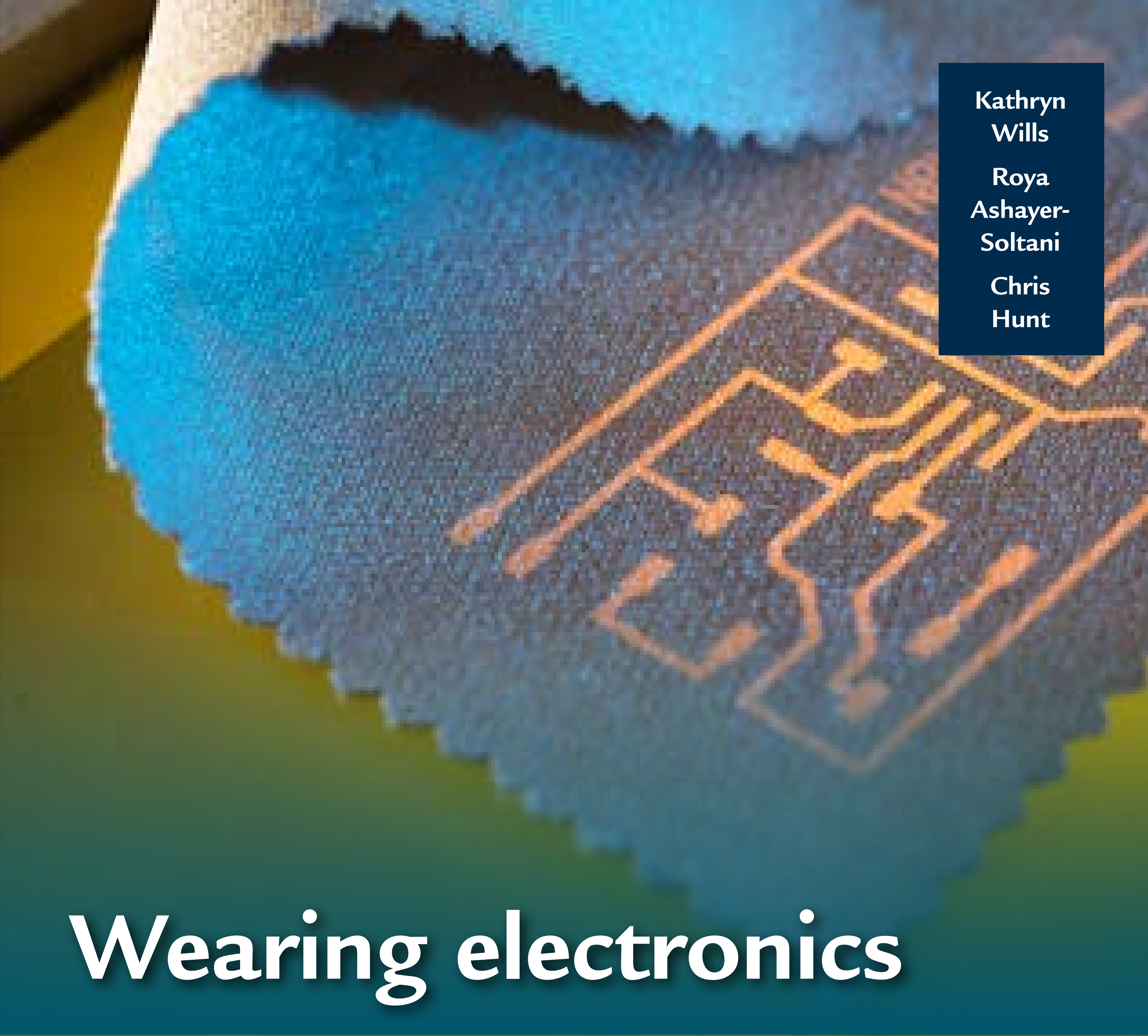

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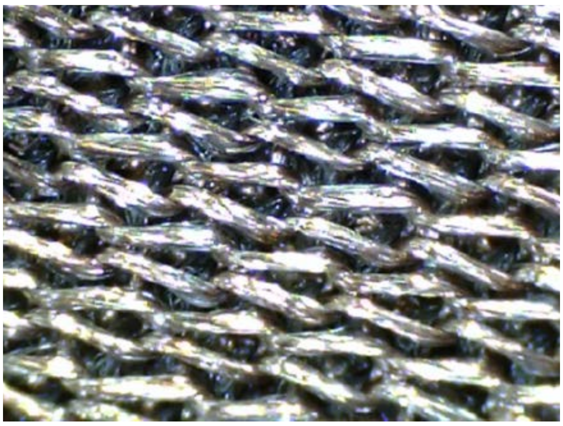
Wearing electronics

The demand to make technology increasingly smaller and more integrated into our lives has driven the development of 'wearable technology', which refers to electronic devices that can be worn on the body, or integrated into clothing or accessories.

Wearable technology is a broad term which can include smart watches and fitness trackers to medical sensors and navigational aids, such as shoes with built-in GPS. Most of the existing products are for protection and the military clothing sector but it is thought that sport and fitness, and health and medical applications will see the fastest development in the next few years.

Electronic devices typically operate with a rigid circuit board, which can be seen when these devices are taken apart. But now, alternative, flexible materials for circuits, such as textiles, are being developed. Within this research-sector there is a push towards making this technology truly wearable by integration of electronics into the clothing you wear every day. These may be described as smart fabrics or electronic textiles. One way to achieve wearable electronics is by having



Stretchable nylon fabric with a conductive coating

Key words

textiles

electronics

conduction

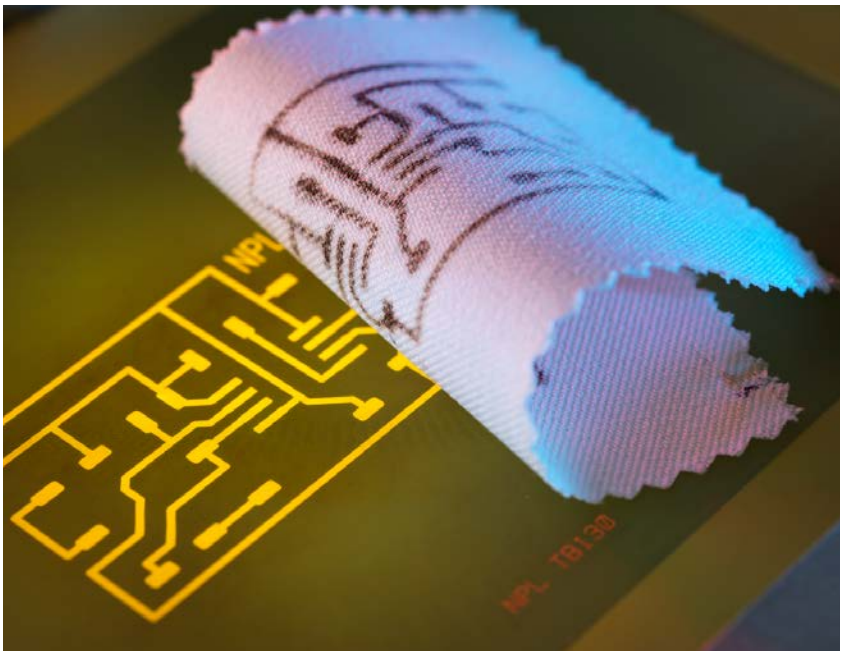
health

Nanoparticles are between 1 and 100 nanometres in diameter. A nanometre is 10^{-9} m, one billionth of a metre.

electrically conductive fabric, which researchers at the National Physical Laboratory (NPL) and Coventry University are currently investigating.

There are different ways of making fabrics conductive, for example, by sewing in conductive silver threads or by printing a conductive ink. The trick is to produce something which is reliable and robust enough to handle our daily life stresses, such as bending, stretching, washing, sweating and weather, whilst retaining the typical handle and drape of the fabric. Conductive threads can fray and ink printed onto a flexible substrate can crack when flexed.

Another approach would be to use a coating of a conductive polymer, such as polyaniline or polypyrrole. These polymers have a delocalised electron structure (like graphite) which allows them to conduct even though they are not metals. However, the conductivity and processability of these organic polymers isn't typically as good as that of metals.



A circuit board design printed onto fabric

Making a fabric conduct

A process developed at the UK's National Physical Laboratory (NPL), and being optimised with Coventry University, involves making a fabric conductive once it's already in its final form, in other words already a garment. This is a multi-step, additive process involving a range of interesting chemistry. It has been done successfully with both natural fabrics (e.g. cotton) and synthetic ones (e.g. polyester).

The process starts by depositing a catalytic seeding layer onto a fabric (a catalyst is something that initiates or speeds up a reaction). This seed layer is typically an unreactive metal such as silver, used as tiny nanoparticles.

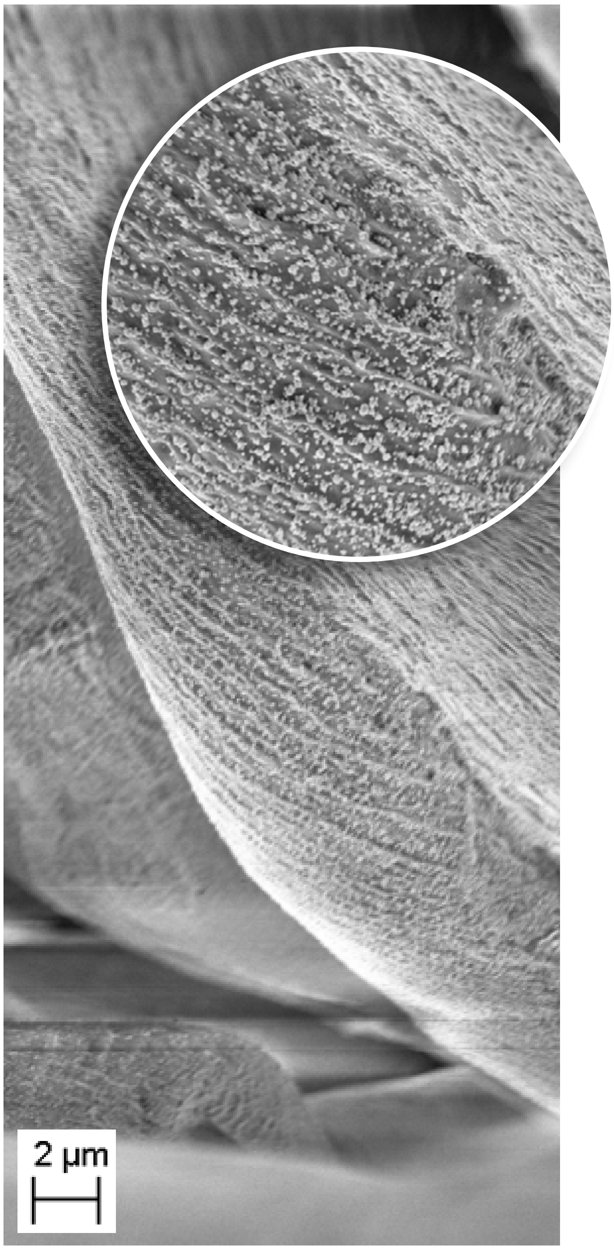
The nanoparticles can be generated in a solution and applied to a fabric pre-formed, or they can be formed directly on the surface of the fabric.

To make silver nanoparticles, a silver salt is reduced to silver on the fabric in the reaction:

$$Ag^{+} + e^{-} \rightarrow Ag$$

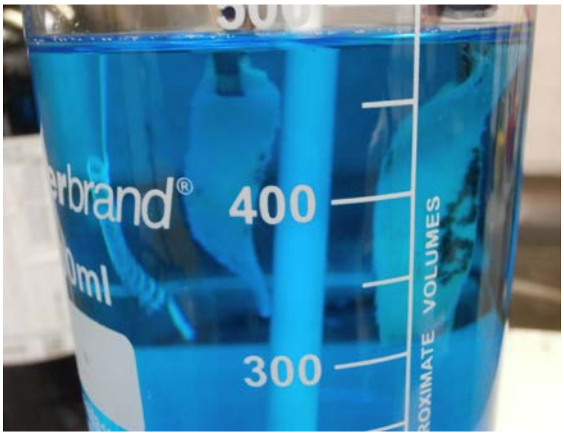
The chemical which reacts with the silver ions to turn them to silver atoms is called a reducing agent.

The size of the nanoparticles is influenced by the choice of reducing agent. Choosing a relatively strong reducing agent, like sodium borohydride ($NaBH_4$), results in smaller particles which are more effective as catalysts. The fibres of the fabric are therefore coated with silver nanoparticles, as seen in the electron microscope images.



Electron microscope images of cotton fibres coated with silver nanoparticles visible in the close up

Although the catalyst itself is a metal, it is not of sufficient thickness on the surface to make the surface very conductive. The electrical resistance at this point in the process is, therefore, still very high. To improve the fabric's conductivity requires more metal to be deposited and this is done using a process from the printed circuit board industry. The silver nanoparticles act as the catalyst for this step.



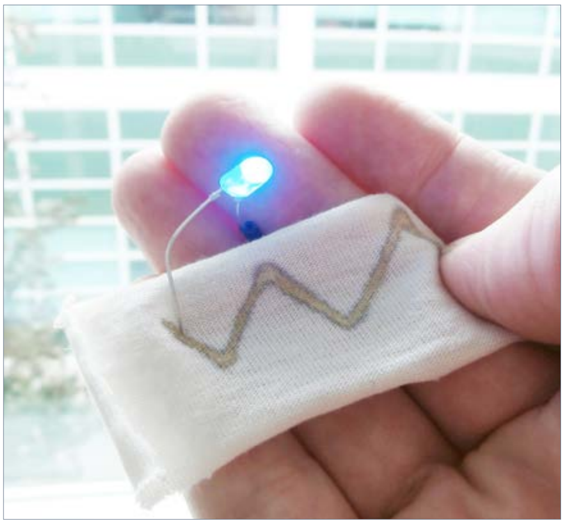
The electroless copper plating bath

The technique used is called electroless metal plating and involves a series of electrochemical and chemical reactions taking place in an aqueous solution. The end result is a metal being deposited ('plated') on top of the silver catalyst layer. The fabric is immersed in the electroless copper plating bath, and the plating occurs where the silver nanoparticles are.

The plating bath contains formaldehyde, which reduces a copper salt to metallic Cu in the reaction:

$$Cu^{2+}(aq) + 2e^{-} \rightarrow Cu(s)$$

It also contains sodium hydroxide, to increase the pH of the plating bath to >11, since copper deposition is more favourable at higher pH. The metal will only plate where there is a silver nanoparticle catalyst on the surface, allowing researchers to be selective with which areas are made conductive. Whole areas of fabric can be made conductive, or tracks can be produced using a technique such as inkjet printing to deposit the catalyst.



A conductive track connected to a battery and LED

Once the surface has been coated with this first layer of copper, the plating continues to build up the metal layer as a self-catalytic process on the copper surface. The resulting fabric is now coated with enough metal to be conductive.

Finally, the fabric surface needs to be coated to prevent the copper from oxidising in air and turning back to copper ions. This can be achieved with a silver immersion treatment, where silver atoms form a thin layer on the fabric by replacing some of the copper. An organic polymer finish is an alternative. At present all preparation is done in the lab but process scale-up is being explored which will allow this technology to be used in commercial products.

Metal plating has been used over the years to produce a number of items such as silver plated cutlery.

Smart clothing

This technique could make integrating electronics into all types of clothing simple and practical by enabling lightweight circuits to be printed directly onto complete garments. There is a growing market for wearable 'smart' electronic devices and the NPL technology could find applications across a range of sectors, such as remote healthcare development. Integrating electronics and sensors that can measure and monitor physiological properties, such as your heart rate or a wound swelling, could allow medical professionals to detect problems early and reduce the number of hospital admissions. Ideally the technology would be integrated so discreetly that its wearer is not conscious of it and it is not visible to other people. An interesting property of the fabrics produced using this method, and with others available on the market, is that the conductivity varies with stretch. This opens up possibilities of using the fabric as a stretch sensor.

As with any new technology, the properties of these fabrics need to be measured in various situations to understand their reliability, and how long they're likely to last. Such tests include measuring how the electrical conductivity of the fabric changes with stretch, which is measured using a stretch rig. A washing machine is used in the lab to see how the conductive coating withstands a laundry cycle with detergent. So far cotton has performed particularly well, with the conductivity of the fabric remaining more or less the same after 100 wash cycles.

There are other innovative applications of conductive fabrics, and one company called Footfalls and Heartbeats has developed a knitted technology where the fabric itself is the sensor. It is used in compression bandages for venous leg ulcers to monitor the applied compression by measuring a change in electrical resistance as the fabric stretches. This can let the medical practitioner know if the bandage has been applied appropriately. They currently knit in conductive silver yarns that act as the connecting wires, but they are looking into printing circuits to make the product more robust.

Interest in conductive fabrics is increasing and they will play an important role in the future of wearable technology. Although there is still research and optimisation to be done on the process, this is an exciting technology which could benefit the healthcare sector in years to come through the incorporation of sensors into garments.

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