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Beyond the nanohype

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Abstract (Summary)
Nanotechnology has grabbed the baton in the scientific relay that extends from atomic physics to biotechnology. In nanotechnology, some scientists see nothing less than another state of matter - adding surface to the existing list of solid, liquid, gas and plasma. The potential to move atoms at will, thus enhancing and augmenting existing structures and even creating new ones, is unprecedented. Impressed by stories about nanotechnology's $1 trillion market potential, governments have started doling out money for nanoresearch in a big way. Chipmakers have also been attracted to it, seeing in nanotechnology a set of tools that will help them postpone the end of Moore's Law. Despite all this, scientists cannot agree on what exactly nanotech is. But debate rages over whether such structures count as nanotech only if they are deliberately created by humans.

Full Text (1822 words)

Nanotechnology is still buoyed more by hype than actual pay-off. Two big issues need to be addressed before nanotech-- like biotech a couple of decades before--can really begin to earn its keep

NANOTECHNOLOGY has grabbed the baton in the scientific relay that extends from atomic physics to biotechnology. Billions of dollars, euros, yen and yuan are being spent on it. It played roles in such movies as "Spiderman" and "Minority Report", and it is the villain in Michael Crichton's latest bestselling book, "Prey". It is sweeping the physical and life sciences, and even making headway in political and social spheres, too. Not bad for a discipline in which you still cannot get a degree.

Why all the hype? In nanotechnology, some scientists see nothing less than another state of matter--adding "surface" to the existing list of solid, liquid, gas and plasma. The potential to move atoms at will, thus enhancing and augmenting existing structures and even creating new ones, is unprecedented. Impressed by stories about nanotechnology's $1 trillion market potential, governments have started doling out money for nanoresearch in a big way. Chipmakers have also been attracted to it, seeing in nanotechnology a set of tools that will help them postpone the end of Moore's Law--or the emergence of Moore's Second Law, which threatens to drive the cost of chipmaking plants up to $10 billion by 2010.

Despite all this, scientists cannot agree on what exactly nanotech is. Of course, nano means one-billionth; one nanometre (1nm) is one-billionth of a metre (a DNA molecule measures 2.5nm across). The American government's National Nanotechnology Initiative defines nanotechnology as anything involving structures less than 100nm in size.

But debate rages over whether such structures count as nanotech only if they are deliberately created by humans. Some include feats of miniaturisation, such as the interconnections on microprocessors or memory chips, which are now being made with features 130nm wide. However, true believers maintain that nanotechnology is the process of creating new structures using the ability to move atoms. They credit a talk entitled "There's Plenty of Room at the Bottom" given by a legendary physicist, Richard Feynman, in 1959 as the inspiration for nanotechnology. For decades afterwards, though, researchers could do little more than theorise along with Feynman.

That changed in 1980, when Gerd Binnig and Heinrich Rohrer at IBM's Zurich Research Laboratory filed a patent for a "scanning tunnelling microscope", which came into use in 1981 and garnered the pair of researchers a Nobel prize in 1986. Four years later, Dr Binnig was back at it, inventing the "atomic force microscope". These two devices let researchers observe things that had been impossible before--such as the entire atomic structures of molecules. In the case of the atomic force microscope, scientists could actually begin to manipulate atoms directly. In short, these microscopes made nanotechnology possible.

Small things that count

Breakthroughs followed fast. In a series of experiments after 1985, two scientists at Rice University in Texas, Richard Smalley (see Last word, page 37) and Robert Curl, along with Sir Harry Kroto of the University of Sussex, in England, discovered a new form of carbon. This was dubbed carbon-60, but quickly became known as the buckyball, because its structure resembles the geodesic dome invented by Richard Buckminster Fuller.

Buckyballs gave scientists insight into how atoms could be structured, and hinted at elongated forms that generated intense scientific interest. Shortly thereafter, Eric Drexler wrote "Engines of Creation", in which he posited miniature self-assembling machines and other fantastic notions. This book popularised the use of the word nanotechnology. It failed, however, to account for the effects of quantum mechanics--the body of physics that explains why very small things behave differently from bigger ones.

Dr Drexler's book certainly captured the public's imagination. But scientists continued to talk about "fullerenes" (again, from Buckminster Fuller) and to argue about the shape of hypothetical "buckytubes". In 1988, three chemists, Paul Alivisatos, Moungi Bawendi and Michael Steigerwald, working under Louis Brus at AT&T's Bell Labs in New Jersey, showed that well-known materials, such as gold, emitted light differently at the atomic level. That quantum-effect experiment is now seen as a landmark in the development of nanotechnology. It proved unequivocally that atoms behave differently from the way that classical physics would predict. But the researchers did not at the time think of it as nanotechnology.

Then came nanotech's eureka moment. In 1990, Don Eigler, a researcher at IBM's Almaden Research Laboratory in San Jose, California, formed the IBM logo out of xenon atoms. A parlour trick, good for nothing practical. But it galvanised other scientists, who had never before seen atoms manipulated so completely.

Dr Eigler's breakthrough came as part of a wave of discoveries crucial to the development, and application, of nanotechnology. Later in 1990, two physicists, Wolfgang Kratschmer of the Max Planck Institute in Germany and Donald Huffman of the University of Arizona, worked out how to make buckyballs in large quantities. That allowed scientists to study them properly for the first time.

Then, in 1993, came the discovery of "carbon nanotubes", following research done independently by Sumio Iijima of NEC in Japan and Don Bethune at IBM Almaden. In fact, Dr Iijima had found multi-walled carbon nanotubes as early as 1991. Indeed, during the debate over the shape of buckytubes, many scientists had unknowingly seen carbon nanotubes. The American patent for carbon nanotubes was actually filed in 1984 by Howard Tennent, a chemist spending his retirement helping a small Massachusetts company called Hyperion Catalysis, which was trying to find ways to use carbon to store energy.

In those days, notes Dr Tennent, scientists measured very small things in angstroms (or tenths of a nanometre), and his patent refers to his structure as a "fibril". But his fibrils had multiple walls, whereas Dr Iijima and Dr Bethune isolated single-walled carbon nanotubes, which were stronger and also superconductive. Still, fibrils have applications, and Hyperion can produce them by the tonne. By comparison, carbon nanotubes merely have potential, and are produced by the gram. Even so, the name nanotube (rather than fibril) has caught on.

Where's the money?

Today, nanotubes have been joined by nanocrystals, nanowires, nanorods and other nanoforms. Research papers proliferate. But nanoresearch is further on than the business of nanotechnology. Commercial interest is intense, even though success remains elusive.

Although Hyperion Catalysis was arguably the world's first nanotech firm, Nanophase of Romeoville, Illinois, was probably the first company founded explicitly to commercialise a nano-substance--and certainly the first to survive long enough to go public (in 1997). Started in 1989 to exploit research done by Richard Siegel, then at Argonne National Laboratory, outside Chicago, and Horst Hahn of the University of Saarland in Saarbrucken, Germany, the company developed substrates that eventually became useful in cosmetic applications, particularly sunscreen. But it took Nanophase years to figure out how to manufacture its product cheaply--a challenge that dogs all of today's crop of nanotech start-ups. Keith Crandell, one of the venture capitalists who helped build Nanophase, confesses that funding the company was an act of youthful naivety.

Still, one can buy nano-enhanced sunscreens, and even self-cleaning windows that use similar nano-engineering to keep dirt from sticking to glass. Also for sale are trousers that use nano-hooks to attach small fibres to cotton, letting it repel stains more effectively than was previously possible. Some vehicles come with body parts made stronger, lighter and cheaper through the use of nanocomposites. Some tennis balls bounce higher for longer, thanks to a special nanocoating. Then there are "quantum dots", nanodevices that are generating a lot of buzz in biology and computing.

It seems inevitable that nanotechnology will continue to spread into materials, much as plastics re-formed business after business in the second half of the 20th century. What is needed is time to work out how to do the basic assembly of atoms into stable structures, and then to learn how to do that continuously on a predictable and profitable basis. For now, the researchers are in the process of turning things over to the engineers. It will be several years yet before they, in turn, hand the prototypes and knowhow over to the manufacturing foremen and the marketers.

Purists in the field see the applications that have been considered so far as "passive" nanotechnology, because they do only one thing. They would like to see greater focus in future on "active" nanotechnology--ie, on nanodevices that interact with one another. They believe that not until components actively interact will any of the promised breakthroughs accrue, in molecular electronics, genetic engineering, bio-sensors and other figments of the nano-optimists' imagination.

Even then there are two big obstacles to overcome. The first is coming up with an interface between living entities and electronic devices--ie, between carbon and silicon. It does no good to have a fuel cell made of carbon nanotubes if it cannot communicate when it is about to run out of fuel. While scientists at IBM, Hewlett-Packard and elsewhere race to release their latest atomic transistor or nanostorage device, they have yet to work out how to integrate such components. At Hewlett-Packard, Stan Williams and Phil Kuekes recall hearing as boys that soon even toasters would run on nuclear power. Despite such false dawns, they still think nanotechnology will be everywhere within 20 years. But until the integration issue is solved, nanocomputing will be as likely as nuclear-powered kitchen appliances.

Solving the integration issue will create another problem: how, in fact, to design and build nanodevices. The unpredictable behaviour of nanoscale objects means that engineers will not know how to make nanomachines until they actually start building them. Such a conundrum could take years to solve--and even then, it will be by trial and error and a lot of luck.

Quarter of a century later

A cautionary tale comes from Feynman's talk. At the end of it, he offered two $1,000 prizes for creating some atomic structures. One, for a tiny motor, was solved quickly, though conventionally, using a toothpick, a lathe and a microscope. The other was to prove that the "Encyclopedia Britannica" could fit on the head of a pin--by writing a page1/25,000th of its normal size. That was not achieved until 1985 (using the first page of "A Tale of Two Cities").

George Whitesides, a prolific Harvard chemist, reckons that nanotechnology is now about halfway through the list of discoveries needed for the field to reach maturity. He believes that it will develop much as biotechnology has--through intensive research and experimentation that yield totally new ways of doing things. Perhaps, one day, there really will be tiny, self-propelling structures that seek out and destroy cancer cells inside the human body. In time, nanotechnology could, indeed, change all of materials science, all of computing and much of biology. A transformation of that scope could generate serious concerns over nano-ethics. It is unlikely, though, that anything would cause the nanotechnology baton to drop. We are watching a classic technological revolution unfold.

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