Materials : Get smart: active materials

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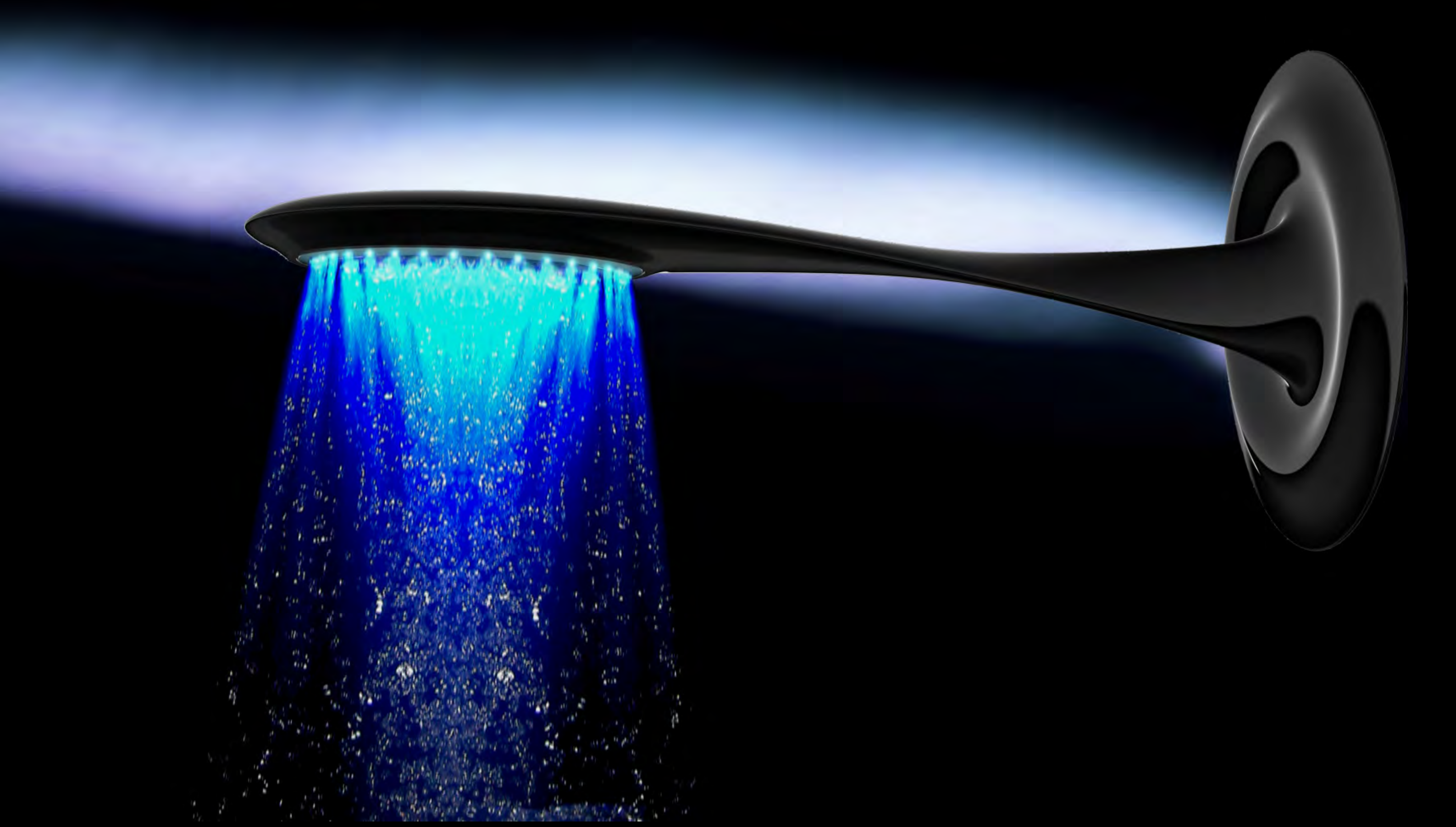
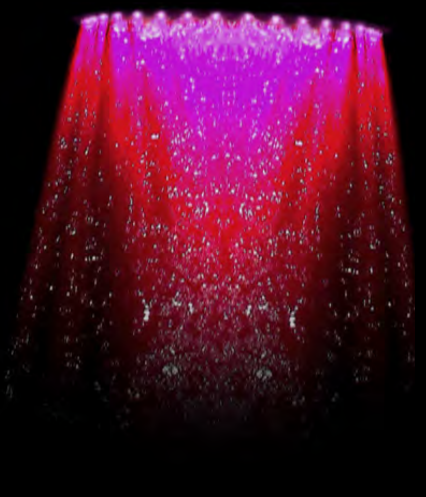


Borealis

Thermo-chromatic LED shower head

Jonathon Allen & Mark Richardson

Uniquely combining low-power super-bright LEDs with a thermo-chromatic coating, the Borealis shower automatically adjusts the colour of the light dependent upon temperature: blue when cold through to white through to red when hot. This not only provides a captivating light display, but acts as an important safety feature to prevent scolding.



Materials : Get smart: active materials

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Jonathon Allen

Active materials, typically referred to as smart materials, are a collection of materials that can change their properties in response to some form of stimulus. These active materials may change colour, shape, opacity, temperature or even move in response to light, heat, electricity, magnetic fields, chemicals or biological agents. Active materials also can include those that can change energy into other forms of energy – such as turning light or pressure into electricity.

These materials are clever and some of the coolest things to see in action. I think as a designer it is the idea of harnessing the cleverness of the material and applying it to create something that reacts and brings life to your designed artefact. Part of the beauty of these materials is the idea of getting something for nothing - say using the material to harness its own power, or using a material to automatically respond to its environment without the need for people to intervene.

There are all manner of reasons why these materials are being researched. Research into photovoltaic materials for instance is resulting in cheaper and more efficient solar cells, and hence contributing to the reduction of greenhouse gas emissions; pioneering work in the use of shape memory materials for use in surgery is now saving people's lives; and you can now keep your beer cool for longer thanks to research into phase change materials.

Heating and cooling

Phase change materials (PCM) can release heat when they change from a liquid to a solid and vice versa. A common example are the translucent liquid-filled heat packs sold in camping stores. The pack contains liquid sodium acetate and a little metal disk that when pressed turns the liquid into a cloudy crystallized semi-solid and gives out heat. These heat packs can be reused many, many times by placing them in boiling water to remove all the crystals and return the material to a liquid.

PCMs can store thermal energy and then release when required and can be used for all sorts of purposes, including recovering waste heat, heating and cooling of foods, transporting of temperature sensitive materials, regulating the temperature in buildings and vehicles and for performance clothing. In the latter example, some apparel manufacturers have developed clothing that keeps you warm or cool – for instance, cooling vests for fire-fighters or for athletes, or warming vests for mountaineers.

Magnetocaloric materials such as Gadolinium-Silicon-Germanium alloys may sound like a mouthful, but are really cool materials (literally). These materials change temperature in a magnetic field, and can be used for refrigeration, thereby having the potential to reduce greenhouse gases. Camfridge in the UK are in the process of developing commercial refrigeration and air conditioning products for "an environmentally conscious age … that will dramatically reduce energy consumption and use no polluting gases." (www.camfridge.com). The Ames National Laboratory (US Department of Energy) are also working on these materials.

Rheological materials – the shape changers

Rheological materials can change their physical shape and viscosity (eg from solid to liquid) – a bit like how applying heat to a material can change melt it from a solid to a liquid. The difference with these materials is that they change states by the application of either electricity (electro-rheological materials) or a magnetic field (magneto-rheological materials), the viscosity of the material can be controlled, and they respond really quickly. These materials have been used for all sorts of interesting applications, including shock absorbers and suspension systems for cars, seismic dampeners for buildings, artificial limbs, and some curious art pieces. Ferrofluids are one common magneto-rheological material that are particularly captivating to watch when variable magnetic fields are applied to the liquid.

Rheological or 'smart' hydrogels

Hydrogels are polymers that can retain water and can be used to simulate biological tissue. Stanford University's Bio-X interdisciplinary research program (amongst others) has worked on developing a bio-compatible artificial cornea for use in eye surgery. Other applications of these bio-compatible hydrogels are for more comfortable and longer lasting contact lenses. Smart hydrogels, however, can rapidly change their shape by swelling or releasing water in response to chemical, biological or electrical stimuli. Smart hydrogels can be used for such things as variable focus lenses, or artificial muscles. The beauty of these materials is that they can be designed to change based on a variety of environmental conditions – to detect and respond to changes in chemical or biological compositions of air or water for instance.

Shape memory alloys and polymers

Shape memory alloys are particularly exciting for their ability to rapidly recover their initial shape after being deformed. Imagine a coat hanger that uncurls and becomes a straight piece of wire by applying a current, or conversely a scrunched up piece of wire that when heated neatly folds up to become a coat hanger – not only this, but this can be done thousands (if not millions) of times. The question, of course, is why stop at the coat hanger – why not the shirt – apply heat and the collar is instantly straight – no need for ironing (apart from providing the heat source!).

There are two main types of shape memory alloys; ferromagnetic shape memory alloys and thermal responsive shape memory alloys. The latter of these will return to their original shape when heat is applied (either directly or through by applying a current to resistively heat the alloy). A variety of metal alloys can exhibit shape memory, but the most commonly known and widely used is an alloy of nickel and titanium (commercially available as Nitinol or Tinel). By varying the composition of the alloy, the temperature at which the material responds can be tuned – for instance set to change at body temperature or at the boiling point of water. The alloy, typically in the form of a wire, is not particularly strong when compared to a steel wire (its about 100th of the tensile strength), but its elasticity is far superior. Whilst it is a relatively expensive material, its ability to recover, and therefore move, makes it great as a replacement for motors and actuators as there are fewer moving parts it is much lighter. Consequently the aircraft industry has used them to adjust flaps on wings.

The phenomenon of shape memory alloys was discovered in 1932, but not really utilised until 30 years later when the Naval Ordinance Laboratory developed nickel-titanium alloys (incidentally Nitinol is an acronym; Nickel Titanium Naval Ordinance Laboratory).

The most exciting thing about these materials is the applications for which they are used. The medical industry has pioneered the use of these materials – particularly for delicate surgical procedures (key hole surgery, arterial clips, catheter guiding wires, stents). Orthodontic use is also becoming more common. Some stranger uses include penile implants for erectile dysfunction, and bras that can change shape to provide different support (reshape the breasts by either flattening or pushing them up) [see Smart bra by ESI Active Materials: http://www.esiactivematerials.com/iBra_interactive_bra.htm].

Shape memory polymers act in a similar way to shape memory alloys, but the response time is typically slower and they are not as strong. However, they have particularly interesting uses in textiles where they can be used to create wrinkle-free garments, or fabrics that breathe (much like the gills of a fish) responding to changes in temperature to provide greater comfort for the wearer. The advent of biodegradeable plastics adds a new dimension to these shape memory polymers – surgical stitches that tighten at body temperature, and then after the patient has recovered dissolve to leave healed tissue are a particularly exiting application. The shape memory polymer suture is particularly useful for keyhole surgery as the shape memory polymer can be used to provide the right degree of tension to hold the tissue together – not too much that it causes necrosis and not tool little that it doesn't hold the wound together.

Colour changing

Thermo-chromatic materials change colour when warmed up. They can be used to change colour at different temperatures and have been used for all sorts of applications, from the 'Hyper-colour' T-shirts of the 90's [or was it earlier] to the hot spot on frying pans. The thermo-chromatic dye can be blended in with many thermoplastics and then moulded conventionally, or alternatively applied as a coating.

Electro-chromic pigments perform in much the same way as thermo-chromatic ones, except the stimulus is an electrical current. A well-known version of an electro-chromic material is liquid crystal displays (LCD) which sandwich a material that polarises when a current is applied. Smart glass or switchable glass can change the opacity of glass – from transparent through gradients of translucency to opaque – by applying a current to the material. [Incidentally here's a rather famous all glass public toilet in the UK that uses electro-chromic pigments to provide some discretion upon locking the door].

Electricity generators

A variety of active materials can generate electricity, and these are particularly useful materials. Probably the most common materials in this group are the photovoltaic materials used for solar cells. Photovoltaic materials use thin coatings, or films, of light absorbing materials that absorb photons of light and release electrons. In turn, an array of photovoltaic cells provides sufficient charge to draw current from.   Photovoltaic materials have been around for a very long time – the effect was first noticed by Becquerel in 1839, but like many materials, it took a long time before photovoltaics were commercially available. In an earlier article I mentioned that flexible solar cells were under development that could be printed or spray coated onto various substrates (entire buildings perhaps), or fabrics (solar clothing, awnings and curtains for instance). Through the use of carbon nanotubes work is underway to produce completely transparent solar panels on windows (as the nanotubes are too small to see when sandwiched between two panes of glass.

Piezoelectric materials generate charge when pressure is applied to them. A common example of the application of them is in gas or cigarette lighters where pressing a button causes a piezoelectric crystal to generate a spark that lights the gas. Conversely, if a current is applied to them they can generate movement. Piezoelectric materials only generate small movements that make them ideal as highly accurate actuators (high precision stepper motors) or as flat speakers.

Potential uses of active materials

The applications for surgery are highly noble and it is great to see that there is often a simple solution to a complex problem by the use of a clever material.

The idea of combining these smart materials in order that one stimulus can trigger multiple reactions fascinates me. For instance a soft helmet that uses several layers of smart materials – perhaps a piezoelectric material that generates an electrical charge on impact that stimulates an electro-rheological material to harden in order to distribute the forces over the entire shell of the helmet, then softens to minimise the forces being transferred to the head.

These materials are typically expensive, and are therefore not economic for all applications. That is relative though – some of these materials can be used to replace several parts (eg a shape memory alloy instead of a motor and linkage assembly), or for applications, particularly transport, where such a reduction in weight results in ongoing cost savings.

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