Materials : Seeing things: windows on our world

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From a humble grain of sand, to satellites in space and ultra-keyhole surgery – glass has come a long way. Glass is not just the stuff of windows – but windows into other worlds. It has helped us discover the miniature world of cells under a microscope to the far away galaxies viewed through a telescope.

Of course, we know glasses help us see, but we probably haven't really appreciated just how much glass has allowed us to open our eyes. Glass has been the unassuming but essential ingredient in scientific discoveries, medical breakthroughs, and engineering feats.

This article explores some of the intriguing developments and applications of glass.

When I'm cleaning windows

Back to those windows. We know glass to be clear, but my windows aren't. Well, they were once, and periodically are, but more often they provide a forensic record of my childrens' exploits in and around the home – traces of their entrances and exits left behind via fingerprints and face smears (thank goodness for safety glass), and not to mention their diet (jam and Vegemite are popular). A bane of my life is cleaning the windows, but thankfully one particular food ingredient sometimes known as E171 is on my side. E171, a food colourant, is actually titanium dioxide – an incredibly versatile material, that when applied as a coating to glass (by a professional I might add, and not by my children) can have some remarkable properties.

A very thin layer of titanium dioxide is clear, and this coating can be used to self-clean glass in three great ways. Firstly, the titanium dioxide coating is hydrophilic meaning that it attracts water and thus helps wash away any dirt that may have found its way onto the glass. This is great for outdoor conditions where the rain can just wash the window for me. Pilkington's Activ™ glass, (see Curve issue 23 "following nature's lead") is one commercial version that has a nanocrystalline titanium dioxide coating.

Titanium dioxide's second way of cleaning glass is with its strong oxidising power – oxidisers are often the active cleaning agents in laundry detergents and stain removers (now I'm really sounding like an add for a cleaning product!). Titanium dioxide coatings also have photo-catalysis effects – that is they help breakdown organic 'dirt' using ultraviolet light (from the sun). This last property of titanium dioxide is an advertiser's dream come true, as this photo-catalytic activity has other key features: it is anti-microbial, anti-bacterial, anti-viral, anti-fungal, and anti-fouling; it can deodorise and disinfect, and it self-cleans. But wait, there's more – it can be used as an anti-fogging agent on glass, as its hydrophilicity causes water vapour to form a continuous flat sheet of water rather than condensing as droplets on the glass.

It's not only clean but can be green too, as another interesting application of titanium dioxide is its ability to perform hydrolysis – the splitting of water into hydrogen and oxygen. Imagine a future, where when it rains not only do your windows clean themselves, but you also get free fuel for your hydrogen-powered vehicle. Now that would be a very smart piece of glass.

The term 'smart glass' though is more typically associated with a material that can change opacity at the flick of a switch. A thin layer of liquid crystal sandwiched between two transparent electrodes is the smart bit – when the power is off the liquid crystal is randomly oriented and the glass is opaque, apply a voltage across the electrodes and the liquid crystal re-orients and the glass becomes see through. A number of companies produce this type of product, including Pilkington, SmartGlass International, Velux, and Polytronix.

Fibre-optics

The notion of getting light to travel along a curved path using refraction was first pioneered in the mid 19th century. Daniel Colladon and Jacques Babinet demonstrated this in Paris in the early 1840s, and later John Tyndall demonstrated this phenomenon in public lectures in London. Refraction simply refers to the change in direction that light (or any other form of wave energy for that matter) travels when it passes from one medium to another (say from air to glass to water). Light travels at different speeds through different densities of materials – that's why when you place a straight stick into a pool of water the stick appears bent; the refractive index of water is higher that that of air.

Fibre optic

In Calladon's experiment, reference is made to a "light fountain" and a "light pipe" whereby light travelled through a stream of liquid – in some respects this was an early version of a fibre-optic. Optical fibres, as we've come to know them, were first developed in the 1950's although experimentation with light travelling along glass tubes had occurred much earlier. John Logie Baird, the visionary inventor of the television (well the first working one), for instance had conducted experiments in the 1920s whereby images would be transmitted along glass tubes.

Optical fibres work by light bouncing off the internal walls of the clear fibre in a phenomenon known as total internal reflection. The clear core of the fibre is coated in another material with a different refractive index, and so light is reflected back into the core rather than scattering out through the coating, thus allowing light to propagate along the fibre. Because the fibres can be so thin they can flex, and so light can travel around bends.

Fibre optic and jellybean

This important feature of fibre optics has revolutionised surgery and medical procedures. In 1956, Basil Isaac Hirschowitz, patented the first flexible fibre-optic gastroscope, which allowed doctors to look inside a patient's stomach relatively non-invasively. Since then, doctors have found many other places to stick fibre-optics to have a look at what's going on, and there are now many fibre-optic based 'scopes' (eg arthroscope or endoscope) that have been developed to investigate different parts of the body, and fibre-optic devices are now the mainstay of non-invasive surgery. Last year surgeons in Paris performed ultra-keyhole surgery on a brain tumour using a water-cooled fibre-optic laser that was guided to the tumour site by the surgeon. The patient was awake during the procedure and felt nothing during it (just a local anaesthetic was used), and was encouraged to talk to the surgical team to ensure that brain functions were not being harmed by the surgery.

Industrial endoscopes (known as borescopes or fiberscopes) are also used to examine and maintain the 'health' of other things in hard-to-get-to places – from jet engines to drains, fibre-optics allow us to view things that have previously alluded us. Fibre-optic devices can be used to monitor the health of structures, machines and systems, as they can act as sensors measuring changes in temperature, strain and pressure in environments that preclude conventional sensors, perhaps because of extreme heat (for instance measuring the temperature inside a jet engine or a furnace) or where strong electromagnetic radiation would affect conventional sensors.

Fibre-optics are not just for viewing and shedding light on a subject. They are of course widely used for telecommunication purposes allowing large volumes of data to be transmitted great distances very quickly. This has made possible the evolution of the World Wide Web and changed the world as we know it.

On not such a world-changing scale, but nonetheless a fascinating application of optical fibres, we now have translucent concrete. Developed by Hungarian architect, Áron Losonczi, Litracon™ is a structural concrete embedded with fibre-optic glass strands that has the same strength and weight as conventional concrete, but looks a lot lighter (forgive the pun). Because light diffuses through the concrete the physical mass of the material looks much less than it is, and the depth of the material is a little deceptive looking a lot thinner than it actually is. At first glance the material looks more like a thin curtain or blind, with shadows cast through from behind. The material has won several design awards, including the 'Best of the Best' Red Dot Award (2006), a Leaf Award (2006), and the 2008 iF (International Forum Design) Material Award.

Meta-materials

The illusionary quality of light-transmitting concrete is nothing compared to that of the meta-materials. These materials have the scientific world aflutter and journalists are dreaming up wonderfully exaggerated headlines to capture our imaginations. We're talking about invisible, cloaking materials. Harry Potter and Lord of the Rings fans of course are familiar with the concept – a material that when placed over you makes you invisible – the reality is not quite so perfect, but these materials can bend and manipulate light through their structures.

All materials have a positive refractive index, but meta-materials have a negative refractive index, meaning that they can bend light backwards. The woven-like structure of these materials negatively refracts light waves because the fibres of the material are smaller than the wavelength of the light (between 400-700nanometers). This ability to bend and manipulate the path of light means that objects can potentially appear to disappear when covered by a meta-material, as the light from behind the object is transmitted through the meta-material to the front. The problem is getting the light to re-align on the other side – the image is likely to be blurred.

Whilst such an application of the science may take some time, the possibilities are very exciting in other areas. Some interesting work is taking place at the University of California Berkeley on meta-materials with applications for superior lenses for microscopes and telescopes.

So we come full circle – and see that whilst there have been some incredible developments in glass, the motivation driving its development is simply to see the world more clearly.

And finally, back to my dirty windows. There was a delightful irony of the jellybean smear on the glass – low and behold the magic ingredient creating that pearlescent shimmer of the sweet, sticky candy was none other than E171 – titanium dioxide.

Should I leave the smear there in the hope it will clean itself?

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