MAKING IT IN MINIATURE

- *Is nanotechnology an important generic technology?*
- *What is its future in the UK?*

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REPORT SUMMARY
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This is a summary of a 44-page report available from the PARLIAMENTARY OFFICE OF SCIENCE AND TECHNOLOGY (extension 2840).

Over the last 3 years, the Government's technology foresight programme has sought to identify opportunities in markets likely to emerge during the next 10-20 years, and its results now inform funding decisions for much of the UK's science and engineering base. However technology moves fast, and such exercises must remain alert to the latest developments - especially where these affect many areas of science and technology. One such 'generic technology' may be nanotechnology, or the technology of the very small, where a human hair would appear as large as a building in a 'nanoscale' world.

To assist Parliamentarians to gauge the potential of this complex field, POST reviewed the science, applications and policy issues involved. This note summarises the full report[1].

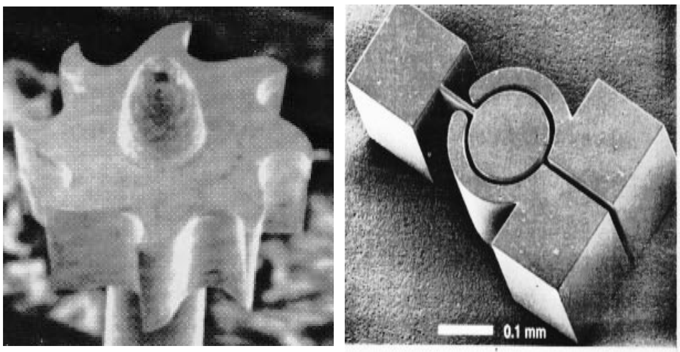
BACKGROUND

The trend to miniaturisation in manufacturing industry is well known - e.g. in microelectronics and computing. Less well known is the extent to which research into 'small scale' technologies and phenomena affects many other areas. Thus the development of new surgical techniques, lighter and stronger materials, fibre optic telecommunications networks and many other applications have led to a need for increasing precision at scales of less than one millionth of a metre. 'Nanotechnology' has been coined as an umbrella term for this inter-disciplinary science and technology[2].

Where does nanotechnology find its main applications? Two inter-linked trends are involved here - the drive towards **miniaturisation** and that towards **precision finishing**. The full report looks at a wide range of current and potential uses in the fields of information technology, electronics and computing (ITEC), biology and medicine, chemical engineering and precision manufacturing.

For instance, since 1950, **machine-tooled tolerances** have been reduced by an order of magnitude, and from 100nm to 1nm for surface smoothness. Such 'ultra precision' machining has had direct applications across

Figure 1 A MICRO-ROTOR AND ACCELERATION SENSOR



manufacturing industry - e.g. in improving car engine performance and aero engine turbine blades, and is replacing 'traditional' methods of obtaining high quality finishes in the manufacture of camera lenses, telescope mirrors, computer hard discs, etc.

The manufacture of **semiconductor devices**, mostly using lithographic techniques, is also pushing into the nanotechnology regime. The number of individual electronic components on a microprocessor has increased from 20,000 transistors in 1980, to 125 **million** on the latest silicon 'chips', with concomitant increases in computing power and memory. The smallest electronic structures, for instance the transistor 'gates' in domestic satellite television receivers, which are less than 100nm across, are currently manufactured using **electron beam milling**. Thin films are also important in the electronics industry, with techniques such as **molecular beam epitaxy** used to build up layers of semiconductor for integrated circuits, magnetic materials for disc drives, etc., as well as for **environmental sensors**.

Closely related to the field of nanotechnology is **microsystems technology**, where nanoscale components such as sensors and microprocessors are integrated with power supplies, 'actuators' (such as micromotors), etc., in useful, miniature devices - for example, the miniature cogs and gears in **Figure 1**. Existing applications range from accelerometers for air bag sensors in the automative industry (also in Figure 1) to the 'lab-on-a-chip' in process engineering and microsurgical instruments in the medical field.

In order to observe and to measure processes and devices at the nanometre scale, the science of **nanometrology** has developed a range of instruments

1. The full report : "Making it in Miniature - Nanotechnology, UK Science and its applications" (44pp) from POST, 7, Millbank, London SW1P 3JA.
2. Formally, one nanometre (nm) is a billionth of a metre, but 'nanotechnology' is normally taken to be the range from 1 to 100nm.

and techniques. Instruments accurate to less than 0.1nm are required, and established methods such as electron microscopy, laser position measurement and X-ray diffraction are being supplemented with techniques such as atomic force microscopy. These techniques also introduce the possibility of **nano-manipulation and nano-positioning** - moving and placing objects on the atomic scale.

INTERNATIONAL ACTIVITY

The full report describes the major national and international programmes in nanotechnology. In the **USA**, the main national sources of funding are the Advanced Research Projects Agency (ARPA - $40Mp.a.), the National Science Foundation (NSF - $5Mp.a.) and the National Institute of Standards and Technology (NIST - $5Mp.a.). There is also support for defence research, specialised projects such as the Advanced Lithography Project and funding at the State level. Centres of excellence have also been established with purpose-built laboratories at, for example, the University of North Carolina and the Massachusetts Institute of Technology. In the field of nanofabrication, the NSF has established the National Nanofabrication Users Network, a partnership of user facilities available to academia and industry. Particular promise is seen in the areas of:

- the automobile industry, including traffic monitoring and regulation;
- process instrumentation (for the food, energy and chemical processing industries);
- medical devices;
- aviation and consumer electronics.

The major industrial sectors using micro/nano-technology in **Japan** are also the automobile industry, process automation and medical devices. There is in addition, a special focus on telecommunications and on office automation, while mechanical engineering and 'domotics' ('home automation') also are areas of envisaged expansion. The current Japanese 'micro machine' market is about Y140B ($1.4B).

In 1992, the Agency of Industrial Sciences and Technology (AIST), launched a project entitled "Research and Development of Ultimate Manipulation of Atoms and Molecules", with a budget of Y25B over ten years. The Joint Research Centre for Atom Technology (JRCAT) has been established, which currently involves 26 Japanese and 4 foreign companies. There is also a Japanese Micromachine Initiative, with government funding of Y25B over ten years. Nearby, **South Korea** is investing heavily in its microelectronic and precision engineering capabilities, with companies such as Samsung mass producing flat panel displays; and **Taiwan** is now the main producer of 'merchant motherboards' for personal computers.

In **Europe**, Microsystems Technology and semiconductor-based research have been supported by a variety of European initiatives under the EU Framework Programmes[3], much of it aimed at the electronics and semiconductor industries. There is no formal 'nanotechnology' programme in the 4th Framework, but nanotechnology potentially has applications relevant to a number of the programme areas. For example, the Biotechnology Action Programme includes some nanotechnology-related research. There are at least 17 running BRITE/EURAM II projects on materials science which could be classed as 'nanotechnology'. In the Biomedical Technologies programme, nanotechnology is used in projects dealing with, for example, artificial limbs, nerves, hearing, sight, etc. The full report also describes a number of EU-funded 'networks' in micro and nanotechnology, to variously support research and development and promote European competitiveness.

As far as national activity in Europe is concerned, **German** institutions and industry are involved in relevant research and development in many key areas. In particular, there are 14 'Fraunhofer Institutes' related to nanotechnology, as well as many other university and industrial research and development facilities, and a national 100 MDMp.a. programme in Microsystems Technology which runs until 1999. **France** has an active 'Club Nanotechnologie' which has many industrial and academic members, and now one of France's seven interdisciplinary research programmes, Ultimatech, is aimed at developing advanced technologies and instrumentation for making nanoscale structures.

UK ACTIVITIES

The **National Initiative on Nanotechnology (NION)** was launched in 1986 by the National Physical Laboratory (NPL) in conjunction with the Department of Trade and Industry (DTI), to promote awareness of nanotechnology. NION had two main strands - a Nanotechnology Forum representing industrial, government and academic interest in nanotechnology, and the Nanotechnology Strategy Committee (NSC), to advise the Government on all aspects of nanotechnology. The Nanotechnology Forum provided the main route for the dissemination of information about nanotechnology in the UK, through regular conferences, direct mailing, a bi-annual newsletter and an Internet/World Wide Web based information exchange.

A **LINK Nanotechnology Programme (LNP)** was launched by the DTI in 1988, with an initial budget of £6M over four years, available to universities and public research institutions provided that matching funds could be found from the private sector. The Science and Engineering Research Council (SERC) joined the LNP in 1989 with a budget of £1.5M, and in 1990 the Defence

3. See recent POST Report on The European Union and Research.

Table 1 UK 'CENTRES OF EXCELLENCE'

Organisation	Principal Areas
Birmingham University	nanoparticles, surfaces
Cambridge University	microelectronics
CCLRC Daresbury	x-ray lithography
CCLRC Rutherford Appleton	masks, laser etching
Cranfield University	precision engineering
DERA	silicon fabrication
Glasgow University	nanoelectronics
Heriot Watt University	microsurgery
Imperial College	microsystems technology
Nottingham University	semiconductors, bio-physics, pharmaceuticals
NPL	nanometrology
Southampton University	silicon fabrication
Warwick University	precision engineering

TABLE 2 "TECHNOLOGICAL SUPREMACY" INTERNATIONAL COMPARISON

Rank	1	2	3	4
Ultra-thin films	JP	USA	D	UK
Nanocrystals	JP	D	USA	UK
Nanometrology	USA	D/F/UK	CH	JP
Ultra-precision engineering	USA	D	UK	
Lateral structuring	JP	USA	Sca	D

Key: D: Germany; JP: Japan; F: France; Sca: Scandinavia.

Research Agency contributed a further £0.26M to one LNP project. A mid-term review of LNP was completed in 1991, and DTI provided an additional £4.7M of funding to extend the programme until June 1994, as well as £0.5M to continue NION until March 1995.

The SERC support for LNP was part of a **Nanotechnology Managed Programme**. Since 1994, following the re-organisation of the research councils, this has been managed by the Materials Programme of the Engineering and Physical Sciences Research Council (EPSRC), and the last major round of projects to be funded (1995/96) are due for completion by 1999. The total SERC/EPSRC expenditure on the Managed Programme was £4.7M.

The National Initiative on Nanotechnology, LINK, and SERC / EPSRC Nanotechnology Managed Programme are all in their final stages, and closed to further applications. Nevertheless, the historical support for research in nanotechnology and related areas, as well as continuing industrial investment, has given the UK several 'centres of excellence' (see **Table 1**). The first UK centre with nanotechnology as part of its brief was established at Warwick University in 1980. Now there are about 1,000 companies, 30 universities and 7 research establishments active across a range of applications. These include medical, measurement instrumentation, environment, process control, manufacturing, military/ marine, automotive, aerospace, safety and security, information technology / communications, household goods and home automation. Many different technologies are used, with the main ones being surface mounting, fibre-optics, thin film technology, micro machining and micro assembly. The full report also describes UK networks and technology transfer activities in nanotechnology and micro-engineering.

FUTURE MARKETS

The full report reviews the many potential applications of nanotechnology which have yet to be realised commercially, ranging from future improvements to existing technologies (such as sensors and computer chips), to entirely new applications which can only be realised using nanotechnology. Predictions of future markets in this area range from 20BECU to over 100BECU by the year 2000. Specific examples include a micro-fabricated CFC-free nebuliser patented by a German company, which estimates a global market for this one product of £4B p.a. and car air bag sensors, where the goal is to replace the current technology, typically costing around £100, with a mass-produced sensor for about £3. As far as penetration into the ITEC market is concerned, nanotechnology has the potential to underpin a wide range of products, from microprocessors to disc drives, display devices and printers, etc. Other key potential applications in economic terms include tools for minimally invasive surgery, sensors for the environmental and automotive industries, and diagnostic and analytical tools for medical and chemical applications.

Such predictions lead some observers to see nanotechnology as a form of 'technological revolution', having significant economic and 'quality of life' impacts which are difficult to evaluate but potentially far-reaching and fundamental. Nanotechnology, they argue, will be a 'keystone' for economic and technological competitiveness into the Twenty First Century. Others see it as merely one of many tools which are assisting the continual process of commercial innovation to take place throughout whole areas of industry.

ISSUES

The main issue addressed in the full report is **whether the UK is keeping pace**. One international 'league table' of *"technological supremacy"* prepared for the German Ministry of Research and Technology (see **Table 2**) shows Japan and the USA in a clear lead, with the UK lagging behind Germany in Europe.

Analogous rankings have not been carried out in the UK. The UK Technology Foresight project included an assessment of UK strengths in each area, but nanotechnology was not dealt with in much detail. Indeed, given the wide range of applications described in this report, and that nanotechnology is attracting increasing interest at European level, the foresight process was remarkable for its lack of mention of the subject, which may be a consequence of the applications-based structure of the programme (agriculture, communications, etc.) having made it weak at identifying 'generic' technologies. In contrast, more recent exercises in the USA focused directly on identifying 'critical technologies' and concluded that nanotechnology is clearly one of those 'generic technologies' underpinning a wide range of technologies and markets, including several key areas identified in Foresight (e.g. sensors, process engineering, etc.).

The full report also considered current trends in **research support and policy**. Here, despite a slow start, the LINK/ Nanotechnology managed programme has been hailed as a success. It supported 28 projects involving over 30 universities and public sector research laboratories and over 50 industrial partners. In 1993/94, PA Cambridge Economic Consultants Ltd. produced an evaluation of LINK and NION for DTI which revealed high confidence in the technical success of the industrial LINK projects. Without LINK, nearly one third of participants report that the probability of success would have been low, and 40% that they would not have been successful at all. This evaluation is essentially an interim report which does not provide a complete picture of the LNP, nor any follow-up to gauge to what extent the projects are leading to commercial products. At this stage, **DTI has no plans for such a 'final evaluation'**.

With the LINK / Nanotechnology programme drawing to a close, the question arises whether the momentum built up on the industrial side by these historical initiatives, is sufficient to allow nanotechnology applications to develop without further government support, or whether the reduction in support will lead to its full potential not being realised. **This question is difficult to answer in the absence of a more detailed review of industry's plans 'post-LINK and NION'.**

Current research priorities, including new DTI funding initiatives such as the Foresight Challenge grants, centre on the recommendations of the 1995 Technology Foresight Programme. As discussed above, with foresight-derived priorities being so important for Foresight Challenge awards, Realising Our Potential awards and the objectives of Research Council programmes, the omission of nanotechnology means that scientists face an uphill struggle for funding. Yet at the same time, advocates point to both the European Commission and European Parliament evaluating nanotechnology's strategic importance, the European Science Foundation recommending that nanotechnology be included as a priority research area in the Fifth European Framework Programme, as well as nanotechnology's appearance as a 'critical' technology in other countries' lists. **There is thus concern that Technology Foresight has missed out an important generic technology and that nanotechnology should be recognised as a research priority.** The full report describes recent cases where some Foresight Challenge proposals involving nanotechnology have been unsuccessful.

Options to strengthen the UK's position in nanotechnology are explored in the full report and include:

- Technology Foresight could re-evaluate the importance of nanotechnology for industrial competitiveness.
- Because of the interdisciplinary nature of the research, another option is to find ways of encouraging and disseminating the results of interdisciplinary research.
- A tangible focus for nanotechnology research could be provided. For instance, this could be in the form of a new, national nanotechnology programme with mainstream funding which, unlike the previous programme, would overarch all of the relevant Research Councils.

At present, the only new DTI initiative is to support a coordinator for 9 months to provide a focus for UK involvement in EU programmes in relevant technologies. **Other options would be to evaluate the case for a successor to the 'LINK' programme and a resurrection of the Nanotechnology Forum**, and other measures to raise awareness in industry of the potential benefits and available UK expertise in nanotechnology. In this, there may be parallels with satellite Earth Observation, in which the DTI has recently launched a 'technology showcase' to familiarise potential users with this new technology and its applications.

Overall, the full report concludes that, with the expiry of the main programmes of support from DTI, the earlier momentum generated is now in danger of being lost. With the UK now at a critical point in deciding national policy on nanotechnology, advocates compare the present situation to the strong position the UK enjoyed in the microelectronics industry in the 1970s, and are concerned that without strong leadership, the UK may also lose ground in this new field. It is hoped, therefore, that this POST report will assist Parliamentarians to understand this complex field and gauge the potential for the future of nanotechnology in the UK.