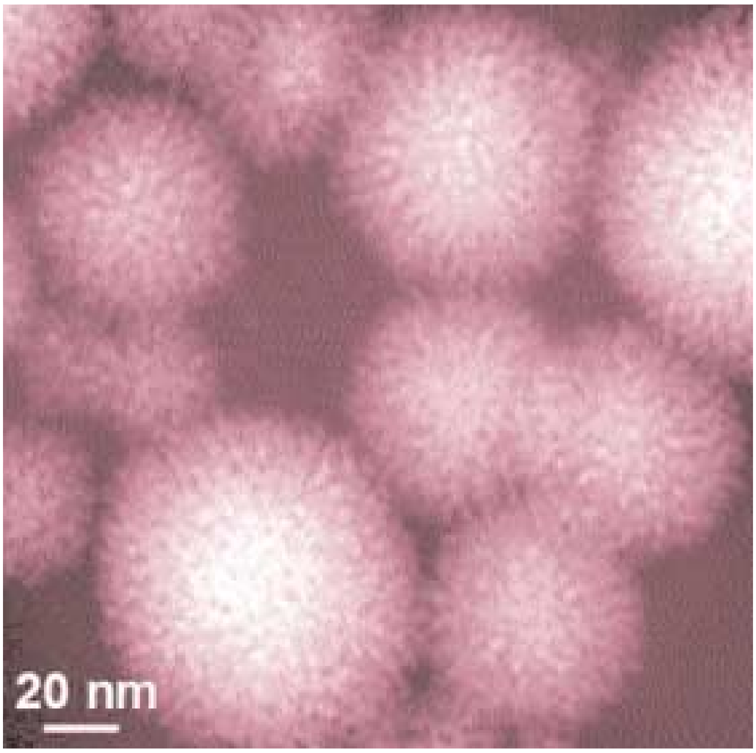


Natural born design

Researchers are learning lessons from biological systems to produce materials with previously unattainable properties. *Richard Butler* explains some of the possibilities opened up by working at nano-scale

Nanotechnology has been an industry buzzword for several years but, with all the speculation about nanobots and grey goo, it has become difficult to tell what it entails and when we're going to see the benefits.

As the name suggests, nanotechnology is the creation and manipulation of matter at the scale of 10^{-9}m (one billionth of a metre). Working at this scale, it should be possible to create materials with different properties to those created at a larger scale. So what are these properties and what might they mean for the future of materials?

At present, between the disciplines of engineering and chemistry, humans have become quite good at manipulating things at the everyday scale and at the atomic scale. However, between these extremes is the nano-scale domain, into which we are only just starting to dip our toes. It involves manipulating vast numbers of atoms and being able to precisely control the arrangement that is then produced.

Essentially there are two ways of working at the nano-scale. The first is to start with an object that is larger than the item you are trying to make, and cut it down to size and shape by some process. The other is to start at a smaller scale than you wish to work at and then build up.

Another way of looking at nanotechnology is to distinguish between the use of particles that are nanometric in size and bound up within another substance and attempts to design structures at a nanometric scale. A lot of the work going on in this second area is based around the idea of self-assembling systems that arrange themselves into specific structures based on the way the molecules are designed.

Some work being done on nanoparticles is based on existing processes that have been refined. Suntan creams, for example, regularly contain nano-sized particles of zinc and titanium dioxide that confer a good level of protection from ultra-violet light in a product that is easily applied without white residue. Such work is mainly being done by large chemical companies such as ICI, BASF and DuPont.

Nano-powders such as these offer additional properties because of their greatly increased surface areas. This allows surface-acting processes, such as catalysis, to be optimised. This, and the efficient electron transfer through nanoparticles, has made them candidates for use in batteries and fuel cells. The tiny size of nanoparticles also ensures that they have few defects in their structures. This makes them useful as abrasive materials and as scratch-resisting reinforcement in composite materials. Mercedes has already introduced a nanoparticle-based scratch-resistant coating for many of its vehicles.

Nano-powders can be used more sparingly than conventional materials in some applications, reducing material usage or allowing the use of additional additives without compromising material integrity, giving rise to the prospect of multi-function polymers.

This first wave of nanotechnology is starting to mature, according to Michael Pitkethly, commercial director of Qinetiq Nanomaterials. "Now people have the production processes and the analytical techniques to work at this level, it's becoming much more of a designer area," he says. "We design a material for a purpose, rather than making something and then working out what to do with it."

Material change: Sandia National Laboratories in the US has found a way of mimicking photo-synthetic proteins to manipulate platinum (above)

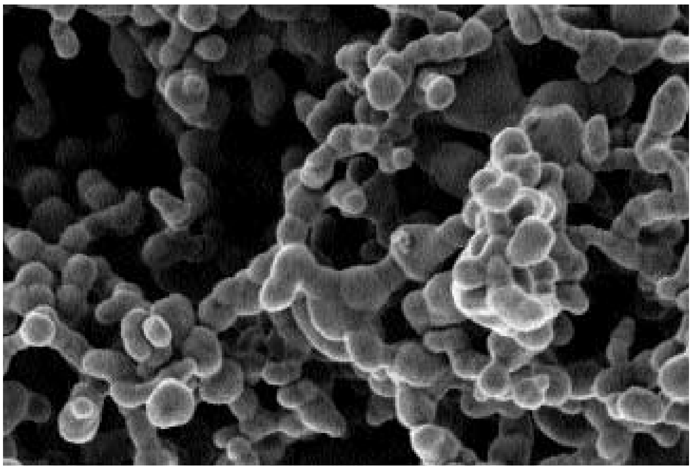
All-pervasive future

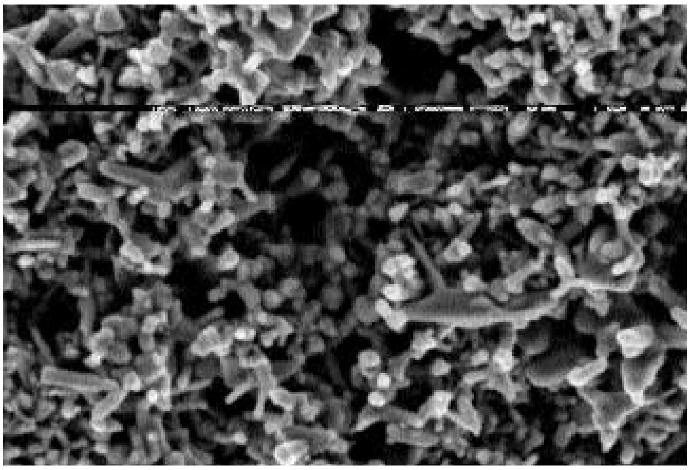
This corner of the nano-world is being more widely exploited all the time. According to Pitkethly, "it'll be all pervasive in a few years. Nanotechnology will cease to exist because it'll just be a part of the process."

Taking things further, the ability to manipulate matter at the nano-scale will allow the design of structures with hitherto unattainable properties. The advantages of working on this scale are hinted at by the way many natural structures and processes operate. According to Jeremy Baumberg, director of Southampton University's nanomaterials facility, "all the proteins in our bodies are effectively nano-scale machines". This, he argues, is because many physical properties are dictated by interaction at the nano-scale: "Atoms are the core of your materials but the electronic, magnetic and optical properties are defined at the nano-scale."

For example, because the nanometric scale is around the same wavelength as that of light, nanomaterials can be made that very selectively filter visible light. This technique has been used to make a prism smaller and more accurate at splitting light than traditional prisms. In turn this allows devices such as spectrometers to become smaller and allows more data to be multiplexed down a fibre-optic cable.

Working at the same scale as the wavelength of light also allows the creation of substances that appear coloured owing to the nano-scale structuring of their surfaces. Unlike traditional dyes, whose colours are derived from the frequencies of light they absorb, natural objects such as butterfly's wings appear to have certain colours because the spacing in their structures is the same as certain light wavelengths. The ability to mimic this using benign substances would avoid the worries about toxicity associated with dyes and the new materials would not be susceptible to degradation by sunlight in the same way.





Think small: Qinetiq has hived off its nano-scale work into a separate company to achieve better focus on such materials as silver (above left) and zinc oxide (right)

Optical chips

Existing models of the behaviour of light are based on the assumption that light will behave in the same manner throughout a material. With materials designed at the nanometric scale, around the same scale as the wavelength of visible light, this needn't be true. So nanotechnology could offer all sorts of new properties for optical materials. Optical chips may also become a practical reality, although at present the devices are large and can contain only 5 or 10 optical transistors on each chip before the light starts leaking away. Comparing this with the billions of electronic transistors that can be fitted on a silicon chip shows how far the technology has to be developed.

Baumberg says: "The problem is that it's often easier to make these structures than it is to model them." The difficulty of predicting the behaviour of a nano-scale material makes it difficult to predict applications and consequently to raise funding for research.

However, applications are starting to present themselves. For example, the principle of Raman scattering of light could be used as the basis of highly accurate chemical detection systems. In Raman scattering, light excites bonds between atoms and emerges with a different colour that tells you what the bond is. But the light scattered in this manner is very faint.

Lasers ousted

It was already known that placing molecules on a rough metal surface could amplify the effect but the results were difficult to reproduce. Working at the nano-scale would allow surfaces to be designed so that they consistently amplify the Raman scattering from a particular molecule. This could allow simple, highly specific detectors to be built without the need to use intense lasers.

Other research is concentrating on manipulating structures at the nano-scale to create stronger and lighter materials. Many biological structures, such as bone, use elaborate nano-structures to provide strength and light weight.

At present, most of the work on nano-structures is at the research stage. As you might expect, the field is dominated by universities and the companies they are spinning out. Baumberg says: "It's hard for larger companies to invest because it's difficult to see applications. When you're working with it every day, applications present themselves." Qinetiq appears to agree, having separated its nanomaterials work off into a separate company to achieve better focus and open avenues for additional investor funding in future.

Because the nano-scale falls between the scope of chemistry and mechanical engineering, it tends to be an interdisciplinary activity, with physicists in particular playing a major role in the optical, magnetic and electrical areas.

Baumberg feels it is these areas that will see the first great advances in nano-structures: "It'll be places where people need solutions. There isn't any great demand from the materials market where existing solutions are pretty good at their jobs. It'll be areas like photonics that will take the lead."

But, he cautions, progress isn't going to happen overnight: "This is something we'll be trying to use and control for the next 50 years." We can leave the talk of nanobots until then.