

Nanotechnology in brief

Overview

- 1) Nanotechnology is not a single manufacturing process or industrial application, it is a broad multidisciplinary science made up of those attempting to develop new functional materials and those seeking practical solutions to existing needs.
- 2) The aim of nanotechnology is to manufacture at a scale of detail so small that the quantum characteristics of materials can be exploited. This will create lighter, stronger materials and will open up a new range of characteristics that ideally could be exploited at will. If atom by atom 'bottom-up' manufacturing were fully realised, materials could be designed to have almost whatever characteristics were required and devices could be made that are dust like in size but have high levels of functionality.

Current nanotechnology

- 3) Nanotechnology was originally a term used applied to ultra small precision engineering but its use has widened to cover all of nano-science. It is now used as a term to describe the production of items involving the manipulation and/or creation of materials at the nanometre (nm) scale either by scaling up from single or groups of atoms or by the refining/reduction of bulk material. To give a sense of scale a nanometre is 1×10^{-9} metres or a millionth of a millimetre, the diameter of a human hair is in the order of 80,000 nm.
- 4) Nanotechnology is currently at the early development, pilot or niche market stage and is composed of advances in material design, sensor development and high performance coatings. The next few years should see a dramatic increase in the industrial generation and use of new types of nano-materials. The properties and surface chemistry of these new materials may be very different from those of traditional material. This exploitation of novel characteristics could potentially lead to new hazards and changes in the level of risk from traditional hazards.
- 5) The limited niche industrial use of nanotechnology in the UK, is mainly as substances for incorporation into other materials e.g. carbon nano-fibres incorporated into plastic to conduct away surface static electrical charge.
- 6) Ultra fine powders now also referred to as nano-powders, have also been in use for some time and are in the main re-named existing technology. There has also been some re-branding of other existing technologies to gain a 'nano' label e.g. some carbon structural chemistry is being given a 'nano' title.
- 7) There has been a rapid increase in the interest and resources devoted to nanotechnology over recent years and there has been a rapid expansion in new fledgling/near future technologies (see Annex 5). The next few years are likely to see a dramatic increase in the industrial generation and use of new types of nano-particles (see Annex 2).
- 8) The possible uses of nanotechnology are extremely wide and it is likely that ultimately every industry sector will exploit its potential

Types of nanotechnology

- 9) Nanotechnology is not one technology, on platform or one sort of material/device. It is the multi-disciplinary, often solution lead development of materials and devices across a range of technical platforms. Nanotechnology can currently be split into 5 general types:

- a) Simple nanomaterials – high quality ultrafine powders, fibres and coatings. Most are still just technological curiosities, but some are commercially available now e.g. ultrafine TiO_2 for sunscreen or TiO_2 coating on self-cleaning glass.
- b) Complex or self-assembling nanomaterials – materials that can assemble into complex or large structures, possibly self-repairing or to create devices e.g. computers. Simple self-assembling materials are at the research stage and starting to move towards commercial development.
- c) There are also some materials, which are referred to as 'smart' materials. Smart materials are not intelligent in any sort of conventional sense but they react in some way to their environment, such as variable binding characteristics or undergo an overall conformational change in response to a local trigger such as heat, metal ion or ultraviolet light.
- d) Simple active nano units – tiny actuators, sensors, photo-emitters that link to more conventional technology. Mainly at the research stage, but some simple devices are available e.g. analytical sensors.
- e) 'Semi or fully autonomous nano devices – so called 'nanobots' these are little mobile robots that set about various activities without direct connection to other devices. These do not currently exist even at the research stage; work in this area is mostly theoretical.

Materials of construction

- 10) Ever-increasing ranges of materials are currently under investigation for exploitation by nanotechnology. In addition to the chemical composition nanotechnology allows complex three dimensional structures to be developed and exploited for their possible functional benefits. The most common materials are currently:
 - a) Carbon nanotubes – regular structure high strength and electrical conductivity, it is also possible to add chemical derivatives to their surface.
 - b) Titanium dioxide – stable particles, can be doped to either increase or suppress its activity as a photo-catalyst.
 - c) Silicon/Germanium etc – materials currently used in the semi-conductor manufacturing industry. Some manufacturing techniques are already developed and their properties are already widely studied.
 - d) Calcium oxide based materials – used for its biocompatibility in bone replacement/reconstruction.
 - e) Metal cored coated particles – often gold cores with thiol derivatives. Used to create stable quantum nano-dots that allow high sensitivity labelling in a range of chemical and biological environments.
 - f) Proteins or DNA – Mostly used as either a mould or scaffold to deposit inorganic materials or as an addressing system to direct the assembly of inorganic materials.

Development and history of nanotechnology

Summary

- 1) There are a number of factors leading to the development of nanotechnology. These are the:
 - a) General industry trend of miniaturisation.
 - b) Convergence of technologies.
 - c) Greatly increased level of government and industry funding.
 - d) Increasing critical mass of knowledge and technical abilities.
- 2) These will all act to increase the rate of development in this area and make nanotechnology a widely exploited technology within the next 10-20 years.

General industry trend of miniaturisation

- 3) The expectation from consumer electronics and the general IT industry is for every smaller devices of greater functionality. Several commentators have noted that there has been a general miniaturisation in technologies and that manufacturing and measuring are becoming ever more accurate.
- 4) This has lead to industry to seek a competitive edge by reducing size. In addition reduced size leads to a reduction in the use or raw materials, this when linked to mass production has also greatly reduced the cost of devices. Low cost, high functionality devices have lead to new markets that can be exploited.

Convergence of technologies

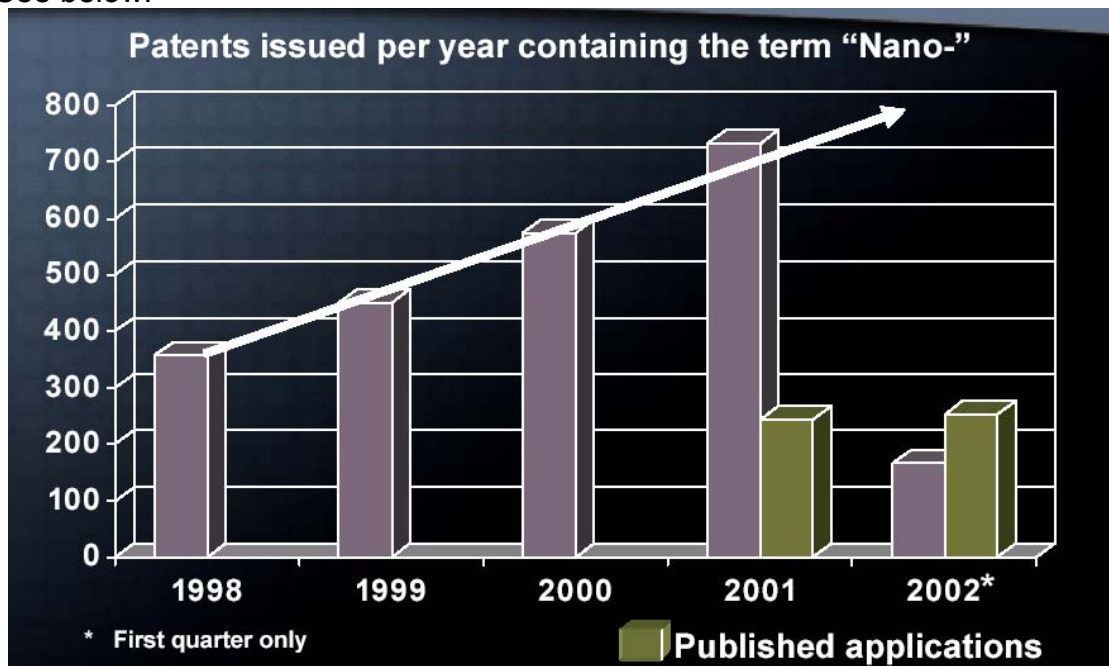
- 5) Many mainstream scientific and technological disciplines are now quite mature. As a result of this industry find it difficult to develop and exploit market advantages over their competitors.
- 6) Currently the main areas in scientific and technological expansion are in the areas of overlap between the traditional branches of traditional sciences - chemistry, biology and physics. These forces of convergence are also pushing towards the development and adoption of nanotechnology.
- 7) On a nano-scale disciplinary boundaries break down an advance in a material developed for one use may be exploited in a seemingly unconnected area. e.g. advancements in printer technology are being exploited to create artificial tissue for medical implantation.

Greatly increased level of government and industry funding

- 8) Funding for nanotechnology research & development in the developed world has accelerated rapidly within a very short time; spending by governments world-wide has increased approximately seven-fold in the last six years i.e. from \$0.43 billion in 1997 to \$3.0 billion in 2003. Private industry is also increasing its level of fund with around \$0.5 to \$1.0 billion of reported funding into R&D projects in 2002.
- 9) Last year DTI committed to spend £90M on nanotechnology research over the next six years. HSE has been asked to review the health and safety elements of the bids. The EU has allocated more than 1.4B euro on various nanotechnology initiatives across Europe.
- 10) A report of the worldwide funding of nanotechnology has been produced and is a separate Annex attached to this paper.

Increasing critical mass of knowledge and technical abilities

- 11) The rate of patenting of nanotechnology is occurring at an ever increasing rate. See below.



- 12) There are also many spin-out and start-up companies being created and most large manufacturing companies either have a nanotechnology research program underway or are actively seeking to acquire such technology.

13) Whilst nanoscience has been in existence for over 100 years with the very small being measured and chemically synthesised from the early days of organic chemistry. The nanotechnology referred to by scientists and the media today is a much newer science. In reality this is only just over 20 years old and has been made possible by new means to manipulate and analyse matter. This was made possible by the development of a number of scientific disciplines. Some milestones on the road to nanotechnology have been:

- a) 1981 – Discover of Spherical cages of 60 carbon molecules, which are named buckminsterfullerene.
- b) 1983 – Discovery of carbon nanotubes
- c) 1989 - Manipulation of single xenon atoms to write “IBM” using a Scanning Tunnelling Electron Microscope (STM).
- d) 1991 - Discovery of tubes of graphite, called nanotubes, which turn out to have extraordinary strength and interesting electrical properties.
- e) 1993 - The US's first laboratory dedicated to nanotechnology is created at Rice University.
- f) 1994 - Production of nanoclusters of gold stabilised to prevent agglomeration
- g) 1996 - Method for producing molecular sized carbon nanotubes.
- h) 1997 - DNA is used as a building block for nanoscale mechanical devices, New York University.
- i) 1999 - Yale scientists create an organic switch in a single molecule.
- j) 1999 - Molecular motor built.
- k) 2000 - US launches National Nanotechnology Initiative putting \$422 million into nanotechnology research.

- l) 2001 - Researchers at IBM and Delft University create the first transistors, and then logic gates made entirely from carbon nanotubes
- m) 2003 - IBM exploits self-assembly to make nanocrystal memory

Commercial exploitation of nanotechnology

14) To give some feel for the likely uptake of nanotechnology a timeline of its industrial use has been created, see Annex 2: Timeline for Exploitation of Nanotechnology.

15) Ultimately such technology will only be used on a wide scale if it is commercially viable. Whilst the benefits of greater functionality, reduced use of raw materials and size reduction appear to be overpowering it will also require low cost production techniques. Currently it is only for the simplest nano-materials that these have been developed.

16) Even if these products are not ultimately commercially viable for the mass market there may still be limited scope for niche markets, e.g. military. If so development is likely to be slower due to narrower funding and innovative base.

Conclusion

17) There are a number of factors pushing forward the development of nanotechnology. As more and more techniques are developed and refined and as materials and devices find their way on to the market, the rate of commercialisation is like to increase. This will be due to increasing cross discipline interactions, the increasing ease of manufacture and the increasing demand created by wider consumer awareness.