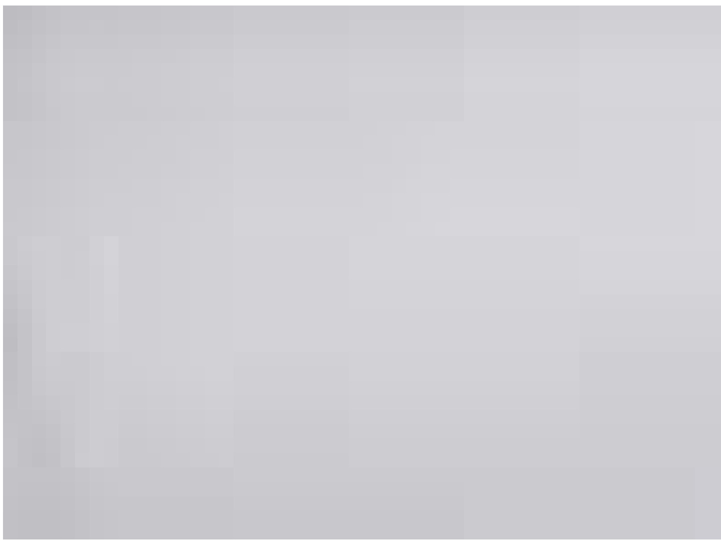
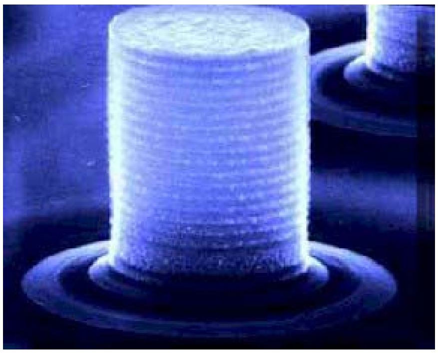
Nanotechnology

at the

University of Sheffield





Nanotechnology will revolutionise the material world…

Nanotechnology investigates structures and materials on the nanoscale, manipulating atoms and molecules in order to create new and *intelligent* materials. Applications being investigated include smart skin for aircraft, skin grafts and artificial muscles, new lasers and display devices, and sensors; nanotechnology promises to overcome the physical limits that threaten to stop computers getting faster. But nanotechnology is not one science in itself; instead it is multidisciplinary, covering areas from Physics and Chemistry, though Electronics, to Engineering and Medicine.

Sheffield's multidisciplinary research culture is ideally suited to this exciting new subject. The University is home to a number of national facilities and initiatives, and it is also committed to working within the region with our partner Universities in Leeds and York.

Sheffield has **outstanding facilities for nanotechnology** and is investing heavily in **new facilities for the future:**

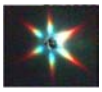
- EPSRC National Centre for III-V Technologies
- Nanofabrication suite include focused ion beam and electron beam lithography
- New Interdisciplinary Research Building for Nanotechnology and Tissue Engineering
- EPSRC/RSC Chair in Nanoscale Analytical Chemistry
- Outstanding nanoscale analysis and characterisation equipment, including Interdisciplinary Nanoscale Characterisation Facility (AFM, SNOM, UHV-STM, SAXS, laser confocal microscopy) and EPSRC FEGSTEM facility.

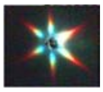
Sheffield's emphasis on **research led teaching** will ensure that the region will have access to the trained manpower needed for the new technology based industries. Our **MSc Course in Nanoscale Science and Technology**, run jointly with the University of Leeds, was one of the first such courses in the world.

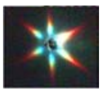
contents

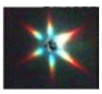
Nanotechnology by industrial sector

Nanotechnology's diverse collection of disciplines and areas of research mean there are specialist applications for many different sectors. The following pages are organised by subject area, but below is an index which puts the themes into an industrial context:





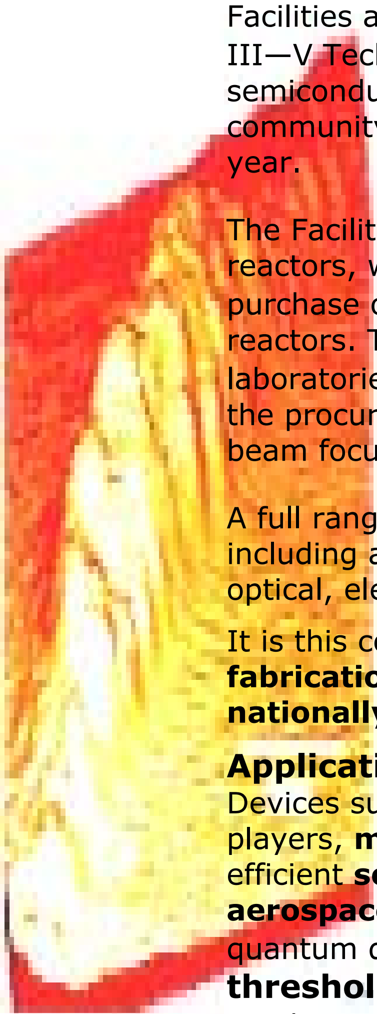




Semiconductor Nanotechnology

Explanation

Semiconductor nanotechnology uses near atomic-scale control of the size and composition of semiconductor structures to produce new optical, electronic, and optoelectronic device functions. The Sheffield has leading fabrication facilities and **world class** materials characterisation. Extensive research programmes into the science and technology of III-V semiconductors are also undertaken.



Investigation

Facilities available include the EPSRC National Centre for III—V Technologies, the **leading provider** of semiconductor nanostructures for the UK university community, supplying up to 600 advanced structures per year.

The Facility's growth capabilities are based around five reactors, which will soon be further enhanced by the purchase of new **state-of-the-art** MOVPE and MBE reactors. The Facility also possesses very well equipped laboratories for **device fabrication**, recently boosted by the procurement of electron beam lithography and dual beam focussed ion beam instruments.

A full range of techniques for characterisation are available, including atomic-resolution analytical FEG-TEM, AFM and optical, electrical and x-ray based techniques.

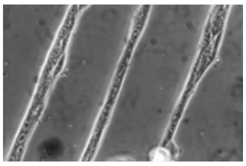
It is this combination of **advanced crystal growth**, **device fabrication** and **characterisation** that gives Sheffield its **nationally leading** status in the field.

Application

Devices such as **blue lasers** for next generation DVD players, **mid-IR lasers** for pollution monitoring, highly efficient **solar cells** and high temperature electronics for **aerospace applications** are made and tested. 10nm size quantum dots form the basis of such devices as **very low threshold lasers**, single photon emitters for quantum cryptography applications and as the basis for solid state implementations of **quantum information processing**.

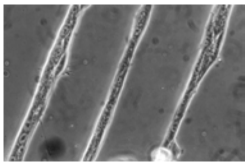
Nanosizing Chemistry

Explanation



Recent advances in nanotechnology have opened up **new vistas** in chemistry and biology, and current research is seeking to explore the exciting opportunities that exist. Focusing on both the characterisation and manipulation of nanoscale chemical structure, behaviour, and properties, important analytical methods and tools are being developed. In areas such as microfluidics, this has led to the design and engineering of structures that will give a mechanical deformation in response to an electrical stimulus, and nanoscale catalysts are also being developed for use in these structures.

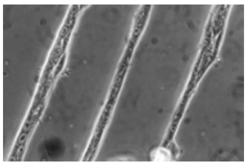
Investigation



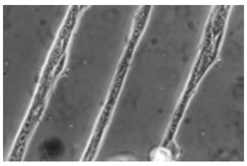
Novel tools like scanning probe microscopy promise to revolutionise the investigation of chemical interactions on the nanoscale. More techniques of analysis, such as atomic force microscopy, provide remarkable images of surfaces and have inspired the development of further **innovative systems** to measure adhesive, frictional, and other phenomena in a quantitative way. The resulting insights are of potential value to a broad spectrum of applications, from personal care products through to packaging and **tissue engineering**.

The manipulation of chemical structure on small length scales is an area of growing interest and importance. By miniaturising analytical systems, for instance lab-on-a-chip technology, processes occurring in small quantities of materials are able to be controlled and monitored, important to many areas including the study of drug metabolism in single cells.

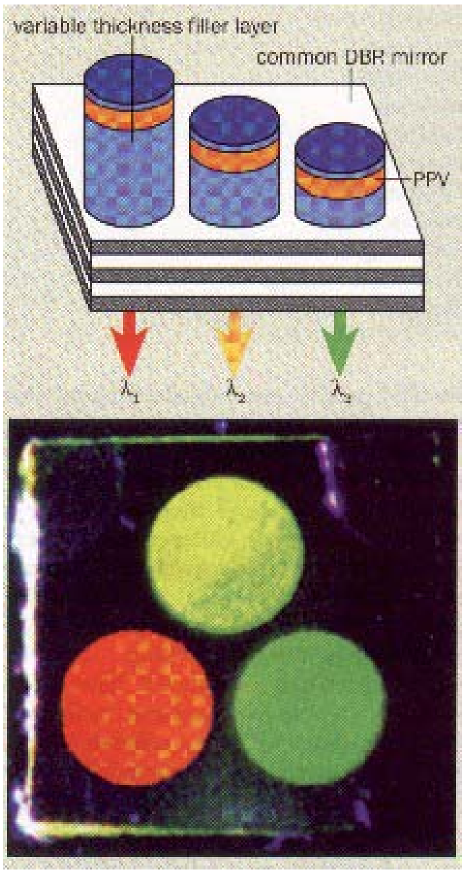
Application



Nanoscale chemistry is of critical importance to many industrial sectors. The printing and packaging industries, the automotive industry, and **aerospace engineering**, among others, will all benefit tremendously from the development of adhesion techniques and **smart lubrication systems**. Microfluidics can be applied in the manufacture of micro pumps and valves, leading to the fabrication of **artificial muscles**, whilst new nanoscale catalysts will lead to more environmentally clean processes that **minimise chemical consumption** and waste production.



Soft Nanotechnology

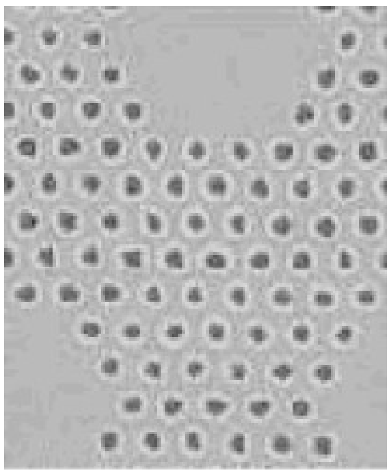


Functional nanodevices that have to work in water encounter challenging environments which require a new set of design principles similar to those used in cell biology. By realising these using **synthetic materials** it is possible to develop a soft nanotechnology.

Block copolymers are the most important class of synthetic systems for creating self-assembled nanostructures. Molecules whose architecture can be controlled to create nanostructures to order, either in an undiluted melt or in aqueous solution, can be synthesised. The size of the resulting structures can be predicted and controlled from nanometer sizes up to length-scales comparable to the wavelength of light. These large structures have interesting **photonic properties**, controlling the propagation of light making them highly suitable for self-assembled optoelectronic devices.

Also in development are materials that respond to their environment by changing conformation, for instance a **thermoresponsive gel** that collapses on heating. Different techniques at varying molecular levels can analyse these changes and investigate their potential.

By putting these ingredients together into a whole system, demonstrator nanoscale devices can be made. Active membranes, pumps and **synthetic molecular motors** are being developed, coupling macromolecular conformational changes with cyclic chemical reactions. This converts **chemical energy** directly into **mechanical work**. This technology could transform **drug delivery** and many other areas that rely on the precise delivery of molecules to their targets.



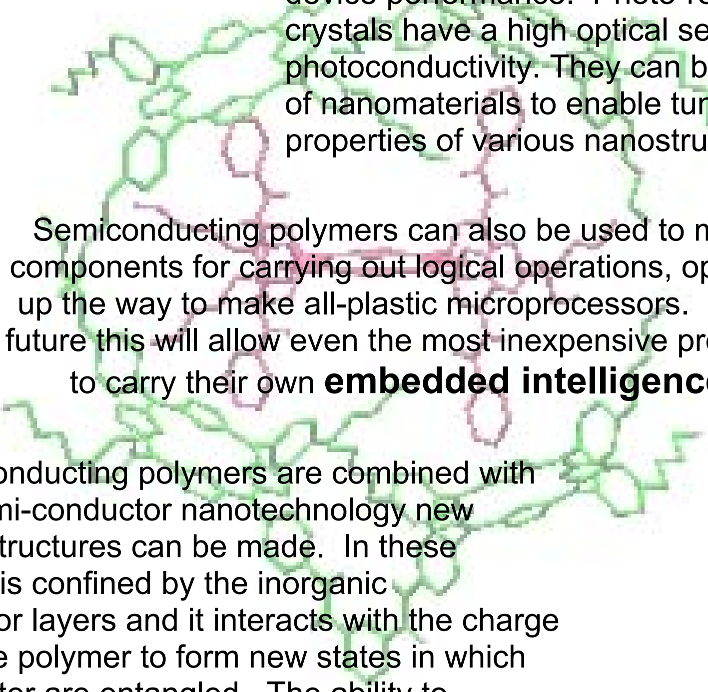
Molecular Electronics

The discovery of **polymers which conduct electricity** means that plastic semiconductor devices will soon be commercialised, and relevant to many different applications.

The first new applications will exploit the advantages of polymers: they are cheap and easy to process, are flexible, and have the ability to cover large areas.

In the future we will use our knowledge of how to manipulate individual polymer molecules and how to control their self-assembly into complex nanostructures to create **entirely new** semiconductor devices in which the basic components are single molecules.

Light emitting diodes and photovoltaics made from semiconducting polymers offer the promise of **display devices** and **solar cells** that cover larger areas cheaply. The nanoscopic structure of these devices can be controlled by self-assembly, leading to improvements in device performance. Photo-refractive liquid crystals have a high optical sensitivity and photoconductivity. They can be put into a variety of nanomaterials to enable tuning of photonic properties of various nanostructures.



Semiconducting polymers can also be used to make components for carrying out logical operations, opening up the way to make all-plastic microprocessors. In the future this will allow even the most inexpensive products to carry their own **embedded intelligence**.

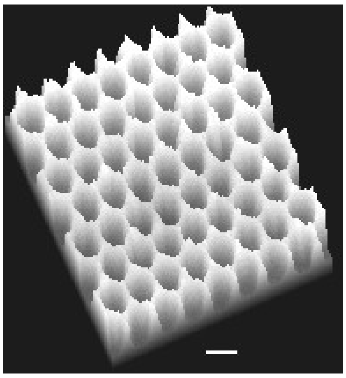
When semiconducting polymers are combined with inorganic semi-conductor nanotechnology new hybrid nanostructures can be made. In these devices light is confined by the inorganic semiconductor layers and it interacts with the charge carriers in the polymer to form new states in which light and matter are entangled. The ability to engineer cell surfaces of liquid crystals means that functions such as switching and filtering can be performed on light. Understanding the fascinating physics of these states may ultimately lead to **new lasers** and affordable high-performance optoelectronic components.

Nanomagnetism & Nanostructured Materials

Explanation

Nanomagnetic materials have been under development for over ten years, by experimentation of their elemental compositions.

The latest permanent magnet materials are composed of rare earth elements with a nanoscale grain size. This results in a competition between various magnetic interactions which leads to the **most powerful magnets** yet developed.

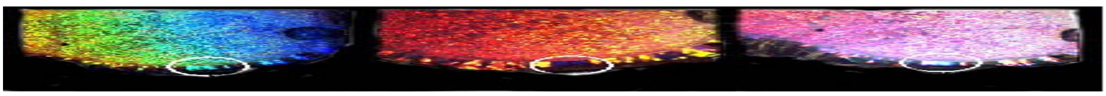


Keeping the nanostructure, but changing the elemental composition results in record soft magnetic materials. The advent of thin film technology has also furthered studies of magnetic materials in the form of multilayer stacks, ideal for read heads. Work in all fields of nanomagnetism continues to **stretch scientific boundaries**.

Investigation

Many years of extensive research has gone into areas such as nanostructured permanent and soft magnetic materials, supported by various magnetic characterisation facilities. Combined they offer **alloy development**, full magnetic and nanostructural characterisation, and proof-of-principle work for applications.

Thin film research incorporates extensive growth facilities, as well as highly developed characterisation facilities. Work is in progress on varying types of thin films for MEMS applications and **spin-valve components**, and projects are planned on self-assembled systems.

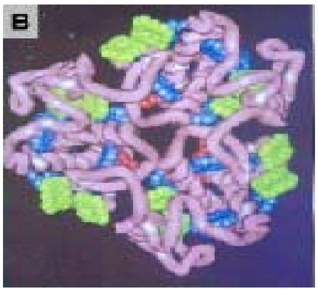


Application

The nanostructured permanent magnets are already seeing use in high efficiency low weight motors, which could enhance the development of the **all electric aircraft**.

The equivalent soft materials can produce sensors, such as switched mode power supplies. New read head technologies already use thin film magnets and nanoparticles, and the future is very exciting for bio-medical and MEMS activities.

Tissue Engineering



Explanation

An especially exiting area for health and medical industries, tissue engineering encompasses several areas of human tissue and cell regeneration. The overall aim is to design new materials to overcome the problems encountered with prosthetic and transplant surgeries.

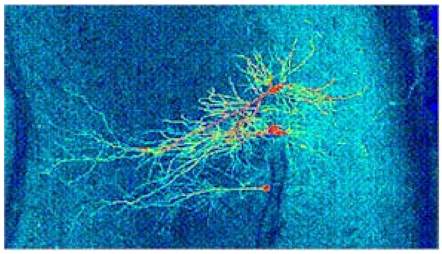
Investigation

Research concentrates on four overlapping areas. **Prosthetics** involves artificial replacements for a variety of natural tissues damaged or lost through injury or disease. This requires a deep understanding of **cell development and control**, from biopsy design (to obtain the correct cells), through keeping these cells alive, to controlling their behaviour in vivo and in vitro.

Tissue engineering concentrates on three target areas – skin, cartilage and tendon. Successful clinical trials of autologous skin cells with natural matrices or on flexible plastic supports have been carried out on patients suffering from **burns injuries** and chronic non-healing ulcers. Virtual tissues and prosthetics enable scientists to evaluate new **implants** before they are introduced into the patient, using three-dimensional models that accurately reflect the behaviour of living tissue. These many fields of research are likely to produce some significant applications.

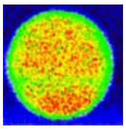
Application

New **high strength bioceramic materials** are being developed for both dental and bone repair work. In the field of prosthetics, human hypertrophic cartilage has been successfully produced and used as a natural scaffold, helping to heal broken bones, and this will begin clinical trials in 2003. Skin tissue applications, from an 'improved sticking plaster' to **complete thickness skin grafts** and three-dimensional synthetic scaffolds, are being investigated, and the virtual simulations expect to dramatically improve designs for heart valves and stents to open up collapsed arteries.

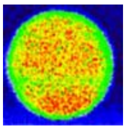


Nanoscale Science & Technology Masters Training Package

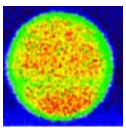
The Masters Training Package (MTP) in Nanoscale Science and Technology is run jointly by the Universities of Leeds and Sheffield. The Package provides a highly interdisciplinary learning experience to enable single-discipline graduates to contribute effectively to the research, development and commercial exploitation of nanotechnology. The central feature of the MTP is a 1 year, full time, postgraduate Masters (MSc) programme in Nanoscale Science and Technology; however, the Package also caters for a wide range of training requirements by provision of part-time MSc study options, the Postgraduate Certificate and Postgraduate Diploma qualifications, 1-2 week short courses and 1-day nanotechnology workshops.



Full-Time MSc 8 modules over 2 semesters, covering a broad range of nanotechnology subjects. There is also a major project that runs throughout both semesters, normally based in one of the many nanoscience / technology-related research groups at Leeds or Sheffield



Short Courses
Preparation and fabrication of nanostructures (1 week)
Characterisation of nanostructures (1 week)
Processing and properties of inorganic nanomaterials (2 weeks)



One Day Workshops The Nanoscale Science and Technology package includes an on-going workshop programme. Recent workshops include: *"Engineering New Futures – Nanoscale Science and Technology"* (9th April 2001), and "*Enterprise in Nanotechnology"* (20-21st May 2002 and 14-15th April 2003).

The Nanoscale Science and Technology MTP is delivered by academic departments spanning the Physics, Chemistry, Biology, Electronic Engineering and Materials disciplines, thus providing a uniquely interdisciplinary programme with optimum coverage of the relevant subject areas. The programme is administered from the Centre for Self Organising Molecular Systems, an interdisciplinary research centre at the University of Leeds.

More information can be found at
www.ee.leeds.ac.uk/nanomsc

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