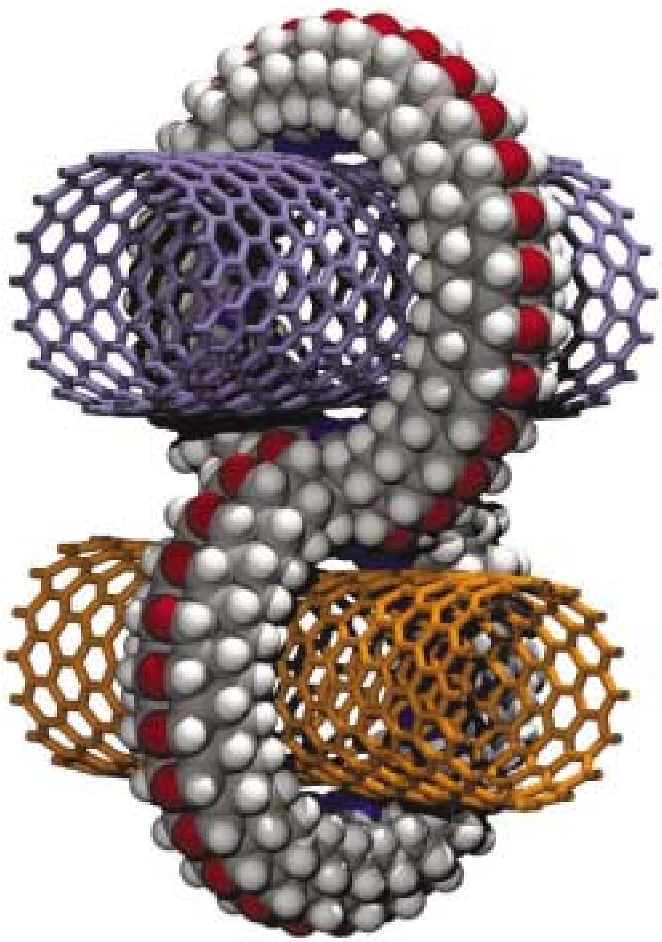
Nanotechnology
The New Technological Revolution

Creating functional "machines" by rearranging atoms sounds like science fiction. But the science of working with things small could change every aspect of our lives.

By Dr. Graham Moore



Nanotechnology has been used freely in the context of describing the manipulation of atoms and molecules to create structures that have applications in the real world. It is an emerging engineering discipline that applies methods from nanoscience to create products and provides a radically new approach to manufacturing and medicine.

Few industries will escape the influence of nanotechnology in the medium term. It is likely to make an impact by providing methods to overcome well understood and long-predicted barriers that stand in the way of the improvement of current technologies.

Nanotechnology is the one area of research and development that is truly multidisciplinary. The contribution of nanotechnology will not be made in isolation from other rapidly developing areas of science. In particular, advances in biology and biotechnology, information technology and nanotechnology itself are likely to reinforce each other in a synergistic way.

Nanotechnology is of interest globally. It has attracted more public funding than any single area of technology. On a global basis, governments are spending some $3 billion on nanotechnology, with each year seeing a fresh effort by Europe, the US and Japan to outbid the others. It has been estimated that this public funding is being matched by corporate R&D spending, giving a total of $5-6 billion per year. The US has the largest number of companies operating in the nanosector with over 400. Japan is second with around 100. The US also dominates the number of research centers involved in the nanosector.

The main thrust of nanoscience and nanotechnology is in the areas of: material science, electronics and optoelectronics, and biomedical science.

MATERIAL SCIENCE

The study of material science has been at the foundation of many research programs. It has always concerned itself with controlling the structure of materials on the nanoscale and for many the advances that are being ascribed to nanotechnology could equally be regarded as incremental developments of existing technologies. However the use of nanoscience and technology will largely facilitate incremental advances on existing materials and technologies. The improved control over nanoscale structure and the better understanding of relationships between structure and properties will be of important use in the developing needs for materials that are stronger and tougher for their weight or have enhanced functionality. Other specific areas in which nanoscience and nanotechnology are contributing to material science include:

- New forms of carbon
- Nanocomposites
- Quantum dots and wires
- Nanostructured materials produced by self-assembly

ELECTRONICS

Most consumer electronics are already approaching the nanoscale. Improvements in the technology for making integrated circuits for central processing units and memory chips will continue and will incorporate the outputs of nanotechnology to achieve incremental enhancement. Areas of particular interest include:

- Semiconductor optoelectronics
- Photonics
- Memory and data storage
- New methods for data input and output
- Plastic electronics
- Molecular electronics

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BIOMEDICAL SCIENCE

Biomedical science has captured the greatest public attention and combines the very incremental with the highly futuristic. Particular areas include:

- Drug delivery
- Tissue engineering
- The laboratory-on-a-chip i.e. sensor systems

Some of the sharpest ethical and social dilemmas arising from nanoscale science and technology will have their origins in the success in this area.

Water droplets rest on a wood surface impregnated with a nanoparticular surface coating, making the surface extremely water-repellent (superhydrophobic). The coating also decreases the forces of adhesion, making the water droplets assume a globular form. Photo courtesy BASF.

FINDING COMMERCIAL APPLICATIONS

Although a significant amount of research has been undertaken in the last twenty years primarily in the academic world, the numbers of commercial realizations of nanotechnology are still few in number. The challenge of finding and recognizing commercial applications of research is one of the biggest problems to progress in nanotechnology. Some transfer from laboratory to market has already taken place. But for the majority of nano-enabled products currently on the market are tools for scientists to apply to nanotechnology research.

The current market is small and concentrated mainly in niche areas, but is growing rapidly. It has been estimated to be a $385 million per year business in the U.S. and one that is likely to reach $3.5 billion by 2008 and $20 billion by 2013.

Small companies have been at the forefront of research and development. Some of these firms, particularly those involved with nanomaterials, have formed marketing and development alliances with large global chemical and plastic suppliers. Much of the potential for the translation of nanoscience into useful and viable products is likely to be realized within the next twenty years. Applications include:

- Tools as enablers for R&D
- New and improved materials
- Electronics and IT
- Health and medicine
- Cosmetics
- Food technology
- Military, security and space applications
- Environmentally related

A frequently used method of nanoanalysis is atomic force microscopy (AFM), by which the surface of a sample can be analyzed with nanoscale resolution. Photo courtesy BASF.

There are technical barriers to commercialism, the principal ones being the development of techniques for mass production and reducing the cost of nanomaterials.

ADVANCED PHYSICAL PROPERTIES

Although many of the potential applications of nanotechnology are some way off from being commercial reality, there are areas of early adoption where nanotechnology is instrumental in the development of commercially available products. The materials and composite market has been shown to be one such area.

Smart paints, pigments and coatings were considered the fastest adopter of nanotechnology and the most promising commercial area over the next five years. Such projections have an important bearing on the packaging, paper and printing industries, which have the potential of being good receptors for such advances in materials and composites.

In packaging, the development of nanocomposites is gaining momentum as the opportunities offered from such technology are identified and realized. Already the present generation of nanocomposite materials has shown enhanced product performance characteristics, with examples such as thermal stability, significantly increased mechanical strength and improved barrier properties. The barrier applications of nanocomposites have already been identified as an area that shows promise and application. Presently, nylon films have been commercialized with improved gas barrier properties by nano scale additives.

The property advantages that nanomaterial additives can provide in comparison to both their conventional filler counterparts and base polymer include:

- Mechanical properties
- Decreased permeability
- Thermal stability
- Flame retardancy
- Chemical resistance
- Surface appearance
- Electrical conductivity
- Optical clarity

The few disadvantages associated with nanoparticle incorporation involve toughness and impact performance. Nanocomposite applications in packaging include:

- Gas barriers
- Oxygen barriers
- Food packaging
- Films

Such developments, although primarily directed at plastics and film based packaging, give the paper packaging sector the opportunity to compete more effectively with competitive materials. Such opportunities are being explored in a large EU (European Union) funded project called "Sustainpack." (see www.sustainpack.com for further details).

[nanotechnology] will affect directly or indirectly so many sectors that failure to respond to the challenge will threaten the future competitiveness of many organizations and companies.

Nanotechnology has also been applied in the development of nano barcodes that are made by electroplating inert metals, such as gold, silver and platinum, into templates that define the particle diameter. The resulting striped nanoparticles are released from the templates. The width and sequence of the stripes can be altered and varied to produce different nano barcodes. Such barcodes are a cheaper alternative to RFID tags.

IMPLICATIONS FOR THE PAPER INDUSTRY

The implications of nanotechnology for the pulp and paper industry are wide ranging and could impinge upon everything from fibers, fillers, wet end chemistry, fabrics, coatings, roll cover materials through to sensors and process control systems.

The potential of nanotechnology to the paper industry is only limited by researchers' innovative capability. The recent TAPPI Conference (Atlanta, April 2006) on "Nanotechnology for the Forest Products Industry" showcased a number of examples of developing research activity directed at the paper industry. One can envisage roll cover materials that can change properties while running; pigments that create new image effects; paper and board products with new combinations of mechanical properties; and the evolution of new grades that will increasingly develop as a result of understanding paper at the nanoparticle level.

There are a number of examples of research already underway. These include:

- Nanostructuring of the cell wall for better paper properties
- Use of nanotechnology in filler-in-fiber engineering and paper coating
- Applications of nanotechnology in purification of process waters
- Paper coatings—binder modification and the engineering of filler surfaces

PRINTING

In printing, recent developments in nanotechnology are beginning to offer novel opportunities and are increasingly being considered by ink manufacturers and customers, to enable inks to be developed with superior performance properties. It is also being used to develop competing systems to conventional printing. For example a nanomaterial electronic display system has been developed for use as an information display in railway stations. Application of this technology can be envisioned for a wide variety of areas.

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These include smart windows, variable density filters and transparent or paper-quality displays. Paper-quality displays are a particularly attractive area as the technology is scaleable from small devices to very large areas.

The wide reaching potential offered by nanotechnology has excited many in the scientific and technical arena. It has created an aura of concern and even fear in others. As to the reality of the situation, many believe that the actual position is somewhere in between these two extremes. Current applications are predominantly limited to advances in well-established areas of applied science, such as material science and colloidal technology. Medium term applications are likely to focus on overcoming barriers to technological progress and practical application, while the longer term applications are the most difficult to predict and tend therefore to be the focus of most concerns.

The threats perceived or otherwise of nanotechnology need to be addressed effectively. The danger is that if such concerns are not answered, there could be a growing momentum to bring in a moratorium on some nano-based research. Such moves could set back all research through a loss in positive momentum and waste of opportunities to develop useful technologies.

CONCLUDING REMARKS

Some of the underlying principles of nanotechnology have been practiced in some areas e.g. surface modification of paint pigments and in aspects of drug design, for a number of years. Not labeled as nanotechnology, the science and technological developments progressed successfully, but without the attention it would currently receive. Now nanotechnology has become a topic of widespread discussion among academics, in the media, among the investment community, and some sectors of industry. Although the subject has been carried forward with a fair degree of "hype," there is no doubt that aspects of nanotechnology are making a much wider impact of various industries and products. Indeed, it has been argued that nanotechnology is set to disrupt the face of much of industry.

Nanotechnology is about new ways of making things. It promises more for less: smaller, cheaper, lighter and faster devices with greater functionality, using less raw material and consuming less energy.

Few industries will escape the influence of nanotechnology. Faster computers, biocompatible materials, surface coatings, catalysts, sensors, telecommunications, magnetic materials and devices are just some examples of where nanotechnology has been embraced. Many of these and aspects of ongoing research have a bearing on the paper, packaging and printing industries; either as a route to improvements in process or product performance, or as a route to the development of competitive products.

In effect, nanotechnology is a radically new approach to manufacturing. It will affect directly or indirectly so many sectors that failure to respond to the challenge will threaten the future competitiveness of many organizations and companies.

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