Nanotechnology and Microengineering
Report of the seventh Foresight Seminar
24 February 1999

Introduction
The aim of the Royal Society of Edinburgh's (RSE) Foresight Seminar series, which focuses on sectors or emerging technologies of significant economic importance to Scotland, is to improve interactions between the science base, small and medium sized enterprises (SME), and larger companies. The long-term goal is to encourage greater R&D investment in businesses located in Scotland to the benefit of the local economy. This investment could be: support of appropriate research in universities and research institutes; integration of research within existing corporate functions in Scotland; or establishment of stand-alone research, development or design centres. The seminars, supported by Scottish Enterprise (SE), the Scottish Higher Education Funding Council (SHEFC) and RSE, were inspired by the national Foresight programme, and by the "Commercialising the Science Base" enquiry, both of which aim to enhance wealth creation through targeted R&D investment.

The Seminar
This seventh Foresight seminar addressed nanotechnology and micromachines. It was held at the RSE on February 24, 1999, and attended by an invited audience of senior representatives from industry, academia and government. An attendance list is attached.

The meeting agenda was as follows:

- Chairman's introduction, Professor Robert Donovan.
- Keynote presentations by Professor Geoff Beardmore on 'Micromachining – Disruptive Technology for the next Millenium', and by Professor Steve Beaumont on 'Nanotechnology Research in Scotland'.
- Presentation on 'Nanotechnology and Foresight', by Ottilia Saxl
- Dinner discussion on topics related to the nanotechnology and micromachining.
- Plenary discussion on presentations and topics raised during the dinner discussions.

Professor Donovan, Vice-President RSE and Professor of Chemistry, University of Edinburgh, described the background to, and rationale for, the Foresight seminars and briefly described the potential importance of nanotechnology and micromachining. He pointed out that these disciplines were not explicitly covered by the first Foresight phase and emphasised that Foresight II afforded the opportunity to redress this.

Professor Beardmore, Microengineering Manager, Smiths Industries Aerospace and Visiting Professor at Nottingham Trent gave an authoritative and panoramic overview of worldwide activity in the related disciplines of micromachines, microengineering, microelectronic mechanical systems (MEMS), and microsystems technology (MST). He outlined the relationship of these to nanotechnology. His talk covered definitions, history, techniques, examples of technology and products, global strategy, business opportunities, markets, and future trends. His numerous examples of microengineered devices drew on his own research and that of colleagues throughout the world.

The different approaches being taken by the global regions were summarised. The Japanese emphasise micromachines with a strong accent on robots. Much of their activity is funded by MITI. The US effort, with a focus on MEMS, receives significant funding from DARPA and NASA and has access to a body of venture capitalists who understand the technology and are prepared to take commercial risks. The European Union supports a major MST activity through programmes such as ESPRIT. UK microengineering researchers have lots of good ideas.

Professor Beardmore estimated that the worldwide market for microengineered devices is currently around $20 billion and that it is predicted to at least double by the year 2002. This is an enabling technology which results in product revenues in excess of five times the device revenue – i.e. $100 billion today. Major sectors impacted by the technologies include healthcare, automotive, aerospace and leisure.

The cost of a fabrication facility can be as high as $2 billion. It need not always be like this. It was pointed out that the devices on one (e.g. silicon) wafer can give a year’s supply of devices for particular applications. He floated the idea of a ‘desktop’ processing capability - referred to as the microfactory in Japan – which can be personalised and taken to the customer for on-site processing.

In the longer term the various micro-terms will coalesce and be referred to as simply ‘engineering’ – which will cover the assemblage of molecules and of structures such as the Forth Bridge. Professor Beardmore suggested that the consequences on manufacturing and global economies will be more profound than that of silicon microelectronics.

Professor Beaumont, Department of Electronic and Electrical Engineering, University of Glasgow and Director of the Institute of System Level Integration, gave a most interesting presentation which focused on nanotechnology with a particular emphasis on research within Scottish universities. He emphasised the relationship between nanotechnology and optoelectronics, biotechnology and electronics, each of which is regarded as being important to the future of the Scottish economy.
Professor Beaumont defined nanotechnology as an emerging field which gives control over material structures of nanoscale size 0.1nm to 100 nm in at least one dimension. He stressed that nanotechnology by this definition already exists and gave examples of one dimensional techniques which included the range of thin film processes, polishing, optical coatings, and epitaxial growth. These technologies fabricate nano-dimension films or prepare surfaces that are defect free at the nanometre level. To give an contemporary example, he announced the formation of CST Ltd, a collaboration between Strathclyde and Glasgow Universities, which will fabricate nanoscale structures for electro-optical applications.

Existing multi-dimensional nanotechnologies include: scanning probe technology which allows the manipulation of atoms; positioning technologies to nanometre dimensions; micromachining; polymer engineering; genetic engineering; DNA sequencing; and chemical synthesis.

Examples of nanotechnology research capability in Scottish universities included: micromachines for dialysis; the influence of surface structure (at the tens of nanometre level) on the biological behaviour of cells on plane surfaces; III–V semiconductor devices with 70 nanometre gate length for 300 GHz amplifiers; 60 nanometre resolution lithography using electron-beam dissociatable organometallic compounds; nanoscale patterned elements for very high density magnetic storage media; the MIAC characterisation laboratory in Edinburgh; and the electron beam lithography capability in Glasgow.

Professor Beaumont emphasised the importance of nanotechnology to Scotland and gave some examples in which we could play to our strengths. These included: biosensors; micro-analytical equipment; lasers; convergence with microelectronics; and on-chip wiring, especially as it relates to system level integration.

Scotland has a strong capability in micro-fabrication and this can be readily extended to nanotechnology. Nanotechnology is expensive and is inter-disciplinary. These features require collaboration among chemist, biologists, computer scientists, engineers and physicists.

Ottilia Saxl, Director of the Institute of Nanotechnology (IoT), outlined the activities of the Institute. Its stated objective is ‘to provide a focus for nanoscale activity in the UK in an international context’. The approach to achieve this is through organising seminars and conferences, preparing reports on strategic aspects of nanotechnology for government agencies, and by creating working groups. Two, on nanobiomedicine and generic technologies, are currently operational.

The point made by the meeting Chairman, that the first phase of Foresight did not adequately address nanotechnology, was emphasised. The IoT has the opportunity to begin to redress this through a report commissioned by OST on ‘Opportunities for Industry in the Application of Nanotechnology’. This report, together with the first edition on IoT’s ‘Nanotechnology Watch’, will be available shortly.

Feedback from pre-dinner questions and discussion

The points generated following the seminar and prior to the dinner discussion are summarised below:

Patents must be a very fertile field. We have access to fabrication facilities in Scotland but a chief obstacle could be lack of patent coverage and the existence of blocking patents that may limit our freedom of action.

Response: Scottish universities do have a number of nanotechnology-related patents, especially in bio-disciplines. Chemists have been manipulating atoms for decades. Automobile catalysts contain nanoscale platinum particles. Flory synthesised penicillin in the 1930s. Molecular sieves have structures with nanoscale pores.

Response: These are prepared by bulk synthetic methods. It is the combination of making and positioning which differentiates nanotechnology.

The Drexler idea of forming structures by putting single atoms together may fall foul of the Uncertainty Principle.

The range of possible applications for the technologies is impressive. However, what is the size of market for technology being developed in Scotland?

Response: By way of example, the AFM sensor from Kelvin Nanotechnology has the potential for revenue of several million pounds just on the sensors. Its not big but its a good start. The research community is not ignoring the economics. Exploitation is regarded as key. Some universities are looking at marketing their nanotechnology capability as a service.

Northern Ireland has, through inward investment, a very significant share of global revenue from technologies relating to magnetic storage devices. These are microengineered machines with some components manufactured using nanotechnology processes.

We should continue looking at substrates other than silicon. From a surface engineering viewpoint carbon or electroactive polymers are easier to handle.
Diamond has remarkable thermal, electrical and other physical properties. Diamond technology could transform the operation of existing devices.

Developing devices and technologies for aerospace is fraught. The market is small. It’s better to target healthcare where the volumes are large.

**Dinner discussion**

Meeting attendees were asked to identify initiatives that could be introduced to encourage the commercialisation of nanotechnology and microengineering in Scotland. The following is a summary of the feedback received during the plenary session:

While there was not unanimity about establishing a focal point for nanotechnology and microengineering in Scottish Enterprise (SE) the pervasive view was that it would be a good idea if one was established in addition to existing focal points and not submerged within existing ones.

However, there was essential unanimity that nanotechnology and microengineering are too broad to be considered as a discrete cluster within SE’s cluster strategy. Individual clusters should include relevant aspects within their existing strategy.

The overwhelming view was that SE should support RSE Enterprise Fellowships in nanotechnology and microengineering. It is a relatively inexpensive way of encouraging younger researchers to commercialise the output of their research.

The remit, structure and funding of the Institute of Nanotechnology should be examined in the light of its potential to provide a focal point for nanotechnology and microengineering in Scotland.

Locate in Scotland (LIS) should be encouraged to attract appropriately skilled people and organisations to establish research, development and manufacturing capabilities in nanotechnology and microengineering in Scotland. There are specific opportunities (e.g. magneto-optic storage) about which LIS should be informed. The academic community is keen to contribute by advising LIS on the technological potential of these emerging opportunities.

Nanotechnology and microengineering opportunities can only be exploited through much greater industry pull. A start can be made by giving researchers and developers access to obsolete semiconductor manufacturing equipment and facilities. This could be of great use to those developing microsensors, microsystems and micromachines.

Scotland must improve its understanding of the market opportunities which can evolve from its nanotechnology and microengineering research. High value added product areas (these could be, for example, sensors and communication devices) should be identified. We should aim for convergence between the research effort and these high value opportunities. The acid test is whether or not these opportunities would be funded by banks, venture capitalists, etc. A validated market evaluation would help.

**Inter- and multi-disciplinary research within and between universities must be encouraged. We must ensure that fragmented research and fragmented facilities does not impede progress. The possibility of establishing a national nanotechnology and microengineering facility should be examined.**

It is important that the quality of research in the science base is maintained. There is perhaps too much focus on spin-outs. Industry must take the lead. However, SMEs may have a long-term view on technology but by necessity have a short-term view on revenue. They are not necessarily best suited to take new ideas from universities forward. Large companies have the resources and entrepreneurs have the attitude.

On a more general point it was suggested that university WEB sites should be searchable and that universities should consider running evening courses on emerging technologies. This would make the information more accessible to those in employment e.g. in SMEs.

**Comment**

Nanotechnology, microengineering and related technologies should be regarded as evolutionary rather than revolutionary. They are the result of incremental research progress in many university and industrial laboratories throughout the world. This has resulted in the development of fabrication technologies down to the atomic level. These technologies will underpin many of the high value products of the next century.

Scotland has substantial research strengths in relevant disciplines. Because of the multi-disciplinary nature of the field it is difficult to put this capability in context of other regions and countries. However Scotland does have a substantial number of international-class researchers in the key chemistry, physics, bioscience, engineering, and computer science disciplines. What is not so clear is whether or not this effort is too fragmented. Proposals from this meeting aimed at encouraging convergence included support of inter-institutional research programmes and...
the establishment of a Scottish Nanotechnology facility. The latter would bring together the expertise and equipment necessary to take nanotechnology and microengineering forward on a co-ordinated basis. It was also proposed that a locus for industrial development be established within Scottish Enterprise.

At the conclusion of the plenary session Professor Beardmore suggested that we learn for the Japanese approach to their national micromachine project. Professor Beaumont was optimistic about the opportunity to gain access to obsolete fabrication facilities and suggested that market studies should be performed by Scottish Enterprise. He suggested that we learn more about generating wealth from academic research and learn how to sell it to others. These sentiments are well in tune with Foresight.

He also said that the academic sector was deficient in information about the marketplace and Scottish Enterprise could assist by sharing its market intelligence.

It is important that the many suggestions, made at this and other Foresight seminars, for improving the contribution that the Scottish Science Base can make to key sectors are critically examined and that potentially useful ones are taken forward by relevant organisations. The RSE and its partners will examine what should be done in order to achieve this.

Acknowledgements

The Royal Society of Edinburgh would like to thank Geoff Beardmore, Steve Beaumont, and Ottilia Saxl for their excellent presentations and for their enthusiastic participation in the stimulating discussions which followed these.

APPENDIX 1 – DINNER DISCUSSION TOPIC

Based on the premise that nanotechnology, microengineering and microsystems represent a major growth industry for which Scotland has strong science base strengths and an appropriate manufacturing skill base, what initiatives which can be introduced to encourage their commercialisation of in Scotland?

For Example:

- Establish a ‘nanotechnology etc.’ focal point in Scottish Enterprise – c.f. optoelectronics; semiconductors; biotechnology etc.
- Relate ‘nanotechnology etc.’ to the Scottish Enterprise Cluster strategy – the pilot clusters are semiconductors; oil and gas; food; biotechnology.
- Encourage Scottish Enterprise to support Enterprise Fellowships in ‘nanotechnology etc’. Currently there are fellowships in optoelectronics; biotechnology; digital media; oil and gas.
- Encourage / support the activities of the Institute of Nanotechnology.
- Identify potential inward investor companies with strong ‘nanotechnology etc’. capability and encourage Locate in Scotland to approach them. Aim for collateral R&D investment by inward investors.
- Can we take advantage of the presence of the large multinationals already located in Scotland who have world class strengths in ‘nanotechnology etc’?
- As semiconductor technology moves on to higher resolution structures would access to potentially obsolete fabrication facilities (process equipment, clean rooms etc.) be beneficial? This applies particularly for microengineering and microsystems. If so, how could we move forward?
- How can ‘nanotechnology etc.’ start-ups and spinouts be best encouraged? E.g. tax incentives, incubators, Faraday Centre, scouting to identify marketable technologies within universities, leverage IPRs (especially patents – do we have many?), etc.
- Commission a market study to relate potential market opportunities to Scottish strengths. Go for a niche product strategy?
- Encourage inter-university collaborations to address topics with strong commercialisation potential.
- And so on ……………………………… ………..