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Development of a roadmap for advanced ceramics: 2010–2025

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Abstract

A roadmap for advanced ceramics for the period from 2010 to 2025 has been developed to provide guidelines for future investments for policy makers, scientists and industry alike. Based on questionnaires, interviews and a final workshop with well-balanced participation of members from industry and academia three roadmaps on application fields and two roadmaps on scientific areas have been developed and contrasted. The three application fields selected are: (i) electronics, information and communication; (ii) energy and environment; (iii) mechanical engineering and the two scientific fields are: (a) structural and functional properties; (b) process technology. Within these fields the tremendous growth opportunities for ceramics as an enabling technology are highlighted and manifold suggestions for future development are provided.

Keywords: Roadmap; Foresight; Advanced ceramics; Electronics, information and communication; Energy and environment; Mechanical engineering; Structural and functional properties; Process technology

1. Introduction

Science and technology are advancing at an increasingly rapid pace and the ways in which they interact with economy, society and environment are becoming increasingly complex.[1] Balancing the essential needs of science quality, of relevant R&D programs, of functional integration and of responsiveness to stakeholders can be very confusing. To remain competitive in the future, and to ensure long-term success, policy makers, other stakeholders and big companies must focus on future markets and apply a well-founded strategy for technology development. To achieve success in today's global economy, companies must be able to produce the right product at the right time. Technology foresight, especially roadmapping as a distinctive method, becomes significant.[1,2]

Technology foresight is a mechanism for strategic decision-making. It is a process which seeks systematically to look into the longer-term future of science, technology and economy, the environment and society with the aim of identifying the emerging generic technologies and the underpinning areas of strategic research likely to yield the greatest economic and social benefits. It helps to identify, select and develop technology alternatives to satisfy future service, product or operational needs.[3–5]

The wide application of technology foresight in certain countries dates back to the beginning of the 1980s.[6] Prior to that, few technology foresight activities using roadmapping have been carried out in the US.[7] It is also highly regarded as a tool for anticipating future market demand and designing development strategies for trans-national companies. Technology foresight is now being increasingly recognized worldwide as a powerful instrument for establishing common views on future development strategies among policy-making bodies, bridging the present and the future. One of its unique features is the participation of a large number of stakeholders, namely governmental

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institutions, scientific communities, industrial enterprises and civil society. This instrument has been implemented in several countries for certain R&D fields including materials research and development.[1]

The fact that materials issues pervade all aspects of our lives is well accepted. Whether these are modern medical procedures or changes in telecommunications, they all depend on materials developments.[8] Since 1992 the Semiconductors Industry Association (SIA) has coordinated a process for building consensus on the future technology requirements for maintaining the historical rate of advancement out of a 15-year horizon. The tremendous progress of silicon integrated circuits (ICs) has been and is still driven by the downsizing of their components. Affordable scaling constitutes one of the identified Grand Challenges quoted in the National Technology Roadmap for Semiconductors (NTRS) for the future.[9]

The "Advanced Ceramics" industry is fundamentally different from the silicon microelectronics industry, due to its higher diversity, higher interdisciplinarity, very different processing technologies and variety of application. This means that a straightforward anticipation of the ever increasing cost benefits from economy of scale and the continuous improvement of yield is inappropriate in the case of advanced ceramics. Unlike the NTRS, existing roadmaps for "Advanced Ceramics" do not simply focus on the reduction of feature size but are aimed at assessing potential advanced ceramics-based products, which will help the industry of the future to meet long-range visions for energy efficiency and pollution reduction, improved capital effectiveness and increased productivity and life quality.

2. International foresight activities

At the first International Congress on Ceramics (ICC) held in Toronto in 2006 for the purpose of creating a ceramics roadmap, researchers and engineers agreed that advanced ceramics, defined as non-metallic inorganic materials, would have a major impact on addressing future challenges and needs. A global roadmap for ceramics was developed, wherein the contribution and the ability of ceramics to solve problems in major markets like electronics, energy generation and storage, environment and transportation, processing and manufacturing, health and safety issues, was elaborated.[10]

The development of ceramics with improved properties will open up an increasing number of demanding applications, like advanced electronic ceramic materials for Si electronics and automotive industries. Furthermore, increasing global demand for energy has led to a strong need for established and alternative energy sources. Advanced ceramics have played and will continue to play a critical role in all aspects of energy production, storage, distribution, conservation, and efficiency. However, there are a number of issues which have to be addressed in terms of future needs for innovative and multifunctional ceramic material systems, robust and affordable manufacturing technologies, system level performance studies, system reliability and durability, and total life cycle cost. Finally, producers are always looking to improve the competitiveness and sustainability of manufacturing.

This progress in advanced ceramics technology will not occur without the continuous support of ceramics fundamental research by government agencies and industry.[10] In order to stimulate and to coordinate this support, technology foresight has been fostered in several countries in the last years. The most important ones are summarized below.

USA: The United States Advanced Ceramic Association (USACA) recognized that changes of present strategies for advanced ceramics R&D are needed. Identified drivers for such changes are unrealized market expectations due to technical challenges in many cases (e.g. CMCs, industry consolidation), soaring prices of petroleum-based goods, growing population, urbanization and aging population. The USACA 2020 vision of advanced structural ceramics is to make these materials cost-effective and to outperform other materials due to reliability, high-temperature capability and other unique properties.[11–13] Products are initially designed for ceramic materials, using established standards and design tools. Automation and other advanced fabrication processes optimize cycle times and yield, ensure predictable and controllable production, and eliminate the need for post-process inspection. New crosscutting R&D programs that impact the ceramics industry for the demonstration of key technology platforms for improving energy efficiency and reducing environmental problems are highly recommended.

UK: In October 2002 the UK government launched PowderMatrix, one of the 24 Faraday Partnerships, to create a network in particulate engineering, initially focussed on the advanced ceramic, powder metal, hard metal and magnetic industries. In December 2004 PowderMatrix released an advanced ceramics roadmap. It projected that advanced ceramic manufacturers will have a wide range of market opportunities from end users who want components to solve critical challenges.[14] Components with better performance characteristics, e.g. improved resistance to fracture, increased reliability, reduced manufacturing costs and increased conductivity will be increasingly needed. In the medium- and long-term the advanced ceramic base is seen to need more understanding and development for innovative materials and processes for new markets which will likely include reduced product development cycles and greater reuse of waste material and cost-effective reuse of materials at the end of life.[14]

Japan: In the past the Japanese Ministry of Trade and Industry has sponsored a national survey project on industrial technology of new inorganic materials (FY2001–FY2005), where three industries were identified to which advanced ceramics would strongly contribute. Those are the network/device industry (i.e. materials for next-generation semiconductors, sensors, storage devices, optical networks, high-speed wireless access and next-generation displays), the Bionic industry (i.e. materials for drug delivery system, medical micromachines, biocompatible materials, artificial organs, and biochips) and the environmental/energy industry which is concerned with issues like materials for fuel cells, transportation and electric power generation, environmental monitoring, elimination of toxins, and environmental improvement.[12] Meanwhile the Japanese government has launched a mid-term program with two main goals, promotion of nanotechnology-driven advanced materials research and promotion of advanced materials research on environment/energy