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Golden Eye Nanotechnology for vision enhancement

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Golden Eye

The optical properties of gold particles have been appreciated since Roman times, but never before have they been used for vision enhancement. Luke Hutson focuses on the nanotechnology company that has its eye on an unexpected application.

Imagine being able to see in almost pitch black conditions without using a pair of bulky night vision goggles. A company in Rhodes Island, USA, is looking to give humans this bionic ability by using gold particles to boost the photoreceptors in the eye. Before contemplating on the rather eye-watering thought of how the particles would actually get there, why would you use gold in the first place?

The man with the answer is Dr Nabil Lawandy, the CEO of Solaris Nanoscience. Rather surprisingly, he begins with a brief historical detour. 'The basic phenomenon we're exploiting is twenty centuries old,' he says, referring to the Roman practice of using gold particles to give glass a ruby appearance. 'If I was doing that,' continues Lawandy, 'I would have expected to see something shiny and metallic looking. Of course, what they ended up creating was something that looked like a deep red cabernet wine.'



End in sight - if gold nanoparticles can be attached to photoreceptors in the eye, night vision goggles could be redundant

The mystery was only unravelled in the mid-1800s when Michael Faraday realised that the particles were exhibiting a resonance, now commonly known as plasmon resonance (see 'Good vibrations' box).

'We're in the business of making antennas in a beaker,' says Lawandy, summing up the gold particles being synthesised in Solaris's laboratories. 'This resonance creates a very large enhancement of the electric field in the vicinity of the particle. And that's a very important aspect to the vision application. Within a couple of particle diameters, the fields can be enhanced by orders of magnitude and that means the intensities by even more than that,' continues Lawandy.

Solaris has set itself the task of creating an antenna for a photoreceptor molecule. The intention is to attach gold particles (silver could also be used) to the molecule, and then let plasmon resonance do the rest. 'The large field generated by the gold particle enhance the reception capability of that molecule, or in other words its ability to absorb light,' says Lawandy.

Setting one's sights

The basic idea in the vision application, says Lawandy, is to take a gold 'antenna', which can be from two nanometres to tens of nanometres in diameter, and to functionalise the surface. In practice, this means placing molecules on its surface to allow it to bind near a photoreceptor in the human eye, such as rhodopsin. According to Lawandy, a good molecule for this binding role is thiol, which is a sulphur-containing compound that binds

very effectively to gold. One end of the thiol molecule would attach to the gold and the other end would have an antibody or some selectively binding half that it allows it to attach to a photoreceptor.

In the dark

The vision enhancement technology could be used for people with impaired and normal vision, says Lawandy. 'If you took people with normal vision, you would expect them to have night vision capability after the treatment,' he says. This would obviously suit military applications, where today soldiers are required to wear goggles for night vision. He also believes the technology could be used to combat retinal diseases, such as age-related macular degeneration (AMD) or diabetic retinopathy (DR). 'In a disease like AMD there is an overgrowth of blood vessels that leak, and the end result is that they destroy a number of rods, and you're left with impaired vision. The idea here is to put antennas on the remaining photoreceptors, so you're getting more light sensitivity on fewer rods.' The rods that Lawandy is referring to are the light-sensitive cells in the eye that respond to low intensity levels but do not respond to colour. The other type of light-sensitive cells on the retina are cones, which respond to higher intensities and colour.

Lawandy is confident that all the pieces of technology are in place. 'The basic proof of principle has been shown, he says, and the thiol linker is in place. The third part, which normally ruins all these ideas, he quips, is the safety factor.



Eyeing up alternatives

So how exactly are these gold nanoparticles going to be introduced into the body? 'This is still an open question,' says Lawandy.

Photodynamic therapy might yield a possible solution. A direct infusion of material to the back of the eye is one possibility, and further into the future an injection or pill might become available to accumulate the material in the right place. 'That part of it is to some extent being done with today's photodynamic therapy drugs,' he adds.

Lawandy feels that Solaris's work is complementary to research being done on AMD. 'Lots of other companies are working on stopping this overgrowth of

blood vessels. But none of them know what to do once you have a compromised state of vision.' Lawandy mentions a company in Massachusetts that is proposing putting a charge-couple device arrangement in the back of a person's eye. 'But at that point you are interfacing silicon architecture to the very complicated architecture that Darwinian evolution has created over many centuries, which is no small challenge,' says Lawandy. In the Solaris approach, the remaining biochemical wiring is left unchanged and the aim is to increase the performance of what is left behind.

But what are the long-term effects of using this technology? Solaris has consulted with a variety of experts to evalu-

ate the likely effects. 'Most of them, apart from being very excited by the technology, feel that the vision enhancement would have a transient effect, which would be perhaps a minus for people with AMD but a plus for night vision applications,' says Lawandy. 'It's been explained to us that many of the photoreceptors on the outside of the rods and cones are replaced. As those are taken off, new receptors are generated.'

Vision for the future

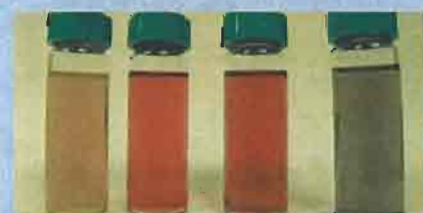
For the moment, Lawandy says that Solaris is concentrating its efforts on synthesising the gold antennae in different sizes, structures and coatings, and on providing unambiguous,

Good vibrations

Michael Faraday, in his Royal Society Bakerian Lecture of 1857, proposed that microscopic particles of silver and gold form colloids in glass and are responsible for the vivid ruby colour, as demonstrated in the Lycurgus Cup (see right), which dates to the 4th century AD. Some 50 years later, Gustav Mie, the German physicist, explained the phenomenon quantitatively as arising from a collective oscillation of the metal electrons confined in these microscopic particles. This collective oscillation is commonly known as surface plasmon resonance. Dr Nabil Lawandy, formerly a professor of physics at Brown University, describes this as a subtle interplay between the motion of the electrons in the metal, which can be viewed as being free, interacting with the light. These particles exhibit intense

absorption in the green part of the spectrum. 'When these particles subtract the green out of the white light, it leaves red,' explains Lawandy. In general terms, the size, shape and material properties of metallic particles determine the colour of such colloids.

According to Lawandy, there are several types of plasmons. The ones that are commercialised today are sensors used in the biotech world, and they use surface plasmon resonance. This is where the plasmon is a charge density wave at an interface. It propagates and therefore carries momentum. The application of gold particles for vision enhancement involves a localised surface plasmon, stresses Lawandy. Such a plasmon does not propagate, and is trapped in the near field around the particle. The near fields are less than a wavelength of the light away from the particle.



The Lycurgus cup contains gold and silver nanoparticles. It appears green in reflected light and red in transmitted light (top). The colour of gold or silver colloids is dependent on the size of particles (bottom)



The Incorporation of nanosized gold rods into liquid crystal displays could bring about an improvement in viewing angle, brightness and power consumption

A place in the sun

Solaris plans to use gold nanoparticles to boost the absorption of dye-sensitised solar cells, commonly known as Graetzel cells. The results so far have yielded a problem. 'We're seeing plasmon enhancement of the absorption on the one hand, but negative electrolyte effects on the other,' says Lawandy. Solaris is developing a shell structure for the particles, with a gold core and an anatase titanium outer shell. The idea is to maintain the plasmon effect in the dye, which is attached to the outside of the titanium surface, while preventing the electrolyte reaching the gold. 'We have a relationship with Professor Graetzel,' says Lawandy, 'and the agreement is that once we have a result that we can reproduce in our laboratories, it will be sent to Lausanne for evaluation. It makes obvious sense in gaining credibility in solar cells.'



Various colours can be seen in a series-connected dye-sensitised solar cell (inset) (Image: Dr Winfried Hofmann RWE-Schott)

Going for Gold

Its resistance to oxidation means that gold is already widely used in electronics applications, and its inertness and anti-bacterial properties make it an established biomaterial. But if companies such as Solaris are developing more applications for gold, what could this mean for its market price? 'If today you created a market for 400 tonnes of gold for industrial applications the price would stay stable,' says Dr Chris Corti, a consultant in international technology at the World Gold Council. One such application is the use of gold nanoparticles as a catalyst. 'There's tremendous scope for gold catalysts. We think it's about to break in terms of commercial applications. There are more patents coming out every day,' Corti says. He estimates that gold catalysts might generate an extra demand of 300-400 tonnes a year. To put this figure in context, 4000 tonnes of gold is used every year. 'One of the problems with the fuel cell business is that if it takes off it's going to consume large quantities of platinum,' Corti continues. 'Gold is much more available than platinum - roughly ten times. With all the gold bars locked away in bank vaults you've got 15 years annual supply sitting around. You can develop applications that will consume several hundred tonnes a year and it won't impact the gold market.'

repeatable measurements showing enhancements in light absorbing systems. 'It turns out that plasmon resonance is such a basic phenomenon that if it can work for a rhodopsin molecule then you'll be able to do it for chlorophyll, or the organo-metallics that are used in dye-sensitised solar cells.' (See 'A place in the sun' box.)

Solaris expects successful results with rhodopsin in the next month or two. 'The next step will be to work with an institution to demonstrate with an animal model. At that point we hope to have enough critical mass to interest a pharmaceutical partner to take it on, with the hope that we would be the suppliers of the antennas,' says Lawandy.

On display

Another application for Solaris's gold antennae is in the liquid crystal display sector. And like any antenna, the particles can be tuned and adjusted. 'It's no surprise that on the nanoscale, metallic gold rods have a different set of resonances. Even by staying in one material, you can tune the aspect ratio of gold rods to tune where the resonance occurs and where the field is enhanced. A sphere is a purely symmetric case, so there's no preference,' continues Lawandy.

In visual display materials, the gold particles would have to be rod-shaped, which is not the case for the vision application. 'What we exploit in the display application is the ability to orientate the rods,' explains Lawandy. If the rod becomes excited perpendicular to its axis, the resonance might be in the infrared region but along the axis it might be in the visible range, or vice versa depending on the materials used.

Solaris plans to use the liquid crystals as a conveyance mechanism to orientate these rods. An ensemble of rods may absorb weakly in the visible when randomly ordered, but absorb strongly when orientated in the right polarisation direction.

'The trick here is to synthesise the rods with controlled aspect ratios and then to decorate them properly so they will be soluble in liquid crystal and not aggregate,' says Lawandy. When the liquid crystal enters an orientated phase under the application of an electric field, it orientates the rods along with them and this results in a strong absorption. 'The beauty of it,' continues Lawandy, 'is this absorption is present over a large angle.'

Solaris is using the gold rods to introduce an absorptive element to the liquid crystals. So why not do that with dye says Lawandy. The problem with dyes is that they fade. Gold on the other hand maintains its photo-structural integrity for centuries. Lawandy says that the gold rods have not been put into any screens so far, and that current work is focusing on ways to prevent aggregation.

Before Solaris makes a penny from any of its three application areas, there is plenty of progress still to be made. As Lawandy will testify, it is a costly business. 'All you need right now to handle Solaris's finances is an ability to subtract!'

Further information

For further information, contact Solaris Nanoscience, USA, website: www.solarisnano.com. The World Gold Council is based in London, UK, website: www.gold.org.