperature (thermochromic and thermoluminescent), deformation or pressure (mechanochromic and mechanoluminescent), chemical concentration (chemochromic and chemoluminescent) and electricity (electrochromic, electroluminescent and LEDs). Some materials also change color when they are submitted to a pressure.

2. Shape changing materials

As for color changing materials, there are several types of existing shape changing materials. The most well-known are shape memory alloys and polymers that recover their initial shape when heated. Other shape memory materials exists that regain their shape under a magnetic field, pressure, a chemical concentration or light (Del Curto, 2008).

In shape memory alloys (SMA), the shape memory effect is due to a change of phase inside of the material: the material is in a phase, or form, called martensitic when cold, and in an austenitic phase when heated at a certain temperature. Since these phases have really different atomic structures, the material is rearranging itself when heated and recover its initial shape. Depending on the SMA, the temperature of phase change is different. Also, this effect can be either one- or two-ways: in the one-way version, the SMA can be deformed by the user in its cold state and will recover its initial shape when heated; instead, the two-way version will have two preset shapes, one when cold and one when heated, and will switch to one form to the other depending on the temperature (Van Humbeeck, 2008).

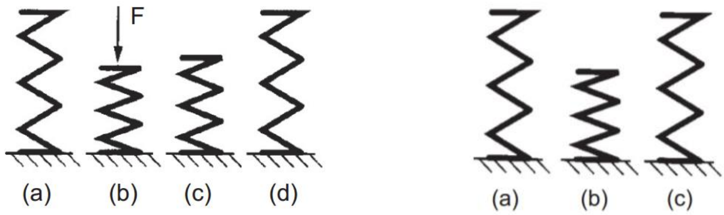

Figure 3: Shape memory alloy (Van Humbeeck, 2008)
Left: One-way configuration – when submitted to a deformation in its cold state, the material will stay deformed (a -> b -> c). Then, when heated, it will recover its initial shape (c -> d)
Right: Two-ways configuration – the material change shape spontaneously when cooling down from one preset form to another (a -> b), and return back to the previous form when heated (b -> c).

Apart from this shape memory effect, other materials exhibit a reversible deformation when submit to the right stimuli. It is the case for photomechanical materials, that change shape under light or UV light, electrostrictive and piezoelectric materials that deform in reaction of electricity, and magnetostrictive materials, that react to magnetic field. Among these, the piezoelectric, electrostrictive and magnetostrictive effects are reversible.

III. How to use smart materials to create new interactions between products and users

As there are many existing types of smart materials, there are also many ways to use them. Starting from the knowledge of the different effects existing, a designer can imagine new features for his product, otherwise not possible to achieve. These new feature can be purely aesthetic, and aimed at creating surprise for the user, but they can also be functional, allowing the object to adapt by itself to the environment, either to give messages to the user or to provide him or her with more convenience.

1. Applications of thermochromic materials

A popular type of smart materials that has already been used in large scale production for some times is the thermochromic class. These materials are commonly used for entertaining applications as furniture, clothes, hidden messages and so on, and for functional uses to give information to the user, as a warning for example. The thermochromic effect can be added to a large range of support materials as dyes, paints or pigments (Ritter A., 2007). Depending on the chosen thermochromic element, the change of color can be either a continuous gradient of color or a unique change at a precise temperature:

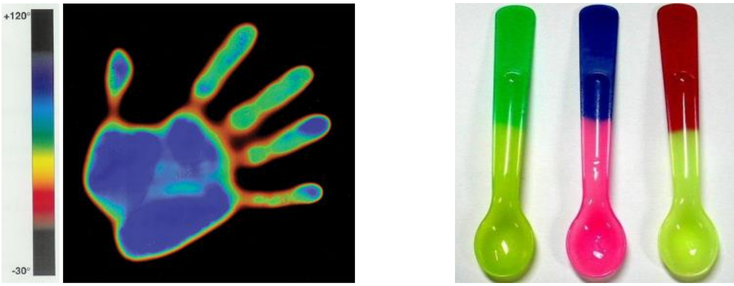

Figure 4: Thermochromic materials
Color gradient or sudden change at a given temperature
Left: Liquid crital paint, scale: http://www.indestructible.co.uk/ and image: http://www.hwsands.com/
Right: Thermochromic spoons, Master Batch www.newcolorchem.com

The color gradient versions can be easily used as thermometer. It has been often used to quickly measure body temperature with more comfort that usual thermometers, and measure a room temperature in an alternative way. There have been also some more playful applications, as the mood rings and mood tests that use the change of color induced by the body temperature variation to supposedly indicate a person's mood.

As for the sudden change version, the materials change color at a given temperature that is different for every thermochromic material. That allow to program the final object to give a signal when a temperature is reached, either to give a warning or to indicate a product is ready to be consumed or used. For example, the above spoons change color to indicate the food is too hot to feed a baby; other uses can be to indicate to show on the kettle that the water inside is boiling, or that a drink inside a can is cold enough. Like in the color gradient case, other uses of this color changing properties can be to make an object more playful: especially, when the change in color is scaled at body temperature, artifacts become sensible to the touch and respond at the contact of the user.

2. Applications of photochromic materials

Photochromic effect is another good example that smart materials can be used in a wide variety of applications. A noted use is for glasses which darken when exposed to the sunlight, protecting the user when it is necessary and turning back to its transparent state when the sun is gone. It can also be used as indicators of how intense is the UV radiation: in the shape of bracelets, tattoos or clothes, they can indicate to the user which protection is adequate for the day. More sensitive versions of photochromic materials can also be used simply as color changing jewelry, furniture and others, and will change color as soon as they come in contact with natural light:

Figure 5: Some applications of photochromic materials
From left to right:
Adapting sun glasses, Reversacol, www.jamesrobinson.eu.com
UV bracelets, http://wristbands-lovers.blogspot.it/
Color changing t-shirt, www.solaractiveintl.com

3. Applications of shape memory materials

When considering materials able to change shape, shape memory materials are the ones with the widest range of applications. These materials are able to recover their original shape when heated after a deformation. Other variations recover their shape when submitted to a magnetic field, a chemical concentration, pressure or light.

This ability to recover their initial shape has led shape memory materials to be used in many technical applications, in particular in medical field, where they are tuned to recover their shape at body temperature. In this case, they are deformed before being applied, and then perform their functions when recovering their preset shape. They have also been extensively used as actuators for mechanical systems or as joints in manufacturing processes (Talbot, 2003)

Beside these technical uses, some more visible applications that interact directly with users have been developed. For example, lighting furniture can take advantage of the heat produced by lamps to change shape when switch on; shirts containing shape memory threads can roll up its shelves by itself when the wearer is too warm; personal items can be adapted to grant the user more comfort.

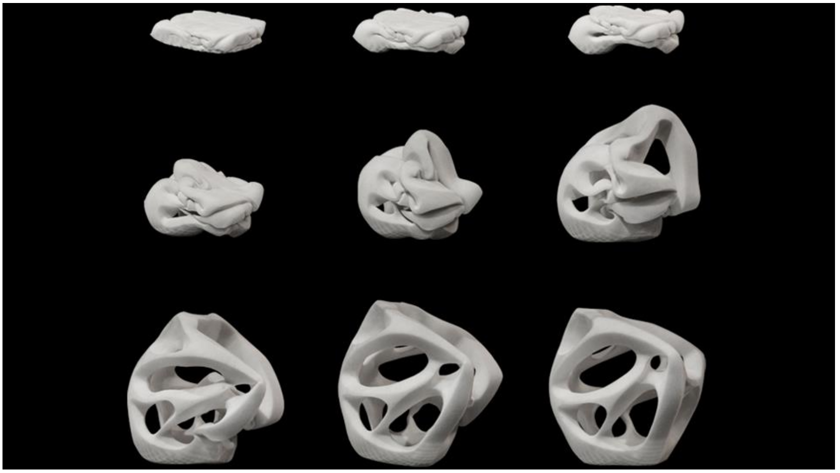

Figure 6: Shape memory chair, Noumenon by Carl de Smet

This experimental chair is stored is a flat form representing 5% of its open form. When heated over 70°C, it takes back its original shape. It can be compressed again and re-open. www.noumenon.eu

4. Applications of other smart materials

As shown in the last examples, their unique properties give each class of smart materials a wide range of applications. These applications can be either extremely technical or directly used to interact with naïve users. These two different ways to use smart materials, in highly technical fields or for naïve interaction, might seem really different, but in many cases, the very same effect can be used for both. For this reason, a link between technical and non-technical uses should be grown, taking advantage of cross-fertilization and from aesthetic exploration to reinforce innovation in all potential fields of applications of smart materials

Conclusion

Through their unique properties, smart materials have the potential to change the relation between the user and a product. It is especially true with materials that directly affect the perception of an object: by reacting to its environment in a tangible way, these materials interact with the user and offer new functionalities and experiences. Since these materials also have a great interest in technical application, a cross-fertilization between technical fields, large consumption and aesthetic explorations could be a real booster for the innovation in this domain.

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