Technology

Nanotechnology:

The Biology and Engineering of Tomorrow

What is Nanotechnology?

Public awareness of nanotechnology has greatly increased in the early part of this new century, with numerous references in popular culture, most notably the "*Grey Goo*" of Michael Crichton's bestseller, *Prey*. There is great confusion and debate as how exactly to define nanotechnology, but for the purposes of this article, we shall adopt the definition: the science and engineering at the dimensions of one to one hundred nanometre (nm), where a nanometre is one billionth of a metre. To give you some perspective of how small this is, imagine a magnifying glass that could make 1 nm appear the height of a letter in this text, using that same magnifying glass would make a human hair appear to be around 200 m wide!

To understand any development in technology, it is always useful to look to its history. In its loosest definition, we can trace nanotechnology to the ancients. When producing the 4th Century Lycurgus Cup the Romans used 70 nm silver colloids to produce colour and sparkle. Is it also possible that the 5th Century masterpieces at Sigiriya did not only use oil based paint, but incorporated metal nanoclusters?

Although the concept of the atom can be traced back to Greek antiquity, with Democritus of Adbera (400 BCE) asserting that all material things are composed of extremely small irreducible particles called atoms, it was not until the English chemist John Dalton (1766–1844) that a firm scientific theory of the atom began to be developed. There were of course many great scientists who went on to further contribute to our contemporary understanding of the world at the nanoscale, but this article does not have space to describe this story, nevertheless we would encourage the reader to read further on the subject.

It is the extraordinary Caltech physicist and Nobel laureate Richard Feynman (1918-1988) that many people cite as the inspiration for modern nanotechnology. In a lecture titled "*There's Plenty of Room at the Bottom*", presented to the American Physical Society in 1959, Feynman outlined the challenges and opportunities afforded by engineering from the atomic scale up.

Given the nature of Nanotechnology, it is possible for developing nations to make a real impact. Thus not only will they benefit from the improved technology, but also build their economies by making an important contribution to the developments. In its 2005 report entitled "Innovation: applying knowledge in development", the UN Millennium Project task force on science, technology and innovation wrote that "*nano-technology is likely to be particularly important in the developing world, because it involves little labour, land or maintenance; it is highly productive and inexpensive; and it requires only modest amounts of materials and energy*".

The Nanotech Revolution: A Panacea for Humanities Woes?

The world we live in today has been altered dramatically by the seemingly ceaseless march of technology. Some would argue this change has been for the worst, but most would agree that the quality of our lives have been vastly improved. The present state of affairs has been achieved through sudden bursts in technological output, often termed as "Revolutions". The first such explosion, the *Industrial Revolution*, occurred in the Britain between 1780 and 1840 with the development of the steam engine, textile industry and progress in mechanical engineering. This was closely followed by a second revolution in main land Europe (1840-1900) with the establishment of the railway infrastructure and the steel industry. Between 1900 and 1950 the hub of the third revolution was the USA, with the advent of the electric motor, the chemical industry, automobiles and consumer goods. The fourth revolution (1950 to present), the *Electronics Revolution*, has been centred on the Pacific Basin (USA, Japan, Taiwan, South Korea), driven by Silicon Valley in California and the apparent insatiable appetites of consumers for ever more sophisticated appliances.

This is really where our story begins. It is the electronics industry that has, from a technological perspective pushed for ever increasing miniaturisation. The invention of the transistor by John Bardeen, Walter Brattain and William Shockley at Bell laboratories in 1947, made it possible to start this revolution in miniaturisation. Jack Kilby and Robert Noyce took it a step

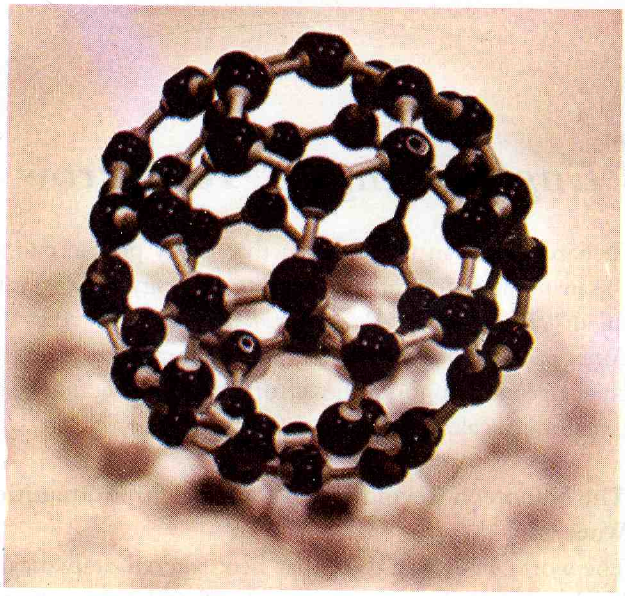

Fig 1 Ball and stick model of a C60 molecule

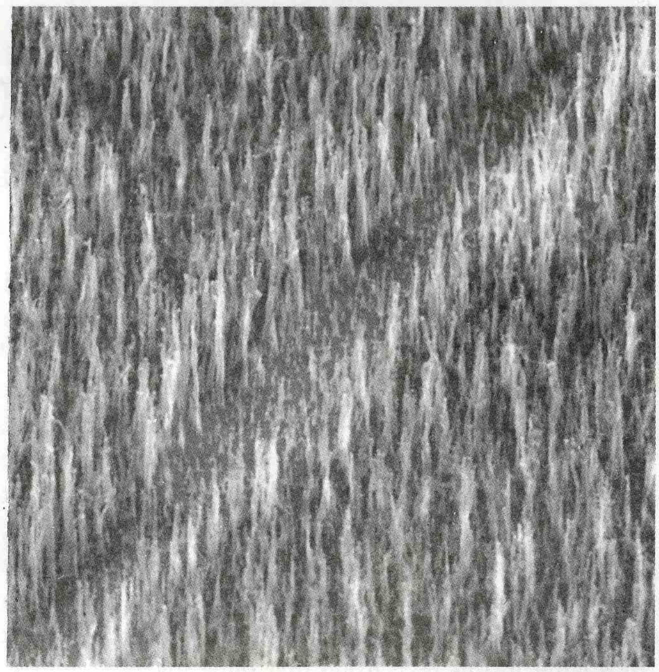

Fig 2 Thousands of carbon nanotubes can be grown over large areas. Each one of these tubes is about 500 nm long and about 80 nm thick

further in the late 1950's when they both independently conceived the concept of the Integrated Circuit (IC), which allowed all the components of an electronic device to be fabricated on a single crystal of Silicon. This led Gordon Moore the founder of INTEL®, to predict in 1965 a doubling of the number of transistors per IC every 18 months. Moore's law has relentlessly held for the last 40 years and been the driving force for change in IC design. Unfortunately, due to fundamental limits associated with quantum mechanical tunnelling in semiconducting and electronic materials it is envisaged that this miniaturisation of devices cannot continue beyond 2010. To overcome this barrier we must look to the potential offered by nanotechnology.

At the University of Surrey we have active research programmes in allotropes of carbon, specifically **Carbon Nano Tubes** (CNT) and **Buckminsterfullerene** (C_{60}). Research in this field began with the discovery of a stable molecule made up of 60 carbon atoms (see Fig 1) by, Kroto, Smalley and Curl in 1985, which led to them winning the 1996 Nobel Prize for Chemistry in record time. This was closely followed by Iijima's identification of CNT's in 1991, creating a burgeoning field of research unparalleled in science. Why the big interest in C_{60} and CNT's?

The CNT, which is an elongation of the C_{60} molecule, exemplifies all that nanotechnology can offer (see Fig 2). Identical in bonding to that found in soft metallic graphite, carbon nanotubes are single layers of graphitic carbon rolled up into a hollow tube, which is capped by half a football shaped C_{60} molecule. By virtue of its shape and bonding, along its axis this material is 20 times stronger than high tensile steel, half the weight of aluminium, has a current carrying capability a 1000 times greater than copper and can form either metallic or semiconducting derivatives based on how the tubes are rolled up. They also have a conduction mechanism that is not limited by the constraints of bulk materials; electrons travelling along the length of the tube don't experience electrical resistance in the same way as bulk materials. This is known as ballistic transport and is possible due to the one dimensional quantum wire nature of the structure. In terms of heat dissipation, it has a thermal conduction twice that of diamond, once thought to be the best thermal conductor in the world.

The applications of CNTs in medical science, electronics, forensics, and the environment could be far reaching and all pervasive. In the field of therapeutic medicine, buckyballs and CNTs offer ideal platforms for encapsulation of pharmaceuticals, enabling targeted drug delivery, thus reducing doses and removing their often harmful side-effects. In biology, the similar dimensions of DNA and nanostructures are proving to be a intriguing enabler that has given rise to *nano-bio-technology*. Lab-on-a-chip, DNA micro-arrays and novel diagnostics are all making the identification of genetic defects, pathogens and foreign matter cheaper, with increased flexibility and accessibility. In the future it is envisaged we will be able to provide 24/7 unobtrusive monitoring of patients in all environments with novel sensors for blood sugar, EEG, glucose, brain wave etc... on the end of say a 'stick-on–plaster', which may communicate with a processor in your watch.

An extremely pertinent example of where nanotechnology could have an enormous impact is on *energy*. Only recently we have seen tensions that can arise from energy demands, with the stand off between the Ukraine and the Russian gas company Gazprom. This could just be the beginning of such crises, particularly as demand for energy grows with fast developing economies such as China. There is also the environmental impact of our current reliance on fossil fuels. If there were sources of cheap renewable energy, it could develop all countries production base and economies, wipe out poverty and the east-west divide, and provide for medical care for the world population. We at Surrey are looking towards composites of CNTs and organic materials to produce high efficiency large area solar cells that could be produced on a roll-by-roll basis.

The Nano-Nightmare!

History has taught us that no technology comes without problems. The industrial revolution brought about excessive air pollution, culminating in the great smog of 1952 which killed an estimated 12,000 people in the city of London, UK. The methyl isocyanate gas leak in 1984 at the Union Carbide factory in Bhopal, India, killed 3,800 people and several thousand other individuals experience permanent and partial disabilities. Perhaps the defining technology of the 20th Century which still provokes great debate is that of nuclear power and weapons. There is no doubt that the world has been irrevocably changed by the bombs dropped on Nagasaki and Hiroshima in 1945, the "Cold War" (1945 – 1991), the Chernoblyl disaster in the Ukraine in 1986 or the continuing strife between the USA and Iran and North Korea. The one thing all these incidents have in common is that root of the dilemma was not the technology but irresponsible use by man.

What are the possible negative side-effects of Nanotechnology? There has been a lot of press about self-replicating nano-bots that could render the whole surface of the earth to grey goo, but this is just sensationalism, and if such a scenario is possible it is a very long way off. A more imminent cause for concern is the toxicity of nano-particles, partly fuelled by health problems associated with asbestosis. Research has shown that nano-sized particles ingested in large quantities may accumulate in the nasal cavities, lungs and brains of rats and that 'buckyballs' induce brain damage in fish yet, other studies show negligible effects. However further research is needed and is being undertaken, as yet the yield in manufacture of nano-materials is low, thus making it expensive to produce the sizeable quantities that would be required to possibly enter the food chain.

The Future...

Around the world many millions of dollars is being spent on research and technology to find competitive positions in this field. In 2003 alone, the US federal budget spent US$700 million, the UK government spent close to US$170 million, the Japanese and EU spent in excess of $500 million. The state of California alone spent over $100 million for research. The US National Science Foundation predicts that the global market for nanotech-based products will exceed US$1 trillion within 15 years.

Given the nature of Nanotechnology, it is possible for developing nations to make a real impact. Thus not only will they benefit from the improved technology, but also build their economies by making an important contribution to the developments. In its 2005 report entitled "Innovation: applying knowledge in development", the UN Millennium Project task force on science, technology and innovation wrote that "*nanotechnology is likely to be particularly important in the developing world, because it involves little labour, land or maintenance; it is highly productive and inexpensive; and it requires only modest amounts of materials and energy*".

What are the 'unknowns'? Is nanotechnology over-hyped? Can it fulfill its promise without comprising society and security? Are its proponents realistic in their claims of what nanotechnology can achieve? Or is it a runaway technology destined to wreak havoc with human health and the natural environment? These are questions that can only be answered with time, but one thing is for sure, nanotechnology will achieve nothing without motivated scientists and engineers willing to take on the challenge. We hope this article will inspire you to take an interest in all areas of science and maybe one day you could be the individual or more likely part of the team that answers these questions!

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