Ink draws on negative charge

Nanotechnology continues to hover around the real world, generally as a misused term for something in existence that is merely 'very small', or in areas where commercial exploitation remains tantalisingly just round the corner. Using carbon nanotubes for sensors falls into the latter category – but it may be about to reach the realisation stage, as **Tim Fryer** reports.

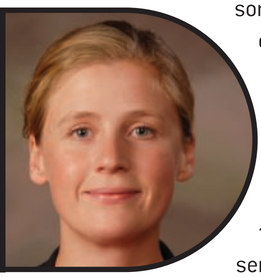
Dr Sian Fogden was a researcher at Imperial College, studying nanotubes for her PhD, when Linde Electronics became interested in her work. Now Linde Nanomaterials, part of Linde Electronics, is pursuing this line of work in California with Dr Fogden at the helm. The resulting product, a nanotube ink, was launched at NT13 – the international nanotube conference held in Helsinki in the closing days of June 2013.

Dr Fogden is clearly a fan of carbon nanotubes: "Nanotubes is have amazing electrical, mechanical and physical properties. They are stronger than steel. They are more conductive than copper and they are the world's best heat conductor."

Unsurprisingly, they therefore lend themselves to a huge range of applications, one of which is in sensors.

Carbon nanotubes are simply very long, very thin tubes of carbon atoms – like a sheet of graphene (or chicken wire) rolled up – so they have a huge surface area. Nanotubes are made from a naturally occurring allotrope of carbon. Their large surface area aids sensitivity, while the interaction of a molecule with a nanotube greatly affects the conductivity, hence the suitability for nanotubes as a sensing device.

"Manotubes have amazing electrical, mechanical and physical properties. They can also sense in liquids and gases."
Dr Sian Fogden



Some gases react strongly with the nanotubes, while others require functionalisation. "Nanotubes are very pure structures with just pure carbon in the hexagon structure," explained Dr Fogden. "To functionalise it, you just choose a chemical group that would interact strongly with the molecule you want to sense and attach it to the outside of the carbon nanotube. So you break one of the bonds in the nanotube structure and attach it to the molecule of the substance that will interact strongly with the molecule you want to sense."

Sensing any substance

Essentially, this means that any substance can be sensed with a carbon nanotube sensor, as long as it has an identifiable chemical that it can react with.

"Depending on what atoms react with the carbon nanotube, sometimes they become more conductive and sometimes less," Dr Fogden continued. "You can measure very low concentrations. In fact one of the very good reasons for using carbon nanotubes for sensors is that they are much more sensitive than the materials which are used now. You can measure at the very low parts per million for example for some gases and obviously that has huge benefits for the sensing industry."

Nanotubes dissolve spontaneously in certain organic solvents to form a printable ink

To turn these nanotubes into an ink – a useable solution – is not difficult, but Linde has developed a process to ensure that it does it well. Because nanotubes are long and thin, they have high van der Waals forces between them and they stick together. The standard way to separate them is by sonication – high powered sound waves. This has the effect of creating minute explosions within the solution, which can damage the nanotubes and affect their properties.

Dr Fogden commented: "With our inks, we use a very specific process that doesn't require sonication but which produces solutions of individual nanotubes that maintains the length of the nanotube that you put in in the first place – however long it is as a raw material is the length that it is in our ink. The process we use to make our inks is called SEER – Salt Enhanced Electrostatic Repulsion. All that that means is that we add an electron to the nanotube and because negative charges repel, the nanotubes repel each other. It is a very simple idea."

To charge the nanotubes negatively, an alkaline metal, like sodium, is added to liquid ammonia containing nanotubes. When this turns blue, the outer electron in the sodium has joined the nanotube, giving it its negative charge. Removing the ammonia leaves a salt of negatively charged nanotubes, which in turn dissolves spontaneously in certain organic solvents to form the ink – the product that is now being released by Linde. This ink can easily be functionalised to create the desired sensor and can be deposited by printing, spraying or any other regular method of dispensing a liquid.

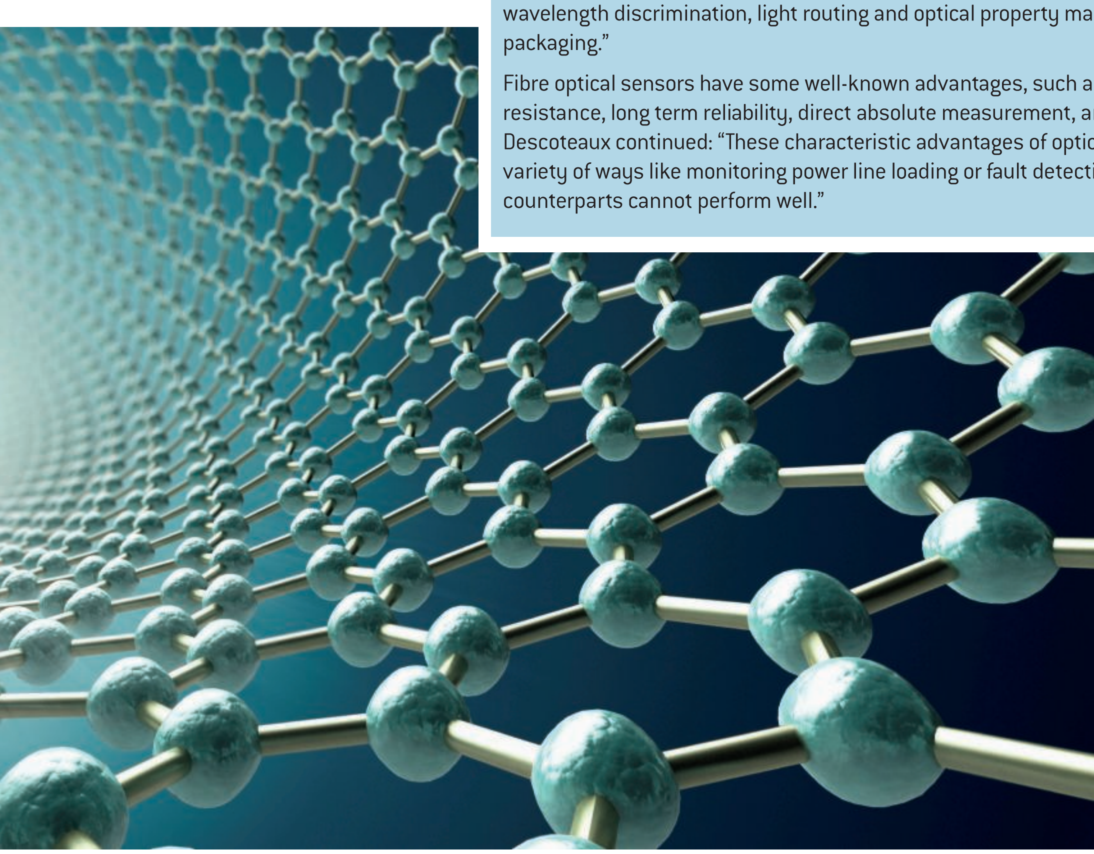
Seeing sense from service provider

One sensor offering comes from what is perhaps an unexpected quarter, given that Sanmina is primarily a service company. It offers custom optical design solutions and manufacturing services from passive and active optical devices, high speed optical modules and circuit packs to end-to-end optical system solutions.

Jose Descoteaux, director of design engineering services at Sanmina, commented: "Customers not only want the optical sensors to meet performance specifications, but also want them to be reliable and manufacturable with shorter time to market."

The types of products in which Sanmina specialises are not at the commodity end of the market. "The optical products Sanmina designs are usually with leading edge technologies, such as 100Gbit/s DP-QPSK modulator, 4x25Gbit/s Transmitter Optical Subassembly and compact Optical Coherence Tomography," said Descoteaux. "For optical sensors, there are standard technologies that can be fairly easily customised for particular applications, but they are getting more sophisticated for advanced applications, and when customers come to us, the optical sensors are usually a combination of leading edge technologies in wavelength discrimination, light routing and optical property manipulating, signal detection, and packaging."

Fibre optical sensors have some well-known advantages, such as EMI immunity, small size, good erosion resistance, long term reliability, direct absolute measurement, and wavelength multiplexing capability. Descoteaux continued: "These characteristic advantages of optical sensors enable them to be used in a variety of ways like monitoring power line loading or fault detection, and metering where electrical counterparts cannot perform well."



Carbon nanotubes – long, thin rolled up tubes of carbon atoms – have a huge surface area. This large area enhances sensitivity

Applications for carbon nanotubes are many and varied and include solar cells and displays, particularly flexible touch screen displays. However, even within the sensor arena, there are many possibilities. Carbon nanotubes are a promising material for gas sensors because they have high sensitivity at room temperature. They have been used to sense a range of gas molecules including: nitric oxide, with the hope of providing real time asthma monitoring by measuring the NO content in breath; ammonia, a toxic chemical used in the chemical and food industry and whose current sensors have problem with sensitivity; ethylene, a chemical released when fruit ripens so could be used to help supermarkets manage fruit shipments; and NO_2, CO, CO_2 and H_2, all of which could be used to produce fire gas sensors to increase the speed and reliability of fire detection.

"One of the unique things about nanotubes is that you can sense in both liquids and gases," Dr Fogden continued. "So they can be used as biosensors, for example to test glucose from saliva to help diabetics to keep better check on their blood sugar levels without having to do a pin prick."