Background

This report has been produced following a series of activities which have sought to engage with a broad section of the UK materials community with an interest in Multifunctional Materials. Following an initial, e-mail based, ‘bottom up’ trawl for information, a preliminary analysis was presented to a Town Meeting and two further, Focus Group, meetings were held to consider, enhance and consolidate the various inputs into a set of specific recommendations for the future development of this technological area. Although, it cannot be claimed that this approach, in the short time available, has been able to capture all possible points of view, a consistent set of issues has emerged throughout the process to inform the final recommendations.

Scope

In the context of this study, the term ‘Multifunctional Material’ is defined to be any material or material-based system which integrally combines two [or possibly more] properties, one of which is normally structural and the other functional, e.g. optical, electrical, magnetic, thermal etc... Likely candidate systems will include aspects of ‘smart materials/systems’ and biologically-inspired materials [biomimetics] and cover all materials types [e.g. polymers, ceramics, metals, composites] and forms [e.g. bulk, coatings, fibres, fabrics]. Both active and passive functionality is included and the concept of ‘designed-in’ functionality is a further useful descriptor.

From within this broad definition, a number of generic topics have emerged as likely key areas for future research and development:

- composite materials
- hybrids
- interpenetrating networks
- coatings
- interfacial and surface properties
- biomimetics
- nanostructured materials
- structural integration
- materials modelling

Overall, the underlying feature of most multifunctional materials will be some form of composite structure, with interfacial properties playing a major role in determining their properties.

It should be noted that, by its very nature, this topic has overlaps with each of the other materials topics being considered within the IGT strategic study. In particular, there are areas of strong commonality with both ‘functional materials’ and ‘biomaterials’. No attempt has been made to draw sharp distinctions between these areas, nor is it sensible to do so: common issues will help to define and substantiate subsequent outputs and recommendations. Many topics have emerged, however, which would not otherwise have been covered within the overall study.

Applications/Benefits

Multifunctional materials represent the next big step in product development, by efficiently combining structural properties with an additional functionality. Many such next generation products may draw inspiration from nature, where size and weight is often critical and multifunctionality is a necessity rather than a luxury. For example; desert beetles, butterflies and electric eels incorporate useful thermal, optical and electromagnetic features within their body structures.

The potential to exploit multifunctional materials spreads over a broad range of market sectors and products. Key areas identified in this study are:

- Healthcare – antimicrobial surfaces and materials; controlled drug release; biocompatible materials and surfaces; biosensitive wearables; remote [tele] healthcare; sensors and biomedical implants
- Security – anti-counterfeiting products; brand protection [including bio-tags]; biometric products
- Energy – membrane technology; fuel cells; batteries; thermoelectric generation; thermal insulation/control materials; more-electric propulsion; energy harvesting
- Packaging – barrier properties; surface texture; controlled release; sterilisable; controlled degradability; integrated tags; printable power
- Aerospace and Transport – damage tolerant, self diagnostic, self-healing structures; morphing structures; switchable, self-healing, conducting adhesives and sealants
- Consumer – smart textiles/wearables; easy/self clean/scratch/corrosion resistant surfaces; flexible displays
- Defence – includes variants of all of the above

For some of the simpler, and less well-integrated, manifestations of materials multifunctionality, fully commercial products can be expected to emerge within around the 5 year time horizon. This will include, for example, some of the surface-related and sensing concepts. Where, an active feature is involved, this timescale will extend out to 10 years and beyond. Additional time will be required for the development of products to be used in difficult environments, with bio-integration being perhaps the most challenging. The widespread use of truly, biomimetic, multifunctional materials will occur only over a twenty year horizon and beyond.

Drivers

The basic underlying technological need for the development of ‘multifunctional’ materials is that solutions to particular problems or needs cannot always be found by using a simple combination of materials with different functions, and a technological ‘barrier’ is reached. Real benefit will often only be found if true multifunctionality can be achieved: for example, using the carbon fibres and resin matrix of a polymer composite structure as battery electrode and electrolyte components, rather than parasitically integrating an independent power source within the structure. This is particularly true in the aerospace sector where weight reduction is at an absolute premium, driven by the needs of reduced operational costs, enhanced performance and environmental issues linked to fuel consumption.

Environmental issues more generally are also a driver for this technological area and are often underpinned by legislative, societal and political issues. A variant of this is found in the healthcare sector where, for example, the current MRSA agenda provides a major impetus to develop hygienic surfaces. Also in the healthcare sector, the move towards remote patient care will require the development of integrated sensory systems into wearable products. Finally in this sector, and an example of where multifunctionality is a major imperative, is the need to develop materials and systems which both serve a useful function as an implant within the human body, e.g replacement joints, drug delivery systems, and are also biocompatible.

Multifunctional materials also have the potential to support the sustainability agenda. For example, structures might be designed for re-use or recyclability, via the use of smart materials or components.

Another major commercial driver for the development of multifunctional materials in the UK is the increasing uncompetitiveness in many sectors of current products and the need to provide added value alternatives based on an increased level of functionality. In the consumer market, this is given extra impetus by the unquenchable desire for ‘gadgets’, driven, in turn, by fashion and fuelled by increased levels of disposable income. A prime example of this is in mobile communications, which is an area which will expand to be part of an ‘interconnected and interactive world’. This will combine communications, computing and other IT functions within a pervasive network, which will again require high levels of integrated functionality within the fabric of the real world. Another feature of this future world is likely to be the increased use of robotic devices and, once again, multifunctionality and multifunctional materials, particularly pulling on biomimetic concepts will be a major contributor.

Barriers

The major underlying barrier to the development of multifunctional materials and systems is, paradoxically, the very thing that gives them their advantage over combinations of single functions – multidisciplinarity. That is, the need to pull together and establish close and sustainable links between often disparate and closed disciplines, including; materials scientists, chemists, physicists, engineers, biologists, physicians and designers.

This problem manifests itself as a lack of focus and co-ordination, from financial, commercial and technical perspectives. There are often fragmented funding strategies and associated processes between government agencies [e.g. DTI, EPSRC, MOD], although the recent rationalisation of industrial research and development funding by the DTI, through its Technology Programme, is seeking better alignment. At the technological level, there is insufficient cross-fertilisation between academic disciplines. This is also partly a funding-related issue, where, in particular, funding streams for academia have often been 'stovepiped' into single discipline-based programmes; although this too has been somewhat softened in recent years. There remain difficulties across, for example, the biology-physics boundary and in engagement with the design community, for consumer-based applications. The different languages used within each of these disciplines particularly highlight this communications barrier. However, this lack of multidisciplinary interaction is also reinforced by both the historic single discipline organisational structure within UK universities and by the teaching curriculum within schools. A lack of pull-through at the interface between the science base and industry, is often based on a combination of poor awareness of potential opportunities and issues of commercial risk. This is often perceived as high in this area, based on relatively low technology readiness levels and a lack of confidence in the assessment of multidisciplinary ideas. In this respect, there is a lack of funding streams which are aimed at crossing the so-called 'Valley of Death', by enabling the fabrication of proof of concept and prototype demonstrator products. A further barrier to the development of commercial products is also a lack of awareness and cross-over between market sectors, e.g. the opportunity to modify defence-related products for commercial use.

In such an innovative and fast moving area, it is also necessary to establish funding mechanisms to support targeted but 'high risk' research ideas. This might be a staged process, based around the initial funding of small feasibility studies, with further higher levels of support for only the most promising ideas.

Other significant barriers specific to Multifunctional Materials development and use include a lack of [multifunction] modelling and design tools; the need to develop a relevant and expanded [truly multifunctional at many size scales] metrology base; and the potential complexity of the supply chain that will be needed in the production and exploitation of products incorporating this technology. Further, the general consumer may often be the end-user in this supply chain, introducing complex people-related issues related to the design and use of complex products.

UK position

In this area of technology, as others, there is a general perception that the UK has a strong, if often fragmented, science base. There are some subjective views expressed as to specific strengths and weaknesses, but with little substantive supportive evidence. An area where the UK is recognised as a world leader is that of organic electronics, which could be used in a variety of multifunctional applications. There is some qualitative evidence of a lack of critical mass in some areas, especially where there is a strong need to form multidisciplinary teams. Some IRCs in materials related areas exist, but are often still relatively narrow in their scope. Faraday Centres and Partnerships have provided the UK with a research and development supporting structure in a variety of relevant topics and some have been successful in engaging people from different backgrounds. Overall, the UK does not support large multidisciplinary teams in Centres of Excellence, as is the case in some other countries.

In respect of funding for research in this area, the issue seems not to be so much about the absolute level of support available from existing government initiatives, but more about a lack of an integrated strategy and set of processes appropriate to such a multidisciplinary topic requiring inputs from both the science base and industry. Some opportunities in this general area have been available through the DTI's Technology Programme, including a 2004 Call on 'Smart Materials and Structures'. From a strategy perspective, the EPSRC included the topic of Multifunctional Materials within a series of Materials Challenge Workshops during 2004 and the Smart Materials and, separately, Functional Materials topics were the subjects of Foresight Studies during 2003. A DTI ITS Mission to Japan in 2003 captured the science and technology strengths of some of the largest Japanese companies utilising piezoelectric materials for smart actuation applications. The UK position was deemed to be at a relatively high status, although lacking options for exploitation of ideas into products.

There is relatively little industrial investment currently in this field and, to date, limited commercial exploitation has been achieved. This is partly due to the degree of risk involved in such innovative technology development, especially for the SME sector. A further specific weakness, compared to other countries, appears to be a lack of a system for through-career industry/academia or cross-discipline academic interchange opportunities.

Competitiveness

In many areas encompassed by the Multifunctional Materials theme, the bulk of current activity is outside of the UK, although there are opportunities, for example, for UK organisations to participate in projects such as those funded under the European Union's Framework 6 Programme.

The indicative budget allocated to the Thematic Priority – Nanotechnologies and Nanosciences; Knowledge-based Multifunctional Materials and New Production Processes and Devices – within FP6 is EUR 1.4B. Key topics under the Knowledge-based Multifunctional Materials theme include:-

- Development of fundamental knowledge
- Interfacial phenomena
- New generation characterisation tools
- Methods of computational modelling
- Production, transformation and processing technologies
- Advanced materials processing
- Multifunctional ceramic thin films

A current relevant programme under this theme is the 'Multi Material Micro Manufacture [4M]' European Network of Excellence. The Network intends to integrate facilities and create synergistic links to on-going R&D programmes with total values exceeding EUR 110M and EUR 63M, respectively. The core theme of the Network is non-silicon microtechnologies and involves 15 core partners from 15 countries; the UK is represented by Cardiff, Cranfield and Bath Universities plus Rutherford Appleton [RAL].

Another activity under the Knowledge-based Multifunctional Materials theme, is the 'Multifunctional Integrated Devices' [MIND] European Network of Excellence. The objectives of MIND are to increase the level of understanding of all phenomena in piezoelectric materials and structures, and to apply this knowledge to the design of new and improved devices such as sensors, transducers, actuators & motors for applications ranging from medical diagnostics and therapy to industrial measurements, as well as transportation and products for the citizens. It aims at the creation of a European Institute on piezoelectric materials, structures and devices; through durable integration of research teams covering expertise ranging from material synthesis to integrated device development. The Network is supported through an EU budget of EUR 7M, and involves 11 core partners from 9 countries, with the UK being represented by the National Physical Laboratory and Cranfield University.

Looking to the future, the European Union is also currently funding a Specific Support Action [SSA] under the banner of "SMART", which is a 'Foresight Action for Knowledge Based Multifunctional Materials'. This project, started in April 2005, aims within 2 years to identify highly relevant research areas in the field of knowledge-based, multifunctional, materials in the perspective of the next 5-30 years. Road maps will be developed, to include information on scope, time-horizon and bottlenecks, from which suggestions for future research needs and actions will be developed. The IoM3 are a project partner and the UK will also be represented on the Advisory Board. This activity reinforces, at the European level, the perceived importance of the multifunctional materials area over the coming decades and will provide an evolving source of detailed information relating to future government funding, including Framework 7.

In the USA, 'Structural & Multifunctional Materials' was one of the key topic areas within a major national study undertaken by the National Materials Advisory Board entitled "Materials Research to Meet 21st Century Defense Needs". There are now major programmes underway, often supported by defence-related agencies; e.g. DARPA, and undertaken by national Centres of Excellence, within academia, industry and the US system of National Laboratories. The relevance and momentum of DARPA Programmes is continuously refreshed by the fixed-term appointment of 'expert' Programme Managers, drawn from across the science base and industry. This approach leads to significant support for potential 'disruptive' technologies for a fixed period of time, with the more promising subsequently progressing into more applied programmes, both accelerating the pace of R&D and often leading to first to market status. As a typical example of the scale of DARPA Programmes relevant to this topic, it has supported, over a period of some 5years, projects worth $40M targeted specifically at the underpinning technology of 'Direct Writing', within its Mesoscale Integrated Conformal Electronics [MICE] Programme. A current major DARPA Programme area is 'Synthetic Multifunctional Materials'.

It should be noted, however, that despite a much higher level of support for research and development in some overseas countries, there has also been relatively little real commercial exploitation of multifunctional materials technologies. In this respect, therefore, the door is still open for UK industry.

Recommendations

Multifunctional Materials represents a highly diverse, sometimes poorly defined, strongly multidisciplinary area, with links to functional, structural and biomaterials topics. Strong market drivers exist to develop added value products across numerous sectors, including aerospace and transportation; healthcare; packaging; energy; security; consumer products and defence. In addition, there are strong environmental, energy-related and sustainability drivers, increasingly being underpinned by legislation. This has led to an increasingly strong worldwide interest, and funding of major programmes, in this area over the last decade. However, as discussed, there are significant barriers which exist to the future successful development and commercial exploitation of this technology which must be overcome if the UK is to derive significant benefits in terms of industrial competitiveness, wealth creation and economic growth.

The following key recommendations to Government from this study are to:

- establish a national consensus of target technologies, products and markets [based on agreed metrics];
- establish an improved co-ordinated [national] funding strategy for basic and applied research, development and demonstration, together with associated processes, including metrological needs, focused on target technologies, products and markets; and
- encourage collaborative national and international, multidisciplinary, industry-led programmes, especially within Europe and the USA.

Each of these activities should be guided by, and build upon, current UK and worldwide best practice. A national funding strategy should address both the specific multidisciplinary issues associated with this technology and its science base, and be attractive to the UK industrial sector, including SMEs.

Consideration should also be given to the establishment of one or more UK ‘Centres of Excellence’ to cover this area of technology. These could be either virtual entities which bring together existing programmes and capabilities or, preferably, new ‘bricks and mortar’ Centres, focusing on specific product types or markets. In either case, they must achieve the task of establishing relevant multidisciplinary teams of sufficient critical mass and must receive additional targeted funding.

In terms of awareness, information and outreach across the science base/ industry and market interfaces in this area, the recently established DTI Smart Materials, Structures and Surfaces Network [SMART.mat] will provide a valuable forum. Internationally, support should be provided for relevant Overseas Missions via the DTI Global Watch initiative. A further useful national asset would be the establishment of a comprehensive database of equipment.

Finally, due consideration must be given to the need to establish new educational paradigms, again in order to stimulate multidisciplinary thought and achievement. This should apply to teaching in schools, undergraduate and postgraduate training and through-life Continuous Personal Development.