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SMART MATERIALS AND SYSTEMS

'Smart' materials and systems sense and respond to their environment and have applications in areas as diverse as health, defence and packaging. The UK has a long track record of research in this area and the government has launched a number of initiatives to encourage exploitation of this research. This POSTnote gives an overview of current research and potential applications. It also examines the factors driving smart materials research and those holding back their exploitation.

Background

The most commonly accepted definition is that smart materials and systems can sense and respond to the environment around them in a predictable and useful manner. For example, the 'photochromic' materials used in reactive spectacle lenses become darker in response to increased light. Smart materials arise from research in many different areas and there is a large overlap with nanotechnology. Some types of smart material are described in Box 1.

Smart *systems* also sense their environment and respond, but are not constructed from a single material. They may incorporate smart materials, but can also be constructed using traditional technology. Pacemakers are a smart system designed to respond to an irregular heart rate with an electrical impulse that regulates it.

The significance of smart materials and systems

Smart materials and systems open up new possibilities, such as clothes that can interact with a mobile phone or structures that can repair themselves. They also allow existing technology to be improved. Using a smart material instead of conventional mechanisms to sense and respond, can simplify devices, reducing weight and the chance of failure.

Box 1. Types of smart material

Smart materials sense changes in the environment around them and respond in a predictable manner. Some types of smart materials include:

Piezoelectric - Applying a mechanical stress to these materials generates an electric current. Piezoelectric microphones transform changes in pressure caused by sound waves into an electrical signal.
Shape memory - After deformation these materials can remember their original shape and return to it when heated. Applications include shape memory stents - tubes threaded into arteries that expand on heating to body temperature to allow increased blood flow.
Thermochromic - These materials change colour in response to changes in temperature. They have been used in bath plugs that change colour when the water is too hot.
Photochromic - These materials change colour in response to changes in light conditions. Uses include security inks and dolls that 'tan' in the sun.
Magnetorheological - These fluids become solid when placed in a magnetic field. They can be used to construct dampers that suppress vibrations. These can be fitted to buildings and bridges to suppress the damaging effects of, for example, high winds or earthquakes.

The commercial importance of smart materials is beginning to be recognised. In 2003, smart materials were the subject of a report produced by the Foresight Materials Panel - a government funded project that brings experts together to provide technological visions of the future.[1] It predicted that "the key to 21st century competitive advantage will be the development of products with increasing levels of functionality. Smart materials will play a critical role in this development". Some experts believe that adding functionality in this way offers the best opportunity for UK industry to compete with low priced imports.

Smart materials research is of long standing but commercial exploitation has been slow. The Foresight report concluded that "smart materials technology provides an excellent opportunity for the UK. However, despite significant progress over the last five years, supported by various government programmes, it [the UK] remains relatively poorly positioned worldwide".

Research in the UK

Smart materials and systems are interdisciplinary subject areas so funding does not come from a single research council. However, the majority of research council funding is allocated by the Engineering and Physical Sciences Research Council (EPSRC). Materials research is one of its six core programmes and it currently has a commitment of £21m to smart materials research in 28 UK universities. This includes the EPSRC's contribution to smart materials projects run in collaboration with 35 different organisations including the Ministry of Defence, British Aerospace and Du Pont.

In addition to research councils, the government also allocates funding through the Technology Strategy Board. This is an executive non-departmental public body, established by the Government to stimulate innovation in those areas which offer the greatest scope for boosting UK growth and productivity. Advanced materials are one of the Technology Strategy Board's key technology areas, which provide the framework for deciding where it should invest funding and support activities. In 2007, as part of its support for collaborative research and development, the Technology Strategy Board allocated funding of £7m to a competition for research proposals in Smart, Bioactive and Nanostructured Materials for Health. The Technology Strategy Board also manages and primarily funds 23 Knowledge Transfer Networks (KTNs), including the Materials KTN (see "Links between academia and industry").

Budgets for the Technology Strategy Board and the research councils come from the Department for Innovation Universities and Skills, but other government departments such as the Department of Health and the Ministry of Defence also fund research on specific applications. The Ministry of Defence identifies "smart materials and active structures" as a priority technology. However, its investment in these areas has decreased markedly in recent years as developments are increasingly driven by global civil markets and commodity products that are often adequate for its needs.[2] It currently emphasises monitoring external research rather than producing it in-house.

Research worldwide

The US is the world leader in smart materials research, mainly because of the large defence research and development budget. The US Defense Advanced Research Projects Agency has had an in-house programme of smart materials and structures research since the early 1990s, in contrast to the UK.[3] However, the UK is strong in many areas and is at the forefront of research into structures that can repair themselves. Other countries have other strengths - Japanese research is very strong in electronics and packaging; Germany has a lead in biomimetics (science that imitates nature) and France is active in packaging research and development. The EU funds some smart materials and systems research through the Seventh Framework Programme.

Drivers and applications

Smart materials and systems have a wide range of applications. Investment in research and development is driven by factors such as legislation, reducing waste and demand for higher quality of life.

Engineering

Structures such as buildings, bridges, pipelines, ships and aircraft must be robustly designed and regularly inspected to prevent 'wear and tear' damage from causing catastrophic failures. Inspection is expensive and time consuming, while designing to prevent damage can compromise performance. With some modern materials, damage can be internally serious but leave very little surface evidence. Researchers at institutes such as the Universities of Bristol and Sheffield are working on systems that can diagnose and repair this type of damage automatically in both defence and civil applications.[4]

- **Structural health monitoring** - Embedding sensors within structures to monitor stress and damage can reduce maintenance costs and increase lifespan. This is already used in over forty bridges worldwide.
- **Self-repair** - One method in development involves embedding thin tubes containing uncured resin into materials. When damage occurs, these tubes break, exposing the resin which fills any damage and sets. Self-repair could be important in inaccessible environments such as underwater or in space. The European Space Agency is collaborating on work in this area.

Reducing waste

Legislation is forcing producers to consider the entire life of a product at the design stage and customers are increasingly demanding more environmentally sensitive products. Innovative use of smart materials has the potential to reduce waste and to simplify recycling.

Electronic waste

Electronic waste is the fastest growing component of domestic waste in the UK.[5] The EU Directive on waste electronic and electrical equipment (WEEE) requires that it be processed before disposal to remove hazardous and recyclable materials. Manual disassembly is expensive and time consuming but the use of smart materials could help to automate the process.

Research in this new area of 'active disassembly' has been carried out by UK company, Active Disassembly Research Ltd. One example uses fasteners constructed from shape memory materials that can self release on heating. Once the fasteners have been released, components can be separated simply by shaking the product. By using fasteners that react to different temperatures, products could be disassembled hierarchically so that materials can be sorted automatically. The company has collaborated with Nokia and believe that this technology could be in use in the next two years.

Reducing food waste
Food makes up approximately one fifth of the UK's waste. One third of food grown for consumption in the UK is thrown away, much of which is food that has reached its best before date without being eaten.[6,7] These dates are conservative estimates and actual product life may be longer. Manufacturers are now looking for ways to extend product life with packaging, often using smart materials.

As food becomes less fresh, chemical reactions take place within the packaging and bacteria build up. Smart labels have been developed that change colour to indicate the presence of an increased level of a chemical or bacteria. A ripeness sensor for pears is currently being trialled by Tesco.

Storage temperature has a much greater effect than time on the degradation of most products. Some companies have developed 'time-temperature indicators' that change colour over time at a speed dependent on temperature, such as the Onvu™ from Ciba Speciality Chemicals and TRACEO® by Cryolog. French supermarket Monoprix has been using time-temperature indicators for many years, but they are not yet sufficiently accurate or convenient for more widespread introduction.

Health
Companies like Smith & Nephew and DePuy are developing smart orthopaedic implants such as fracture plates that can sense whether bones are healing and communicate data to the surgeon. Small scale clinical trials of such implants have been successful and they could be available within the next five years. Other possible devices include replacement joints that communicate when they become loose or if there is an infection. Current technology limits the response of these devices to transmitting data but in the future, they could respond directly by self-tightening or releasing antibiotics. This could reduce the need for invasive surgery.

Biosensors made from smart materials can be used to monitor blood sugar levels in diabetics and communicate with a pump that administers insulin as required. However, the human body is a hostile environment and sensors are easily damaged. Researchers at Queen Mary, University of London are working on barrier materials to protect sensors.

The ageing population
There are now more people aged over 60 in the UK than there are children, creating a new market for products that make life easier for the elderly. Many of these could use smart materials and systems to include added functionality. For example, shape memory materials could be used in food packaging that automatically opens on heating for people with arthritis. Researchers at the University of Bath have developed a smart home for people with dementia that uses sensors to monitor behaviour and to ensure that the resident is safe. This technology is already in use in a joint project with Bristol City Council. This type of technology has been examined in a previous POSTnote on 'pervasive computing'.[8]

Vaccines
Time and temperature cause degradation in vaccines. This is a particular challenge in developing countries where vaccines must often withstand high temperatures, poor refrigeration facilities and travel over large distances. Time-temperature indicators are now used worldwide to ensure the quality of vaccines. For example, every vial of oral polio vaccine supplied through UNICEF has a time-temperature indicator.

Constraints on exploitation
In academia and industry there is general agreement that to exploit smart materials and systems fully there must be more collaboration both between academic disciplines and between academia and industry. The Economic and Social Research Council's Science in Society programme, notes that investment in science does not inevitably produce economic benefits, as there are intervening factors such as the ability of firms to make the most of the new insights that emerge.[9]

Links between academic disciplines
Smart materials and systems are interdisciplinary research areas. Some researchers find that the traditional subject division of teaching and research can lead to difficulties bridging the knowledge gap between different subjects. However, this situation is improving and many multidisciplinary centres are now emerging in the UK, such as the Interdisciplinary Research Centre in Biomedical Materials at Queen Mary, University of London.

Research councils are also divided by subject, which can lead to difficulties funding interdisciplinary activity. However, they are increasingly collaborating. For example, the EPSRC Life Sciences Interface programme supports research in collaboration with the Biotechnology and Biological Sciences Research Council, the Medical Research Council and the Natural Environment Research Council.

Links between science and industry
Knowledge Transfer Networks
The aim of these networks is to aid the transfer of knowledge and experience between industry and the science base to improve the UK's innovation performance. In response to a recommendation in the Foresight report, the Materials KTN launched SMART.mat, a network devoted to smart materials, surfaces and structures, in 2006 (see Box 2).[10] Although it is too early to judge how much impact SMART.mat has had, members' opinions are mixed. Some of them believe it will most benefit small and medium sized enterprises who have less networking experience.

Box 2. SMART.mat

SMART.mat is a Technology Strategy Board funded project and is part of the Materials Knowledge Transfer Network concentrating on smart technology. The primary aim is to stimulate UK wealth creation and economic growth through the widespread use of smart materials by UK businesses. SMART.mat has QinetiQ, the National Metals Technology Centre and the Institute of Materials, Minerals and Mining as partners as well as members from academia and industry. It carries out a variety of activities including:

- organising conferences, seminars and other networking events;
- funding SMART.idea awards of up to £5000 for problem solving, proof-of-concept, technology demonstration and other development activities;
- producing a smart materials design guide that contains a section for each type of smart material, listing useful information such as what properties it has, how readily available it is and which companies supply it;
- providing technology translators to communicate technical information to non-specialists.

Incorporating science into design

Scientific developments can be inaccessible to designers who may not understand them or even know what is available. Researchers also say that they have difficulties persuading industry to invest in products based on smart materials. The cost of changing manufacturing processes or ensuring compatibility with other products can lead to 'technology lock-in' where industry is reluctant to adopt new technologies.[11]

Some designers believe that researchers do not always focus on areas of importance to them, such as how to manufacture materials and incorporate them into products. The Foresight report noted that there is a need "to enhance the practical realisation of the existing materials-based technologies, tailored to particular customer and market requirements". It recommended the establishment of a National Centre of Excellence on smart materials "based around the issues of device fabrication, miniaturisation and integration; product manufacturability and life cycle use, including recycling". However, there are currently no plans for such a centre.

Coordinating research and development

Coordinating and guiding research and development requires liaison between the Technology Strategy Board, research councils, government departments, regional development agencies and devolved administrations. Following Lord Sainsbury's review of Science and Innovation, published in October 2007, the Technology Strategy Board has been assigned a leadership role to coordinate activity across the UK.

Environmental risks

Smart materials and systems are hugely varied and are applied in a wide range of fields. It is hard to make generalisations about their environmental impact as this depends on the specific materials and applications. However, recyclability is not an issue that most researchers are addressing. They believe that smart materials are either too early in their development or used in such small quantities that this is not yet an issue. Nonetheless, integrating 'smartness' and multifunctionality into products generally makes them more complex and inherently harder to recycle.

The EU Directive on the restriction of the use of hazardous substances limits the use of certain hazardous materials, including lead, commonly used in piezoelectric materials. Alternative piezoelectric materials are therefore being investigated.

Some smart materials are also nanomaterials. Little is known about the effects that nanoparticles could have on human health or the environment. However, research is underway and the Department for Environment, Food and Rural Affairs is working to protect the environment while ensuring that the benefits of nanotechnology are realised. The Royal Commission on Environmental Pollution is currently investigating the environmental effects of novel materials and applications and is due to publish a report on its findings in 2008.

Overview

- Smart materials and systems are able to sense and respond to the environment around them.
- They have the potential to improve existing technology and add new functionality to products.
- They have applications in a wide variety of areas and could have an important role in waste reduction.
- Although smart materials and systems have been researched for decades, commercial exploitation has been slow. The interdisciplinary nature of the subject and the divide between scientists and designers have slowed this exploitation.
- The Technology Strategy Board has provided funding for SMART.mat (part of the Materials Knowledge Transfer Network) to encourage collaboration and increase exploitation of smart materials and systems.

Endnotes

1 *Smart materials for the 21st Century*, Materials Foresight, 2003
2 Defence Technology Strategy, 2006
3 *The Past, Present, and Future of DARPA's Investment Strategy in Smart Materials*, JOM, 2003
4 *State of the Art Review - Structural Health Monitoring*, SMART.mat, 2006
5 POSTnote 291, *Electronic Waste*, 2007
6 *Smart and Active Packaging to Reduce Food Waste*, SMART.mat, 2006
7 *Understanding Food Waste*, WRAP, 2007
8 POSTnote 263, *Pervasive Computing*, 2006
9 *Science in the economy and the economics of science*, ESRC Science In Society Programme, 2007
10 SMART.mat website: http://tinyurl.com/yrdv9s
11 *Innovation Policy and the Economy*, Jaffe *et al*, 2004

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