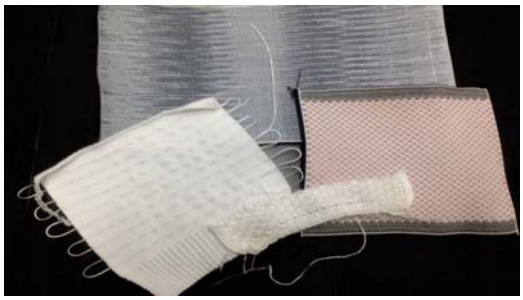


Smart Materials

Not just a gadget. Can materials think?

Connie Huffa

Fabdesigns, Inc.

Photo credit: https://futurism.com/

What are smart materials?

The words “Smart textiles”, “Smart Fabrics” or “Smart Materials” are as over used as “Wearable Tech” and include many categories.

But what are “Smart Materials” really?

What are 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 of the above.

What types of Stimuli?

Stimuli could be

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

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 fluids

How do we describe change? The associated changeable physical properties could be shape, stiffness, viscosity, damping, etc. The changes should be significant, measurable, and happen over a specific period of time. **They can change with environment – one way or reversible.** (example of one way is shipping humidity sensors)

Cause and Effect

Material Type	Input	Output
Piezoelectric	• Deformation	• Potential Difference
Pieziochromic	• Pressure	• Color change
Piezorheologic	• Pressure	• Viscosity change
Electro restrictive	• Potential Difference	• Deformation
Magneto restrictive	• Magnetic Field	• Deformation
Magnetorheological	• Magnetic Field	• Viscosity change
Thermo electric	• Temperature	• Potential Difference
Shape Memory Alloy	• Temperature	• Deformation
Super Elastic Alloy	• Temperature /current	• Deformation
Photochromic	• Radiation	• Color change
Heliotropic	• Sun	• Color change
Biologic	• H2O, bacteria, etc.	• various

Why would we want Smart Materials?

We are used to controlling the world around us, to find the settings that suit us best. Many of these technologies are based on bio-mimicry and will harmonize our environments.

- Security & Privacy
- Safety
- Protection
- Early Detection
- Entertainment - VR
- Wellness
- Medical
- Sports
- Communication
- Home
- Aerospace
- Architecture
- Transportation
- Infrastructure
- Energy Harvesting

Non-Newtonian Polymers that react to Pressure

- Non-Newtonian fluids flow and stretch easily. But when you move it quickly, the viscosity changes and it locks together tightly, instantly absorbing the energy.
- Sheer thickening fluids absorb the force of Kinetic energy. Corn starch, Silly putty, some soups
- Example of a polymer: D3O® can be found in more than 100 products—everything from cell phone cases to kneepads to ballet shoes. It is soft but reacts to impact.

https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/past-issues/2016-2017/february-2017/no-hit-wonder-d3o.html

Non-Newtonian

- Corn starch is also known as an Oobleck, after Dr. Seuss' book Bartholomew and the Oobleck, where a gooey green substance fell from the sky. It is either a solid or a liquid, depending on the environment.
- Recipe:
  - 1 cup water
  - 1.5-2 cups corn starch
  - a few drops of food coloring of your choice

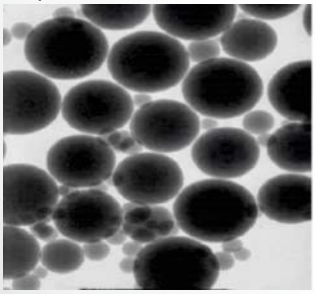


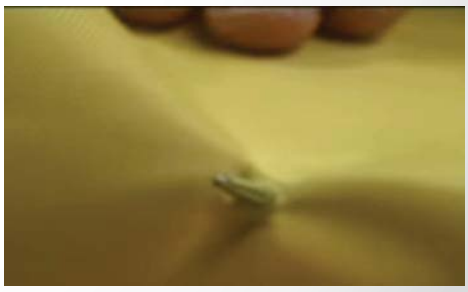

http://www.instructables.com/id/Oobleck/ and https://www.youtube.com/watch?v=Sl0BHueSjvA

Smart Armor

- Kevlar fabrics impregnated with a **'shear thickening fluid',** the exhibits the same kinetic energy dampening effect – like the oobleck, offer fabric flexibility, and light weight armor. At impact, the fluid thickens, creating hydro clusters in a lattice formation that become as hard as ceramic for a split second, enhancing the ballistic protection, while also preventing knife / shank penetration. Plain Kevlar does not prevent knife point penetration. Applications: Sanitation, first responders, industrial . . .

Silica thickening particles
suspended in PEG

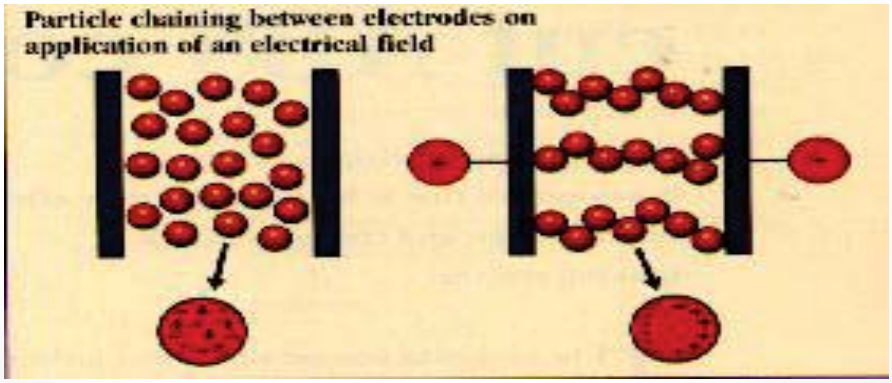




https://www.youtube.com/watch?v=GagzssoU1yo and https://www.youtube.com/watch?v=rYIWfn2Jz2g

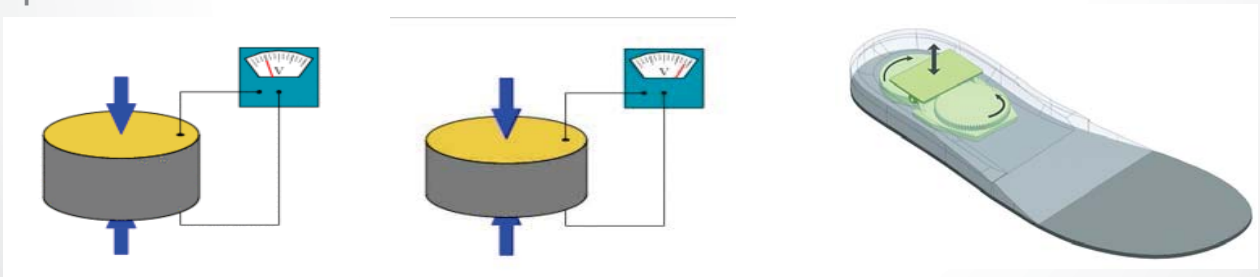
Electrorheological Fluids

- **Electrorheological fluids** are a type of **"smart" colloid** capable of varying viscosity or even solidification in response to an **applied electric field**. The rheological variation is reversible when the field is removed. The response time can be as short as a few milliseconds. **These are used in mechanical vibration control.**
- Electro-rheological fluids (ER) (mixing corn flour in a light vegetable oil or silicon oil)



Piezoelectric

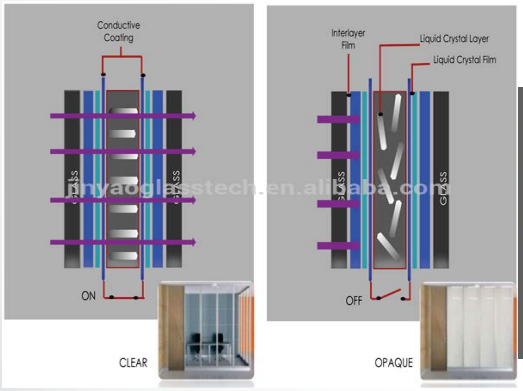
- **Piezoelectricity** is Electric polarization in a substance resulting from the application of mechanical stress. Voltage is produced when stress is applied
- Piezoelectricity is the electric charge that accumulates in certain solid materials in response to stress or pressure. Materials include crystals, ceramics, and biological matter such as bone, DNA and proteins



https://en.wikipedia.org/wiki/Piezoelectricity
http://www.popsci.com/article/science/invention-awards-2014-charge-gadgets-your-footsteps?dom=tw&src=SOC

Intelligent Glass

- Selectively reflects the infrared on hot days
- The secret is super thin coating of vanadium dioxide molecules doped with tungsten – Liquid crystals - LC
- At low temperatures vanadium dioxide is transparent to infrared
- At higher temperatures the bonding between the molecules changes and the material becomes reflective, like metal



https://french.alibaba.com/product-detail/electric-privacy-film-smart-glass-tinting-film-for-car-window-for-home-window-60305739499.html

Piezochromic Pigment

Pressure sensitive to shock, impact, and strain

Reversible and Irreversible **Color change** at a given pressure and **color recovery** when the constraint decreases.

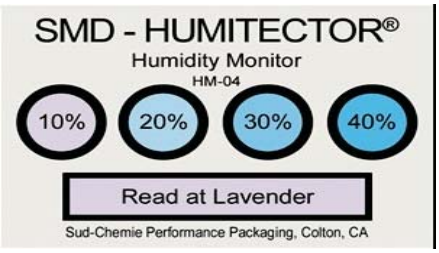
Reversible Applications : visualization of the mechanical behavior of various materials under pressure (tensile, compressive and torsion loading), material health testing.

Irreversible Applications : non-destructive material testing during production, use or maintenance (folds, breaks, wear, corrosion, cracks) / Visual detection of impacts and shocks for the industrial and transport sectors.

Credit: http://olikrom.com/en/olikrom-products/piezochromic-inks-pigments-pressure-sensitive-paints/

Piezochromic Pigment

Humidity: sensitive to moisture



Reversible and Irreversible **Color change** at a given humidity and **color recovery** when the ambient humidity decreases. This is usually blotting paper **impregnated** with cobalt(II) chloride base, or less toxic, copper(II) chloride base.

Reversible Applications : weather indicator

Irreversible Applications : packaging for electronics, clean rooms, etc.

Credit: http://protektivepak.descoindustries.com/ProtektivePakCatalog/Bags/Desiccant-Humidity/48882/#.WU2c02jyv-g/

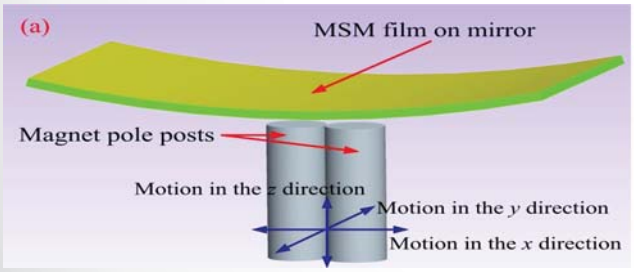
Magnetostrictive

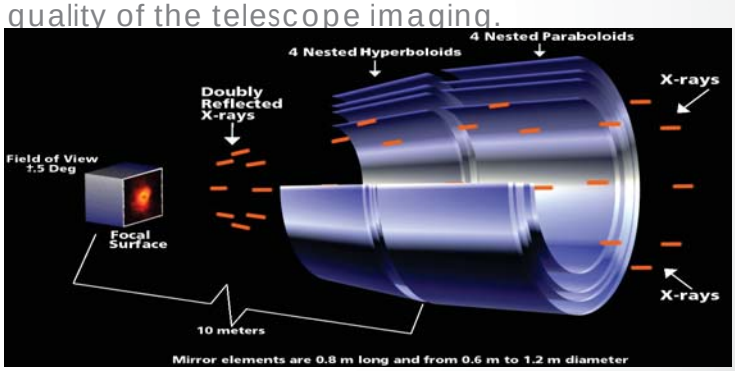
- **Magnetostrictive materials** - electrostriction) is a property of ferromagnetic **materials** that causes them to change their shape or dimensions during the process of magnetization. The variation of **materials**' magnetization due to the applied magnetic field changes the **magnetostrictive** strain until reaching its saturation value, λ. -Wikipedia
- Magneto-strictive materials (cobalt, Terfenol-D, etc.)
- **Example:** We use the piezoelectric effect in our daily lives. **The igniter on most gas grills**, consists of a piece of a piezoelectric material. This piezoelectric element when it is stressed by the impact of a small hammer which is cocked and released by pushing the button, cr placed near the gas burner.

credit diagram: http://www.ctgclean.com/tech-blog/ultrasonics-transducers-piezoelectric-effect

Magnetostrictive

- We can correct deformation by coating the non-reflective side of the mirrors with "smart" materials that respond to various stimuli, such as temperature changes, magnetic fields, or voltages.
- This project specifically uses magnetic smart materials (MSMs) to try to counteract mirror deformation. We can use a magnetic field to actively control the surface profile of the mirror and consequently improve the quality of the telescope imaging.

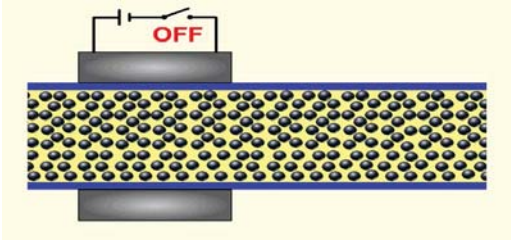


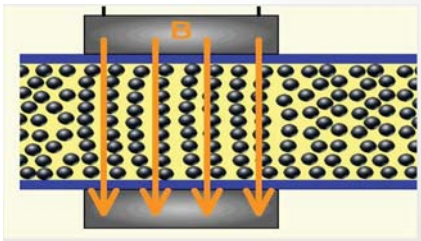


credit diagram: http://ampl.mech.northwestern.edu/research/current-research/magnetostriction.html

Magnetorheological

- **Earthquake dampers** – Seismic mitigation of buildings - The Magnetorheological fluid inside modern dampeners are kept solid in normal conditions, but change to liquid and back as sensors activate and deactivate a magnetic field during an earthquake, allowing the dampeners to absorb the shockwaves and reducing damage to the structure. The fluid can change from liquid to solid and vice versa. Fluid is 3 ingredients: carbonyl iron, lubricant, and hydrocarbon oil. The Magnetorheological fluid inside the dampeners changes a building from a rigid structure that must absorb the shockwaves to a **'smart' structure** which adapts instead.



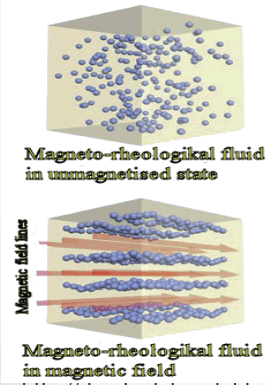


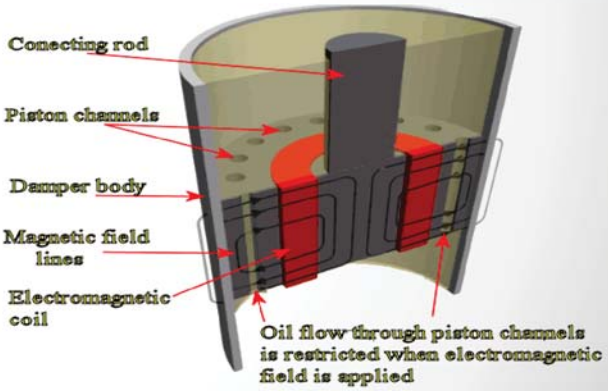
http://www.tech-faq.com/magnetorheological-fluid.html and Wikipedia

Magnetorheological

- **Shock absorbers** – 'Magnaride'

The strength of the bonds between the magnetized iron particles causes the viscosity of the fluid to apparently increase. The magnetized fluid is not, technically, more viscous, but it is more resistant to passage through the restrictions in the damper because the concentration of magnetized fluid forms a kind of deformable plug.





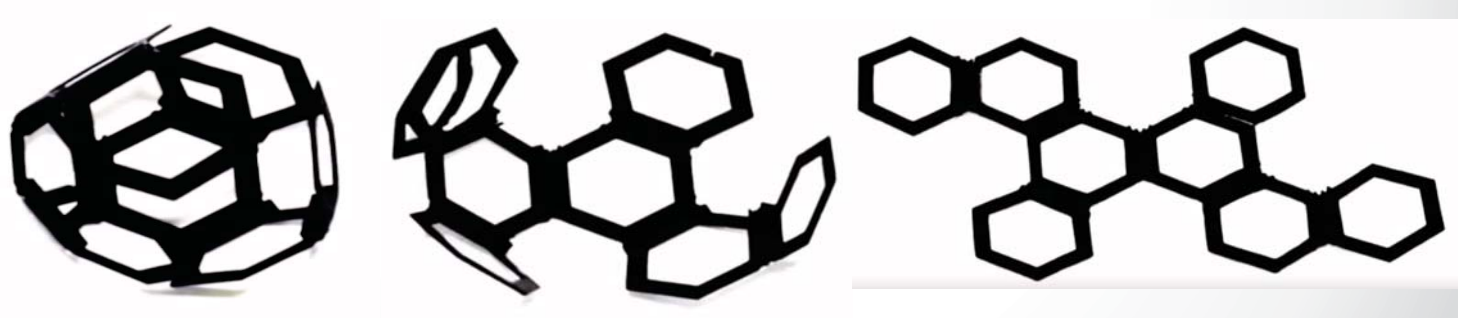
http://dipalpatelmech.blogspot.com/2014/09/magnetic-damper-magnetorheological.html

Shape Memory Alloy

- NiTinol Nickle Titanium
- **Self assembly is** when independent parts come together on their own to create specific things.

Shape Memory Alloy

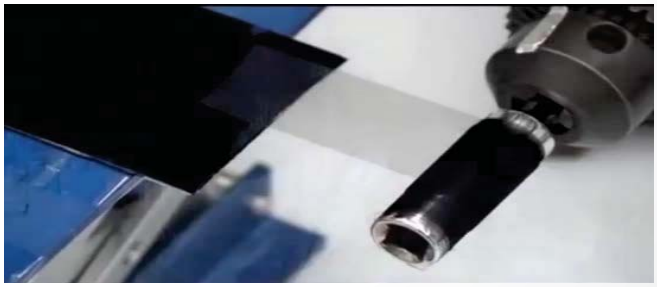
- NiTinol Nickle Titanium SMA
- Self assembly is usually easier to 3D print flat. We can orient the geometry of each cell to link cells in a way to build stiffness in one direction and flexibility in others.



MIT self assembly Lab https://www.youtube.com/watch?v=GIEhi_sAkU8

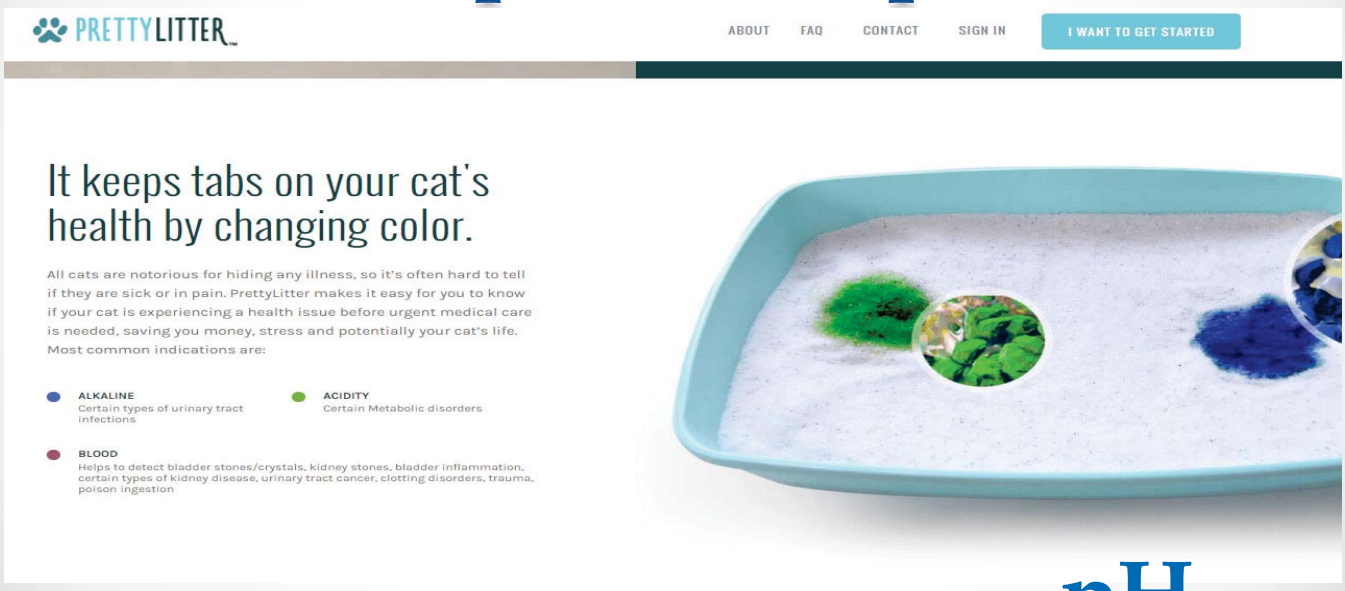
Super Elasticity

- **NiTinol** Nickle Titanium muscle wire. Biocompatible
- **Nylon fishing wire** twisted on itself 1000's of times and heat set.
- **Carbon nanotubes** – lightweight, transparent, conductive, thermo-conductive, 40 times stronger than steel & 32 times stronger than human muscle– electrical charges causes the tubes to repel each other – result is compression.
- **Pros:** Mimics tendons and muscles and compresses with heat or electrical charge. **Cons: Graphene** oxide is toxic to humans.



https://www.youtube.com/watch?v=Q-POw1su5ss and https://ucrtoday.ucr.edu/22044

Response to pH



pH

Biological Smart Materials

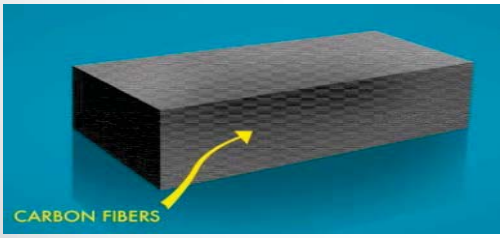
- Concrete that heals itself with bacteria. The bio concrete is mixed just like regular concrete, but with an extra ingredient -- the "healing agent." It remains intact during mixing, only dissolving and becoming active if the concrete cracks and water gets in. The bacteria are active in concrete, and produce repair material for the concrete -- and that is limestone.

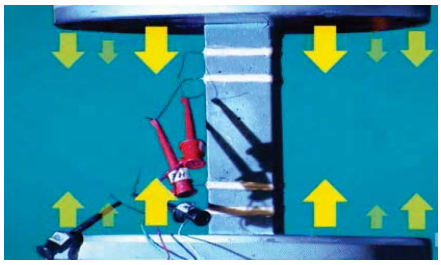


http://www.cnn.com/2015/05/14/tech/bioconcrete-delft-jonkers/index.html

Response to water
Smart Concrete

By adding carbon fiber to **concrete** mixture, a slab of **concrete** is able to conduct electricity and enhance a material that has been used for eons. "**Smart concrete**" has many potential applications, including helping structural engineers to identify hidden trouble spots of damage or deformation in a **concrete** structure long before stress or cracking is visible to the human eye. It can detect minute changes in stress. As the compression increases, the electrical resistance decreases, making the concrete more conductive.
Unistress – Pittsburg Patent US 005817944A





Credit: https://science360.gov/obj/tkn-video/0cf5bb00-0421-412f-b77d-9e0c48c510df/science-innovation-smart-concrete

Heliochromic

Sensitive to UV

Reversible and irreversible color change at a given UV intensity and color recovery when the temperature of the surface of the pigment decreases.
Reversible Applications : glasses
Irreversible Applications : aerospace
Biomimicry – sunflowers, melanin

Credit: http://www.ctvnews.ca/sci-tech/sunflowers-use-internal-clock-to-track-the-sun-study-1.3015991
https://bobbylamb.wordpress.com/tag/smart-materials//

Response to Heat Thermochromic

- Left: Reversible and Irreversible **Color change** at a given temperature and **color recovery** when the temperature of the surface of the pigment decreases. Thermometer application.
- Right: Lauren Bowker, founder of The Unseen created a calfskin backpack that shows vivid flushes of color in response to air pressure as the atmosphere brushes across it's surface, and an Italian alligator-skin shoulder bag with environmentally responsive ink that changes to reflect the different seasons in the UK. It turns black in the winter, red in the spring, blue in the summer and green fading to red in the autumn.

Credit: https://www.forbes.com/sites/rachelarthur/2015/11/11/material-science-hits-selfridges-with-the-unseens-color-change-accessories-line/#36e93c6e684a

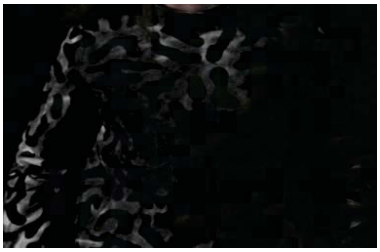
Emotional (thermochromic)

- **Chameleonic gemstones map brain activity across headdress by The Unseen.** Lauren Bowker, founder of The Unseen has created a gemstone-encrusted headdress that changes color in response to varying energy levels in the brain. Excitement, nerves, and fear all produce different colors, and quicker shifts in emotion create more dramatic patterns. She has also has created a ink that is responsive to wind – uses - aerodynamics

https://www.dezeen.com/2014/07/31/the-unseen-color-changing-gemstones-headdress/

Carbon Monoxide

- New York designer **Nikolas Bentel** has developed a range of color changing dye patterned shirts that change color in response to air pollution or radioactivity. The Carbon Monoxide shirt functions in a similar way to a CO spot detector, which features a patch of palladium and molybdenum salts that turns black (oxidizes) when carbon monoxide is present and an iron metal salt robs back the oxygen and turns clear when the CO is removed. As CO oxidizes on the shirt, the dye's color is white as it loses oxygen atoms. Once the carbon monoxide's removed from the air, the metal salts absorb oxygen from the air. This changes the dye back to its original chemical form, and the color to black again. Ink Patent US20030199095 A1


https://www.dezeen.com/2016/07/29/nikolas-bentel-aerochromics-shirts-change-color-air-pollution-radiation/?li_source=LI&li_medium=bottom_block_1

Future Scopes

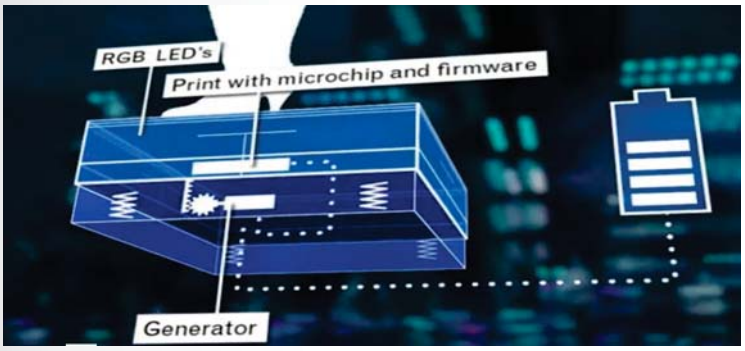
- Next generation will change color, emulate muscles, respond to light, heat, radiation and magnetic fields.
- Materials will become more light weight with super strengths and multiple functions varying with their environment
- Materials which can discriminate whether the loading is static or shock and can generate a large force against shock stresses (mega and micro shock absorbers)
- Materials possessing self repairing properties which can heal damage in due course of time (self healing materials)
- Materials that can be used in ultra high temperatures by changing the composition through transformation (application in space shuttles which encounter high temp in reentry to atmosphere)

Combining Material Science with Communication

- Interactive Wearable for health and sports
- Adapt to Physiology
- Biomechanics – replacement of canes, wheel chairs, etc.
- Improve efficiency, accuracy, balance
- Customize gear, clothing and home – Physiological analytics 3D
- Mitigate risk of injuries
- Assess readiness for competition
- Quantify return to play. Healing wounds
- Faster recovery with less clumsy products
- Comfort
- Automatic massage for better circulation

The Future

Piezo-electric flooring

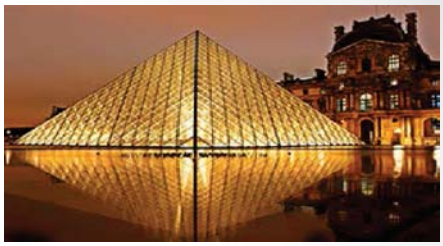


Our energy floor modules flex slightly when stepped on. Inside each module is an electromechanical system, which transforms the small vertical movement produced by dancing or walking people into a rotating movement that drives a generator. Each module by the size of 75x75x20 cm can produce up to 35 watt of sustained output, between 5-20 Watt per person.

Credit: http://www.energy-floors.com/

The Future

Piezo-electric flooring



Veranu – Italian company from Sardegna recycles Foot Traffic:
Louvre 20 million visitors/yr. 20 meter passageway powers LED strips, the Pyramid, and façade at night. Annual savings .55 tons of CO_2 emissions
Rockefeller Center 70 million/yr. – 40 sq. meters of tile powers LED strips and 30,000 lights on tree. Annual savings .8 tons of CO_2 emissions
Other places: Colosseum in Rome; Flinders Railway Melbourne

Credit: http://www.veranu.eu

The Future

Piezo-electric Roads

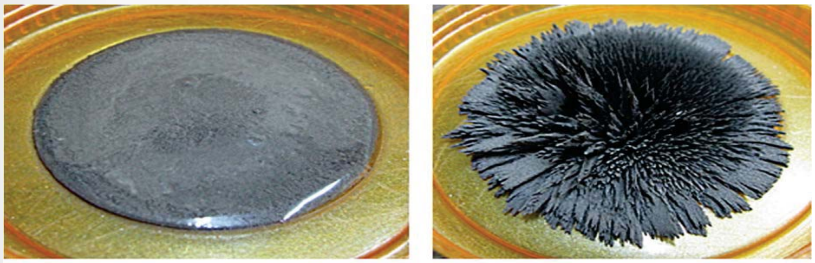
Good Vibrations? California to Test Using Road Rumbles as a Power Source

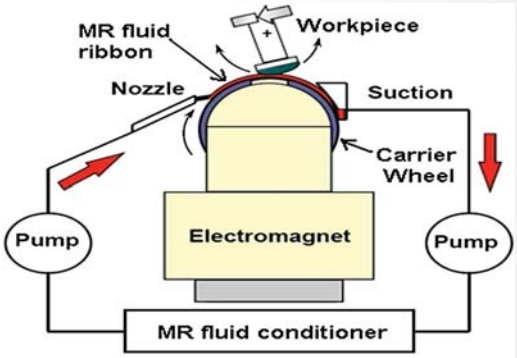
A total of US $2.3 million will be invested in two projects. First up, a 60-meter (200 foot) stretch of roadway near the campus of the University of California, Merced, north of Fresno,. The other project, to be run by Pyro-E, LLC of San Jose, will use similar devices to generate power for off-road use; the company speaks of scavenging enough power to supply 5,000 homes.

http://spectrum.ieee.org/cars-that-think/transportation/infrastructure/good-vibrations-california-to-test-road-vibrations-as-a-power-source

The Future

Magnetorheological polishing





High precision finishing methods with automated finishing without manual intervention, using magnetorheological Nano finishing without any manual (human) effort in manufacturing processes.
Application: Ceramics are extremely sensitive to surface defects.

Credit: http://opticalengineering.spiedigitallibrary.org/article.aspx?articleid=1857354

The Future

Electro oobleck

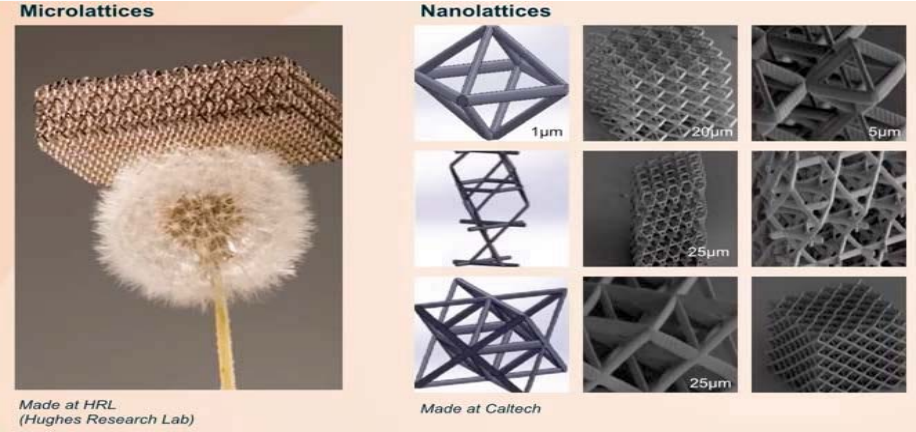
Assistive materials that electronically change shape and become stiff when needed and flex. Like an electronic wetsuit. Replaces a cane.

Credit: https://www.youtube.com/watch?v=Q-POw1su5ss

The Future

Smart X Smart

- Material Strength vs Density: Light weight and weak or strong and heavy
- Micro-lattices and micro trusses are architectural structures using materials the width of a human hair
- Nano -lattices are about 1/100,000th of a human hair
- Some materials get stronger at Nano (single crystals), so more ductile (metallic Glass), some damage resistant. (ceramics)
- Fabrics combining physics, chemistry and materials science, using structures, plus nanofibers or nanotubes , and combining with smart materials to engineer functional performance

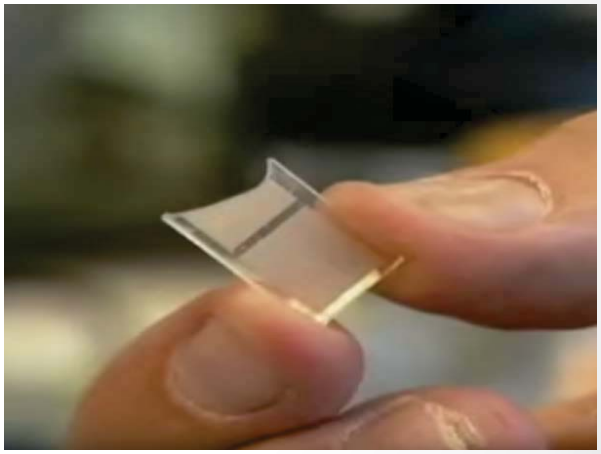


https://www.youtube.com/watch?v=TjHYHY_IkUk

The Future

Smart Healthcare

- Modular materials that change color with dosage
- Materials which can discriminate levels of bacteria
- Materials possessing self repairing properties which can heal damage in due course of time (self healing materials)
- Materials that can be used in recovery by changing their composition as they age
- Self assembling – stents
- Drugs that are dosed over time – up to 5 years – torsion engineered delivery.
- Next gen Chemo – targeting cancer with nanoparticles, mimicking a water molecule to trick immune system



https://www.youtube.com/watch?v=i6n8cpLKzHE

The Future

Piezoelectric agility - Transportation

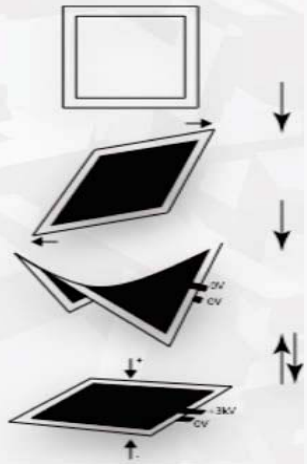
- **Work and Transportation:** Next generation will change color, emulate muscles, respond to light, heat, radiation and magnetic fields.
- NiTinol Nickle Titanium muscle wire

https://www.youtube.com/watch?v=i6n8cpLKzHE

The Future

Piezoelectric agility - Transportation

Source: Manuel Kretzer – "Shapeshift"



Dielectric elastomer – shape shifts and compresses with a charge on each side. Is silent, and light weight

https://www.youtube.com/watch?v=Q-POw1su5ss

Thank you

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