would be particularly exciting[4]. Coupling such extremely long-wavelength radiation directly into the nanocoaxial cable is a hopeless proposition. However, it has been shown that nanotubes with different diameters can be joined together by conical sections[5]. One could therefore imagine growing the metallic multiwalled nanotube from the tip of a conducting graphitic cone[6], also clad with an insulator and outer conductor, to form a coaxial cable with a horn antenna wide enough to pick up radiation in the far infrared.

Additionally, the most efficient way to couple into a coaxial system is to use radially polarized light, which can be tightly focused[7] and which has a polarization matching that of the TEM mode inside the coax. A microscope with 100 nm resolution — that delivers plenty of photons at wavelengths from the visible out to the little-explored THz territory — will open new windows in materials science, biophysics and other areas.

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NANOMATERIALS

Enzymes on nanotubes thwart fouling

Composites of carbon nanotubes and polymers act as hosts for enzymes and can prevent protein contamination on the surfaces of medical devices.

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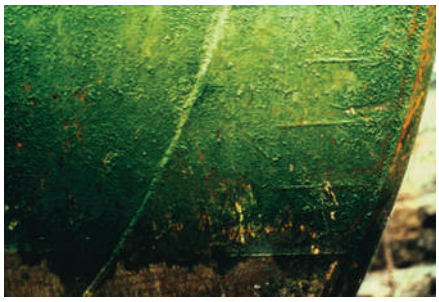
The adsorption of proteins on surfaces — a process known as fouling — is a major problem in medical implants, such as cardiovascular stents, and surfaces that are prone to contamination, such as ship hulls and bioreactors. These proteins help cells and bacteria attach to surfaces, which may result in the growth of biofilms that can significantly reduce the performance of devices. There is, therefore, a need for 'non-fouling' surfaces that can resist adsorption of proteins.

One common approach is to functionalize surfaces with hydrophilic polymers such as poly(ethylene glycol) (PEG). At sufficiently high densities, these polymers form 'brushes' that block the adsorption of proteins by creating a physical barrier. Although a significant reduction (>99%) in protein adsorption is achieved, PEG brushes are successful only for short-term *in vitro* environments and are less promising in the harsher *in vivo* milieu where PEG is susceptible to degradation[1]. For example, when implanted into mice, PEG-coated implants continued to suffer fibrous encapsulation — a common problem in implantable devices where a protein capsule creates a barrier between the implant and the surrounding tissue[2]. A number of other polymers are being investigated to create anti-fouling surfaces, including some that resemble proteins[3], but it is not yet clear if their long-term *in vivo* performance will be satisfactory.



M. E. CALLOW

Figure 1 Biofouling is a problem on surfaces as different as medical implants and the hulls of ships. Biofouling on ships reduces speed and manoeuvrability, which increases fuel consumption. Researchers in the US have demonstrated a new approach to 'self-cleaning' surfaces based on carbon nanotubes, which could have applications in medicine.

Writing in *Small*, Jonathan Dordick, Ravi Kane and colleagues from the Rensselaer Polytechnic Institute in the USA describe how adding enzymes to carbon nanotubes can create 'self-cleaning' surfaces that resist protein adsorption[4]. A composite material is made by attaching enzymes (known as proteases) that break down proteins onto single-walled carbon nanotubes (SWNTs) and dispersing them in a matrix made of the polymer poly(methyl methacrylate). The continuous break down of the proteins by the proteases creates a 'self-cleaning' surface that prevents protein build up[5].

The novelty of this approach lies in the use of SWNTs as supports for the enzymes. The higher surface area of the nanotubes can support a much higher density of enzymes than previous approaches in which the proteases were attached directly to polymer matrices. In addition, this SWNT–enzyme composite exhibited 30 times higher overall catalytic activity than control composites where the proteases were conjugated to a non-nanoscale graphite support. Importantly, the enzymes preserved more than 90% of their initial activity over 30 days in an aqueous buffer, with only negligible amounts of enzymes leaching out.

When incubated with a variety of proteins, the composites reduced protein adsorption by as much as 95% compared with controls without the enzymes or those with enzymes conjugated to graphite. Moreover, when combined with another enzyme that breaks down fibrinogen (a protein that is involved in blood clot formation), the composite reduced fibrinogen fouling by 92%. This is an important step towards reducing clot formation in stents and other cardiovascular implants.

In addition to polymeric composites, it is also possible to make films composed solely of SWNTs and enzymes known as 'biocatalytic buckypapers'. This is done by filtering suspensions of SWNT–enzyme conjugates through a 0.8 μm polycarbonate membrane. These films, which can contain up to 30% enzymes by weight, resisted up to 99% nonspecific protein adsorption, which is comparable to the best PEG-based coatings

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to date. Similarly, SWNT–enzymes added to paints also reduced protein adsorption by more than 90%.

Another attractive aspect of this work is that it may be possible to use these composites to degrade other biopolymers such as bacterial polysaccharides, which are sugars that protect bacterial colonies attached to surfaces. SWNT composites containing enzymes that degrade these polysaccharides could catalyse the breakdown 30 times faster than films with identical amounts of enzymes attached to graphite supports.

Also promising is the ability to combine different enzymes on the SWNT support to fight various surface contaminants by active 'self-cleaning'. This is in contrast to the current passive methods based on surface modification strategies, such as PEG brushes, that aim to prevent protein adsorption rather than clean the surface. Furthermore, this approach is attractive for a wide range of potential applications because it is simple to produce, is stable and has a well-sustained enzyme activity over a broad range of conditions.

Researchers working on medical devices often talk about the 'race for the surface' as macromolecules, cells and bacteria compete with each other to attach to the devices implanted into the body[6]. A material that can sustain the active degradation of unwanted proteins at surfaces and direct the race in favour of cells and tissue is, therefore, highly desirable.

A number of major challenges need to be overcome for both the active and passive approaches before they can become a practical reality. Although *in vitro* studies, such as those reported by Dordick and colleagues, can effectively help us identify how well materials prevent fouling, the biggest challenge is to demonstrate their long-term anti-fouling performance *in vivo*. As with the passive approaches, stability is also an important consideration because, under realistic conditions, materials are susceptible to chemical degradation. Nevertheless, this new work presents a general route towards cleaner surfaces.

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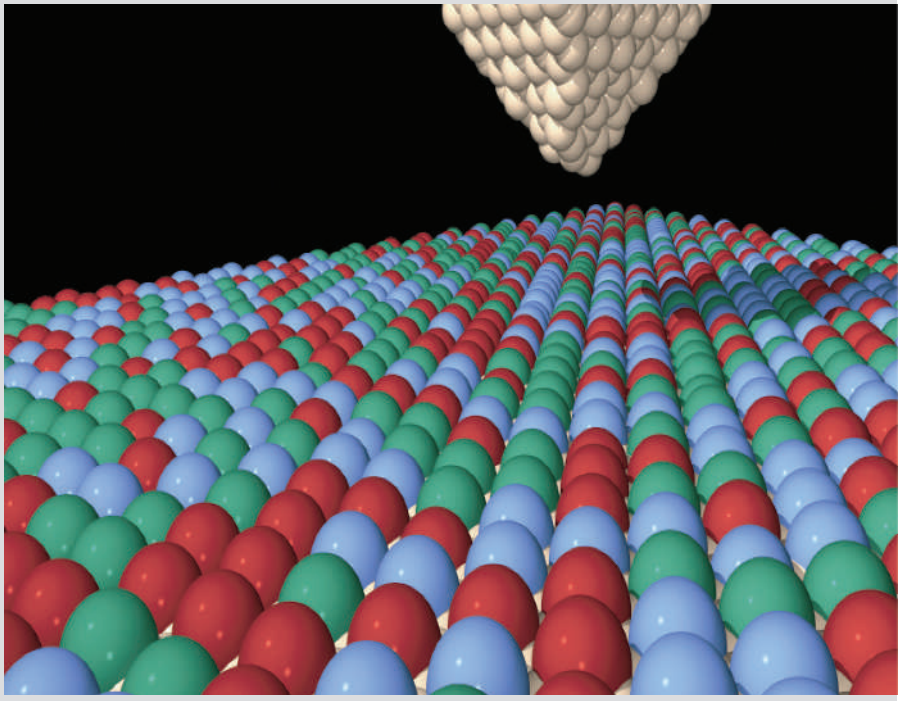
SURFACE SCIENCE

Resolving the identity crisis

The chemical forces measured by an atomic force microscope (AFM) as it scans across a surface are full of information about the atoms that make up the surface, so it should be possible, in theory at least, to identify different atomic species. Unfortunately, because the tip of the AFM tends to change shape over time, the details of the force measurement change as well. Identifying atoms with confidence can require time-consuming comparisons between the experimental data and the results of theoretical models and simulations.

What is needed is a reliable 'standard' for distinguishing atoms, akin to the element-specific forms of spectroscopy that have been used to study surfaces for years and that can work under a range of conditions. Writing in *Nature*, Oscar Custance of Osaka University in Japan and colleagues in Spain and the Czech Republic describe a robust approach to identifying atoms on a surface with AFM (*Nature* **446,** 64–67; 2007).

To demonstrate their technique, Custance and co-workers prepared a single layer of a lead–tin–silicon alloy on a silicon surface. Distinguishing between these three different atoms (indicated in the image by different colours) with standard topographic AFM approaches is difficult because they have very similar electronic structures and tend to sit in similar positions on the silicon surface. Instead, the group measured the maximum attractive chemical force between each atom and the AFM tip as it approached the surface. They showed that the maximum force for tin and lead relative to that of silicon, used here as a 'reference' atom, provides a sort of element-specific fingerprint that allows them to identify all three atoms. Moreover, even when the structure or chemistry of the tip changes, these force ratios are preserved.



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This calibration technique can be performed at room temperature and, in principle, can be extended to other types of atoms, although it will always be necessary to first extract reference measurements and to minimize the contribution from long-range forces. The importance of the work lies in its ability to identify atoms quickly and reproducibly, which will greatly improve the ability of the AFM to manipulate atoms into useful structures.

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