Nanotechnology- Impacting in Life science and Technology

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ABSTRACT

One of the most pressing issues facing nanoscientists and technologists today is that of communicating with the non-scientific community. As a result of decades of speculation, a number of myths have grown up around the field, making it difficult for the general public, or indeed the business and financial communities, to understand what is a fundamental shift in the way we look at our interactions with the natural world. This article attempts to address some of these misconceptions, and explain why scientists, businesses and governments are spending large amounts of time and money on nanoscale research and development.

Take a random selection of scientists, engineers, investors and the general public and ask them what nanotechnology is and you will receive a range of replies as broad as nanotechnology itself. For many scientists, it is nothing startlingly new; after all we have been working at the nanoscale for decades, through electron microscopy, scanning probe microscopies or simply growing and analysing thin films. For most other groups, however, nanotechnology means something far more ambitious, miniature submarines in the bloodstream, little cogs and gears made out of atoms, space elevators made of nanotubes, and the colonization of space. It is no wonder people often muddle up nanotechnology with science fiction.

Introduction

Nanoscale

Although a metre is defined by the International Standards Organization as `the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second' and a nanometre is by definition 10^{-9} of a metre, this does not help scientists to communicate the nanoscale to non-scientists. It is in human nature to relate sizes by reference to everyday objects, and the commonest definition of nanotechnology is in relation to the width of a human hair.

Unfortunately, human hairs are highly variable, ranging from tens to hundreds of microns in diameter (10^{-6} of a metre), depending on the colour, type and the part of the body from which they are taken, so what is needed is a standard to which we can relate the nanoscale.

Science fiction

While there is a commonly held belief that nanotechnology is a futuristic science with applications 25 years in the future and beyond, nanotechnology is anything but science fiction. In the last 15 years over a dozen Nobel prizes have been awarded in nanotechnology, from the development of the scanning probe microscope (SPM), to the discovery of fullerenes. Even more significantly, there are companies applying nanotechnology to a variety of products we can already buy, such as automobile parts, clothing and ski wax. Nanotechnology is already all around us if you know where to look.

Many of the initial applications of nanotechnology are materials related, such as additives for plastics, nanocarbon particles for improved steels, coatings and improved catalysts for the petrochemical industry. All of these are technology based industries, maybe not new ones, but industries with multi-billion dollar markets.

The nanotechnology industry

Many of the companies working with nanotechnology are simply applying our knowledge of the nanoscale to existing industries, whether it is improved drug delivery mechanisms for the pharmaceutical industry, or producing nanoclay particles for the plastics industry. In fact nanotechnology is an enabling technology rather than an industry in its own right. No one would ever describe Microsoft or Oracle as being part of the electricity industry, even though without electricity the software industry could not exist. Rather, nanotechnology is a fundamental understanding of how nature works at the atomic scale.

Fantastic voyage

Shrinking machines down to the size where they can be inserted into the human body in order to detect and repair diseased cells is a popular idea of the benefits of nanotechnology, and one that even comes close to reality. Many companies are already in clinical trials for drug delivery mechanisms based on nanotechnology, but unfortunately none of them involve miniature submarines. It turns out that there is a whole range of more efficient ways that nanotechnology can enable better drug delivery without resorting to the use of nanomachines.

Shrinking stuff

Another common misconception is that nanotechnology is primarily concerned with making things smaller. This has been exacerbated by images of tiny bulls, and miniature guitars that can be strummed with the tip of an AFM, that while news worthy, merely demonstrate our new found control of matter at the sub-micron scale. While almost the whole focus of micro-technologies has been on taking macro-scale devices such as transistors and mechanical systems and making them smaller, nanotechnology is more concerned with our ability to create from the bottom up. In electronics, there is a growing realization that with the end of the CMOS roadmap in sight at around 10 nm, combined with the uncertainly principal's limit of Von Neuman electronics at 2 nm, that merely making things smaller will not help us. Replacing CMOS transistors on a one for one basis with some type of nano device would have the effect of drastically increasing fabrication costs, while offering only a marginal improvement over current technologies.

However, nanotechnology offers us a way out of this technological and financial cul-de-sac by building devices from the bottom up. Techniques such as self assembly, perhaps assisted by templates created by nano imprint lithography, a notable European success, combined with our understanding of the workings of polymers and molecules such as Rotoxane at the nanoscale open up a whole new host of possibilities. Whether it is avoiding Moore's second law by switching to plastic electronics, or using molecular electronics, our understanding of the behaviour of materials on the scale of small molecules allows a variety of alternative approaches, to produce smarter, cheaper devices. The new understandings will also allow us to design new architectures, with the end result that functionality will become a more valid measure of performance than transistor density or operations per second.

Nanotechnology is new

It often comes as a surprise to learn that the Romans and Chinese were using nanoparticles thousands of years ago. Similarly, every time you light a match, fullerenes are produced. Degusssa have been producing carbon black, the substance that makes car tyres black and improves the wear resistance of the rubber, since the 1920s. Of course they were not aware that they were using nanotechnology, and as they had no control over particle size, or even any knowledge of the nanoscale they were not using nanotechnology as currently defined.

What is new about nanotechnology is our ability to not only see, and manipulate matter on the nanoscale, but our understanding of atomic scale interactions.

Building atom by atom

One of the defining moments in nanotechnology came in 1989 when Don Eigler used a SPM to spell out the letters IBM in xenon atoms. For the first time we could put atoms exactly where we wanted them, even if keeping them there at much above absolute zero proved to be a problem. While useful in aiding our understanding of the nanoworld, arranging atoms together one by one is unlikely to be of much use in industrial processes. Given that a Pentium 4 processor contains 42 million transistors, even simplifying the transistors to a cube of 100 atoms on each side would require 42 x 10^2 operations, and that is before we start to consider the other material and devices needed in a functioning processor.

Of course we already have the ability to build things atom by atom, and on a very large scale; it is called physical chemistry, and has been in industrial use for over a century producing everything from nitrates to salt. To do this, we do not need any kind of tabletop assembler as in Star Trek, usually a few barrels of readily available precursor chemicals and maybe a catalyst are all that is required.

Attack of the killer nanobots

In terms of capturing the public imagination, unleashing hordes of self-replicating devices that escape from the lab and attack anything in their path is always going to be popular. Unfortunately nature has already beaten us to it, by several hundred million years. Naturally occurring nanomachines, that can not only replicate and mutate as they do so in order to avoid our best attempts at eradication, but can also escape their hosts and travel with alarming ease through the atmosphere. No wonder that viruses are the most successful living organisms on the planet, with most of their `machinery' being well into the nano realm. However, there are finite limits to the spread of such `nanobots', usually determined by their ability, or lack thereof, of converting a sufficiently wide range of material needed for future expansion. Indeed, the immune systems of many species, while unable to completely neutralize viruses without side effects such as runny noses, are so effective in dealing with this type of threat as a result of the wide range of different technologies available to a large complex organism when confronted with a single purpose nano-sized one. For any threat from the nano world to become a danger, it would have to include far more intelligence and flexibility than we could possibly design into it.

Our understanding of genomics and proteomics is primitive compared with that of nature, and is likely to remain that way for the foreseeable future. For anyone determined to worry about nanoscale threats to humanity should consider mutations in viruses such as HIV that would allow transmission via mosquitoes, or deadlier versions of the influenza virus, which deserve far more concern than anything nanotechnology may produce.

Nanotechnology Applications in:

Medicine

Researchers are developing customized nanoparticles the size of molecules that can deliver drugs directly to diseased cells in your body. When it's perfected, this method should greatly reduce the damage treatment such as chemotherapy does to a patient's healthy cells.

Electronics

Nanotechnology holds some answers for how we might increase the capabilities of electronics devices while we reduce their weight and power consumption.

Food

Nanotechnology is having an impact on several aspects of food science, from how food is grown to how it is packaged. Companies are developing nanomaterials that will make a difference not only in the taste of food, but also in food safety, and the health benefits that food delivers

Fuel Cells

Nanotechnology is being used to reduce the cost of catalysts used in fuel cells to produce hydrogen ions from fuel such as methanol and to improve the efficiency of membranes used in fuel cells to separate hydrogen ions from other gases such as oxygen.

Solar Cells

Companies have developed nanotech solar cells that can be manufactured at significantly lower cost than conventional solar cells.

Batteries

Companies are currently developing batteries using nanomaterials. One such battery will be a good as new after sitting on the shelf for decades. Another battery can be recharged significantly faster than conventional batteries.

Space

Nanotechnology may hold the key to making space-flight more practical. Advancements in nanomaterials make lightweight spacecraft and a cable for the space elevator possible. By significantly reducing the amount of rocket fuel required, these advances could lower the cost of reaching orbit and traveling in space.

Fuels

Nanotechnology can address the shortage of fossil fuels such as diesel and gasoline by making the production of fuels from low grade raw materials economical, increasing the mileage of engines, and making the production of fuels from normal raw materials more efficient.

Better Air Quality

Nanotechnology can improve the performance of catalysts used to transform vapors escaping from cars or industrial plants into harmless gasses. That's because catalysts made from nanoparticles have a greater surface area to interact with the reacting chemicals than catalysts made from larger particles. The larger surface area allows more chemicals to interact with the catalyst simultaneously, which makes the catalyst more effective.

Cleaner Water

Nanotechnology is being used to develop solutions to three very different problems in water quality. One challenge is the removal of industrial wastes, such as a cleaning solvent called TCE, from groundwater. Nanoparticles can be used to convert the contaminating chemical through a chemical reaction to make it harmless. Studies have shown that this method can be used successfully to reach contaminates dispersed in underground ponds and at much lower cost than methods which require pumping the water out of the ground for treatment.

Chemical Sensors

Nanotechnology can enable sensors to detect very small amounts of chemical vapors. Various types of detecting elements, such as carbon nanotubes, zinc oxide nanowires or palladium nanoparticles can be used in nanotechnology-based sensors. Because of the small size of nanotubes, nanowires, or nanoparticles, a few gas molecules are sufficient to change the electrical properties of the sensing elements. This allows the detection of a very low concentration of chemical vapors.

Sporting Goods

If you're a tennis or golf fan, you'll be glad to hear that even sporting goods has wandered into the nano realm. Current nanotechnology applications in the sports arena include increasing the strength of tennis racquets, filling any imperfections in club shaft materials and reducing the rate at which air leaks from tennis balls.

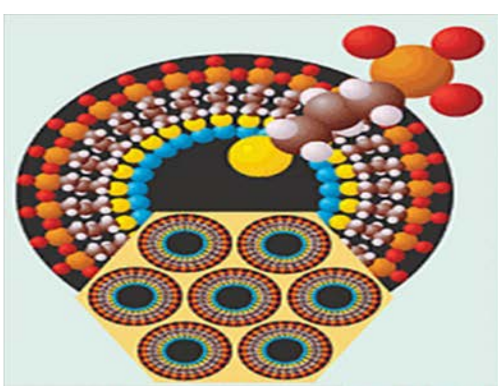
Fabric

Making composite fabric with nano-sized particles or fibers allows improvement of fabric properties without a significant increase in weight, thickness, or stiffness as might have been the case with previously-used techniques.

Some examples of how nanotechnology impacts our lives now

Nanocomposites

Researchers at Pacific Northwest National Laboratory have developed a coating process to make sponge-like silica latch onto toxic metals in water. Self-Assembled Monolayers on Mesoporous Supports easily captures such metals as lead and mercury, which are then recovered for reuse or contained in-place forever. One example of a SAMMS nanocomposite (**S**elf-**A**ssembled **M**onolayers on **M**esoporous **S**upports). An hexagonally close-packed cluster of tubular pores (end view) is shown in the foreground. A single pore, in this case coated with a mercaptopropylsiloxy monolayer, is shown in the background. A model of one surfactant molcule is also shown.



A plastic nanocomposite is being used for "step assists" in the GM Safari and Astro Vans. It is scratch-resistant, light-weight, and rust-proof, and generates improvements in strength and reductions in weight, which lead to fuel savings and increased longevity. And in 2001, Toyota started using nanocomposites in a bumper that makes it 60% lighter and twice as resistant to denting and scratching.

Impact: Will likely be used on other GM and Toyota models soon, and in other areas of their vehicles, as well as the other auto manufactures, lowering weight, increasing milage, and creating longer-lasting autos. Likely to impact repair shops (fewer repairs needed) and auto insurance companies (fewer claims). Will also likely soon be seen everywhere weight, weather-proofing, durability, and strength are important factors. Expect NASA, the ESA, and other space-faring organizations to take a serious look, soon, which will eventually result in lower lift costs, which will result in more material being lifted into space.

"Metal nanocrystals might be incorporated into car bumpers, making the parts stronger, or into aluminum, making it more wear resistant. Metal nanocrystals might be used to produce bearings that last longer than their conventional counterparts, new types of sensors and components for computers and electronic hardware.

Nanocrystals of various metals have been shown to be 100 percent, 200 percent and even as much as 300 percent harder than the same materials in bulk form. Because wear resistance often is dictated by the hardness of a metal, parts made from nanocrystals might last significantly longer than conventional parts."

Smith & Nephew markets an antimicrobial dressing covered with nanocrystalline silver (A patented Technology of NUCRYST Pharmaceuticals). The nanocrystalline coating of silver rapidly kills a broad spectrum of bacteria in as little as 30 minutes.

Nanoparticles

Stain-repellent Eddie Bauer Nano-Care^{TM} khakis, with surface fibers of 10 to 100 nanometers, uses a process that coats each fiber of fabric with "nano-whiskers." Developed by Nano-Tex, a Burlington Industries subsidiary. Dockers also makes khakis, a dress shirt and even a tie treated with what they call "Stain Defender", another example of the same nanoscale cloth treatment.

Impact: Dry cleaners, detergent and stain-removal makers, carpet and furniture makers, window covering makers .

BASF's annual sales of aqueous polymer dispersion products amount to around $1.65 billion. All of them contain polymer particles ranging from ten to several hundred nanometers in size. Polymer dispersions are found in exterior paints, coatings and adhesives, or are used in the finishing of paper, textiles and leather. Nanotechnology also has applications in the food sector. Many vitamins and their precursors, such as carotinoids, are insoluble in water. However, when skillfully produced and formulated as nanoparticles, these substances can easily be mixed with cold water, and their bioavailability in the human body also increases. Many lemonades and fruit juices contain these specially formulated additives, which often also provide an attractive color. In the cosmetics sector, BASF has for several years been among the leading suppliers of UV absorbers based on nanoparticulate zinc oxide. Incorporated in sun creams, the small particles filter the high-energy radiation out of sunlight. Because of their tiny size, they remain invisible to the naked eye and so the cream is transparent on the skin. From Nanotechnology at BASF

Sunscreens are utilizing nanoparticles that are extremely effective at absorbing light, especially in the ultra-violet (UV) range. Due to the particle size, they spread more easily, cover better, and save money since you use less. And they are transparent, unlike traditional screens which are white. These sunscreens are so successful that by 2001 they had captured 60% of the Australian sunscreen market.

Impact: Makers of sunscreen have to convert to using nanoparticles. And other product manufactures, like packaging makers, will find ways to incorporate them into packages to reduces UV exposure and subsequent spoilage. The $480B packaging and $300B plastics industries will be directly effected. See Big Opportunities for Small Particles

Using aluminum nanoparticles, Argonide has created rocket propellants that burn at double the rate. They also produce copper nanoparticles that are incorporated into automotive lubricant to reduce engine wear.

AngstroMedica has produced a nanoparticulate-based synthetic bone. "Human bone is made of a calcium and phosphate composite called Hydroxyapatite. By manipulation calcium and phosphate at the molecular level, we have created a patented material that is identical in structure and composition to natural bone. This novel synthetic bone can be used in areas where natural bone is damaged or removed, such as in the in the treatment of fractures and soft tissue injuries."

Nanostructured Materials

Nanodyne makes a tungsten-carbide-cobalt composite powder (grain size less than 15nm) that is used to make a sintered alloy as hard as diamond, which is in turn used to make cutting tools, drill bits, armor plate, and jet engine parts.

Impact: Every industry that makes parts or components whose properties must include hardness and durability. See Nanostructed Materials Get Tough A PDF document

Kodak is producing OLED color screens (made of nanostructured polymer films) for use in car stereos and cell phones. OLEDs (organic light emitting diodes) may enable thinner, lighter, more flexible, less power consuming displays, and other consumer products such as cameras, PDAs, laptops, televisions, and other as yet undreamt of applications.

Impact: all current makers of CRTs, liquid crystal displays (LCDs), and other display types. See OLEDs get ready to light up the market for flexible screens and KODAK OLED technical details [a PDF]

Nanoclays and Nanocomposites

Used in packaging, like beer bottles, as a barrier, allowing for thinner material, with a subsequently lighter weight, and greater shelf-life.

Impact: $480B packaging and $300B plastics industries. Reduced weight means transportation costs decline. Changing from glass and aluminum - think beer and soda bottles - to plastic reduces production costs. Nanoclays help to hold the pressure and carbonation inside the bottle, increasing shelf life. It is estimated that beer in these containers will gain an extra 60 days (from 120 to 180) of shelf life, reducing spoilage, and decreasing overall costs to the end user. Nanocor is one company producing nanoclays and nanocomposites, for a variety of uses, including flame retardants, barrier film (as in juice containers), and bottle barrier (as shown above). "They are not only used to improve existing products, but also are extending their reach into areas formerly dominated by metal, glass and wood."

Nanocomposite Coatings

Wilson Double Core tennis balls have a nanocomposite coating that keeps it bouncing twice as long as an old-style ball. Made by InMat LLC, this nanocomposite is a mix of butyl rubber, intermingled with nanoclay particles, giving the ball substantially longer shelf life.

Impact: Tires are the next logical extension of this technology: it would make them lighter (better millage) and last longer (better cost performance). See Nanocomposites in tennis balls lock in air, build better bounce

Nanotubes

Nanoledge makes carbon nanotubes for commercial uses, of which one mundane (marketing tactic) use is in a tennis racket, made by Babolat. The yoke of the racket bends less during ball impact, improving the player's performance.

Impact: Once companies like Nanoledge can scale-up their production from grams, to pounds, to tons, and can do so while controlling the type of nanotube they produce, the world becomes their oyster: everywhere strength and weight are a factor - such as in the aerospace, automobile, and airplane industries - they will make a major (disruptive) impact. See French firm hopes to get PR bounce out of nanotubes in tennis rackets

Applied Nanotech recently demonstrated a 14" monochrome display based on electron emission from carbon nanotubes.

Impact: Once the process is perfected, costs will go down, and the high-end market will start being filled. Shortly thereafter, and hand-in-hand with the predictable drop in price of CNTs, production economies-of-scale will enable the costs to drop further still, at which time we will see nanotube-based screens in use everywhere CRTs and view screens are used today. See Applied Nanotech demonstrates carbon nanotube TV

Nanocatalysts

China's largest coal company (Shenhua Group) has licensed technology from Hydrocarbon Technologies that will enable it to liquify coal and turn it into gas. The process uses a gel-based nanoscale catalyst, which improves the efficiency and reduces the cost.

One of the characteristic properties of all nanoparticles has been used from the outset in the manufacture of automotive catalytic converters: The surface area of the particles increases dramatically as the particle size decreases and the weight remains the same. A variety of chemical reactions take place on the surface of the catalyst, and the larger the surface area, the more active the catalyst. Nanoscale catalysts thus open the way for numerous process innovations to make many chemical processes more efficient and resource-saving – in other words more competitive.

Nanofilters

Argonide Nanomaterials, an Orlando based manufacturer of nanoparticles and nanofiltration products, makes a filter that is capable of filtering the smallest of particles. The performance is due to it's nano size alumina fiber, which attracts and retains sub-micron and nanosize particles. This disposable filter retains 99.9999+% of viruses at water flow rates several hundred times greater than virus-rated ultra porous membranes. It is useful for sterilization of biological, pharmaceutical and medical serums, protein separation, collector/concentrator for biological warfare detectors, and several other applications.

Impact: In the future, for one application, sterilizing drinking water, this product may have an impact on so-called Third World peoples, who only have access to dubious sources of water.

For more current applications, see Reality is the concept that governs the new nanobusiness world These are just a few of the many ways in which nanotechnology is working itself into our everyday lives. At present, there are no nanobots, no molecular-scale machines, and no assemblers - these are still in the basic research stages, and may not be seen for decades (although many would argue that a concerted effort would bring them to fruition in just a few years).

"What we are seeing is the beginning of a revolution, caused by our ability to work on the same scale as nature. Nanotechnology will affect every aspect of our lives, from the medicines we use, to the power of our computers, the energy supplies we require, the food we eat, the cars we drive, the buildings we live in, and the clothes we wear. And it will happen sooner than most people think. By 2010 you won't be able to count the number of businesses affected by nanotechnology." iTim Harper, Founder and Chief Executive Director of the European NanoBusiness Association, and CEO CMP Cientifica

Conclusions

Nanotechnology, like any other branch of science, is primarily concerned with understanding how nature works. We have discussed how our efforts to produce devices and manipulate matter are still at a very primitive stage compared to nature. Nature has the ability to design highly energy efficient systems that operate precisely and without waste, fix only that which needs fixing, do only that which needs doing, and no more. We do not, although one day our understanding of nanoscale phenomena may allow us to replicate at least part of what nature accomplishes with ease.

While many branches of what now falls under the umbrella term nanotechnology are not new, it is the combination of existing technologies with our new found ability to observe and manipulate at the atomic scale that makes nanotechnology so compelling from scientific, business and political viewpoints.

Maybe the greatest short term benefit of nanotechnology is in bringing together the disparate sciences, physical and biological, who due to the nature of education often have had no contact since high school. Rather than nanosubmarines or killer nanobots, the greatest legacy of nanotechnology may well prove to be the unification of scientific disciplines and the resultant ability of scientists, when faced with a problem, to call on the resources of the whole of science, not just of one discipline.