# In diamond

Materials Lecturer Dr Benjamin Jones and Biomedical Engineer Professor Tony Anson, both at Brunel University, UK, discuss the use of diamond-like carbon in medical devices.

In contrast to the sparkling gemstone, diamond-like carbon (DLC) is a thin film coating that is dense, inert, low friction and hard wearing. The diverse range of areas exploiting DLC, including electronics, razors, manufacturing and medical devices, use a spectrum of materials that the name covers.

The umbrella term includes amorphous carbon, hydrogenated and tetrahedral variants – materials that can be likened to polymers, graphite or diamond. However, in contrast to the well defined crystalline structures of more well known carbon-based materials, DLC has no long-range order, but contains both graphitic and diamond-like bonded carbon atoms, and usually has a significant level of hydrogen. Tuning the balance of these constituents can finely tailor the properties of a material to match the application.

Interdisciplinary research, involving materials scientists, physicists, mechanical engineers, biomedical specialists and clinicians, is continuously expanding the potential and applications of DLC and enhanced carbon-based materials in the medical sector.

## Diffusion barriers

Medical implants may contain undesirable elements in bulk or trace quantities. Nickel (Ni), chromium (Cr), cobalt (Co) and vanadium (V) can be toxic or cause sensitivity in some patients and are contained in commonly used metal alloys such as stainless steel (Fe-Ni-Cr), Ti-Al-V and Ni-Ti shape-memory alloy. Generally, at least one of the constituent metals is reactive in the presence of oxygen and readily forms protective oxide layers on the implant. These enable large numbers of devices to be implanted without adverse effects on biocompatibility. These oxide layers are, in most cases, effective in reducing contact between tissue and medical implant. However, a significant percentage of the population are sensitive to nickel, for example, and ions are still able to diffuse through the oxide barrier, with potentially adverse reactions.

A diffusion barrier that has little or no effect on human tissue and reduces undesirable metal ion migration is therefore desirable.

Amorphous DLC, plasma deposited as a uniform thin film coating, shows encouraging results as a diffusion barrier. Coating of devices external to the body, such as DLC-coated metal watch straps, provides a barrier between the body and the allergen, eliminating reaction to the nickel content of the metal.

Coatings can even enhance the aesthetics, providing a 'sparkling black' finish (see images below), and can be applied to spectacle frames and other metal items that come in to contact with the skin.

Titanium-alloy total knee prothesis, coated (left) and uncoated (right). Images courtsey of Diameter Ltd, Stanmore Implants Worldwide, RNOH

# health

Unlike varnish-type or polymer products, they are less susceptible to wear that would otherwise re-expose the Ni-containing substrate and trigger a dermatological complaint.

Potentially more of a hazard is that a patient may be sensitive to a metal in a medical implant, such as an orthopaedic or cardiovascular device. Orthopaedic prostheses such as hips, knees and shoulders are comprised of a substantial amount of metal with a large surface area exposed to surrounding hard and soft tissue. Any sensitivity is often detected prior to an operation by giving patients a metal allergy test to circumvent an untoward response to the implant. Diamond-like carbon has been successfully applied to a number of implanted devices, including total knee prostheses for people sensitive to constituents of a titanium alloy.

In addition to protecting the patient from medical devices, the reverse is often required to guard against the harsh environment of the human body. For example, implanted electronic sensors that interface with the neurological system, such as cochlear implants, can react to changes in the environment, fluid contamination or humidity, but need to retain a level of contact with the body. A thin film coating that prevents ingress of fluids can help the device remain functional.

More generally, coatings can reduce the effects of body fluids on implants, which could otherwise lead to increased corrosion and accelerated structural failure. Diamond-like carbon protected implants have the potential to reduce revision operations to replace damaged devices.

## On the surface

The popularity of DLC is not solely related to diffusion barrier properties. The surface topological, tribological and chemical properties make the material beneficial in many medical areas. Cardiovascular applications exploit the haemocompatibility and anti-thrombogenic properties of DLC – the surface structure reduces the likelihood of blood clots when a material is inserted into the blood stream. Capitalising on this, DLC-coated arterial stents are commercially available, preventing closure of arteries and ensuring unobstructed blood flow.

Urinary catheterisation is a common procedure for both short- and long-term use. Coating catheters with DLC reduces friction, both on insertion and in use, reducing local tissue damage and improving patient comfort. The catheter is an effective bacterial pathway into the body and the coating helps to mitigate this, prohibiting biofilm formation and bacterial adhesion.

This property has led to further use of DLC in medical devices, such as in partially-coated osteotomy screws (see image below, bottom) used after the 7 July London bombings in 2005. These are transcutaneous prostheses that protrude outside the body and are used for small fracture fixation, such as hand repair after trauma. The DLC provides an inhospitable

**Top: Diamond-like carbon (DLC) coated aluminium-based instrument used during gall-bladder removal. Image courtsey of Arun Mahendran, Hillingdon Hospital.**
**Below: Partially DLC coated osteotomy screws. Image courtsey of Joe Franks, Diameter Ltd, RNOH**

DLC coated watch straps. Images courtesy of Diameter Ltd

environment for bacterial colonisation and improves the rate of healing.

As well as remedial application to existing devices, DLC is facilitating new products which have the coating designed-in. A DLC-coated assist tool for gall bladder operations, developed at Brunel University, allows the use of aluminium for surgical tools, with the advantage of lighter weight and lower machining costs than traditional stainless steel. The DLC coating of the instrument dispels fears concerning metal transfer into the body.

## Enhancements

In addition to fine tuning DLC and optimising it for the desired application, additional elements or structure can be added during or after deposition. Incorporating silicon into the films expands the range of materials that can be coated, improves adhesion and enhances haemocompatibility, as well as allowing increased flexing without fracture damage. This technique is used in a range of applications from drill bits to expanding stents.

Further processing techniques, such as fluorine incorporation during deposition, or post-deposition oxygen plasma treatment, can control surface hydrophobicity of the coating – a property that affects biocompatibility and fluid flow in medical devices, as well as water resistance of watches.

Work currently under development includes incorporation of biocides, such as macro-patterned or nano-particulate silver, into DLC. This dual coating combines the advantageous surface and diffusion-barrier properties of DLC with the well-established biocidal effects of silver, and has the potential for use in surgical tools and biomedical implants to reduce the prevalence of hospital acquired infections.

### Further information

Dr Benjamin Jones, Experimental Techniques Centre, Brunel University, Kingston Lane, Uxbridge, Middlesex, UB8 3PH, UK. Tel: +44 (0)1895 255793. E-mail: bj.jones@brunel.ac.uk. Website: www.ETCbrunel.co.uk.
Thanks to Joe Franks and Arun Mahendran.