Materials Research in Europe: Mapping Excellence and Looking Ahead

Gerd Schumacher, Dirk Tunger, Alan Smith, Stuart Preston, and Brian Knott

The European Research Area has been established to coordinate national research policies and to encourage shared objectives, expertise, and resources throughout the European Union. To accomplish these goals, the European Research Area first needs knowledge of existing resources, fields of excellence, and potential for improvements as well as an idea of the direction of future research. This article describes the SMART project, established by the European Commission to identify important research topics for the future in the field of materials technology and to map materials research regions of excellence.

INTRODUCTION

In March of 2000 the European Council began the process to create the European Research Area, thereby laying the foundation for a common science and technology policy across the European Union. The European Research Area is an effort to coordinate national research policies in the direction of shared objectives, expertise, and resources. To accomplish these goals, the European Research Area needs knowledge of existing resources, fields of excellence, and potential for improvements as well as an idea of the direction of future research.

To identify important research topics for the future in the field of materials technology and to map materials research regions of excellence, the European Commission established the SMART project. Therefore, SMART is an important step toward establishing the European Research Area. The SMART activities are complemented by European Technology Platforms, which are industrial-research-driven consortia defining future research needs.

The SMART project, coordinated by Project Management Juelich, started in April 2005. SMART does not just focus on smart materials as one might expect, but is so named because of its unusual twofold approach of combining foresight and forecast work, enabling complex analysis with limited resources.

As a consequence of the high profile of recent foresight studies for improving human life, increasing safety and security, and solving energy shortages, these topic areas are seen as most important for European society in the future. To

BIBLIOMETRIC INDICATORS IN A MATERIALS SCIENCE PROJECT

Bibliometrics describes the application of statistical methods for the investigation of science communication. An example is the creation of timelines and hot-spot areas for different topics. Bibliometric analyses focus more on statistics than on real content.

These analyses are generated from literature databases that do not just comprise bibliographic data but also information on the citation and response of articles. The Science Citation Index from Thomson Scientific has proven its worth for the natural sciences. It supplies good coverage, high precision, and rapid provision of data.

What Can Be Investigated

Bibliometrics can be used to investigate the development trend toward research-relevant topics in science, such as which materials will become more significant in the future (Figure A). It proves answers to questions on the publication activity of working groups, such as who are the leading scientists in a field or which groups display outstanding activity in an international comparison? With the aid of bibliometrics, research rankings can be compiled on this basis representing the starting point for further studies.

Normalization by gross domestic product per capita is also possible using bibliometrics (Figure B). Because not every country has the same basis for science, normalization allows the creation of a ranking with the same basis for all countries with a basic activity in a field.

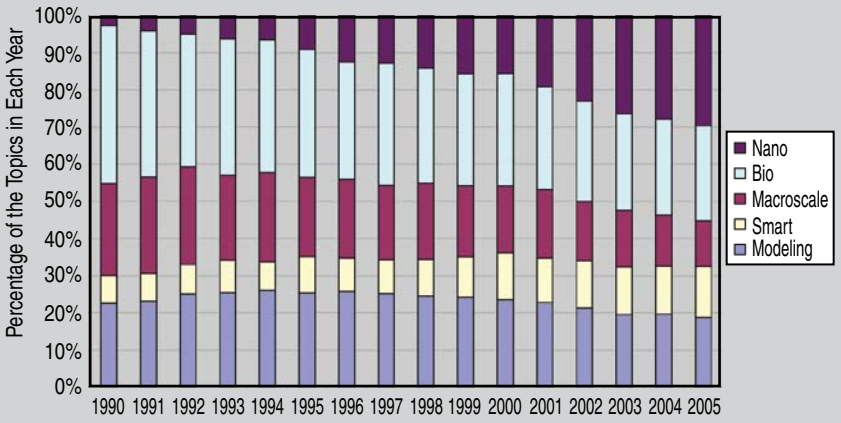

Figure A. A timeline of all SMART topics; displayed is the percentage of each topic on the total publication output of the five SMART Topics in each year

identify how materials technology can contribute to solving these challenges, a screening of recent publications in databases was carried out which is currently being followed by the interviewing of experts and organization of roadmapping workshops.

MEASURING ACTIVITY AND REGIONS OF EXCELLENCE

During the last 15 years there has been an enormous increase in the annual number of publications in all fields of materials technology (Figure 1). Bibliometric analyses (see details in the sidebar) showed that the United States, Europe, Japan, and China are most active in materials research. Simply comparing publication rates might be seen as inappropriate because of the different economic backgrounds of these countries. Therefore, the publication rates have been normalized on the annual gross domestic product (GDP). Such normalized data show that the scientific output of the United States is, in all fields of materials technology, several thousand publications higher than the average publication rate normalized on the GDP/capita of other countries. This leading position of the United States is followed by China, Germany, Japan, and the United Kingdom (the order of the followers being different in each materials research field). The technological activities of countries worldwide have been plotted for all fields of materials (see Figure 2 for a biomaterials example). However, currently these plots are refined toward a regional mapping which is more relevant when considering future investments in R&D.

The analysis of nearly 300 review papers published in the last 5 years relating to future research trends and bottlenecks found that most authors expect technological breakthroughs in nanomaterials, soft matter and polymers, and materials tailoring. Therefore, it is not surprising to see the greatest increase of publication rates in the fields of nanomaterials and biomaterials.

The second stage of the SMART project, based on information obtained from the data screening, involves interviews with materials experts and the development of roadmaps. To date, more than 200 experts, mainly from Europe, have been involved. From these interviews the maps of regions of excellence will be established and it is expected that the information on future trends and bottlenecks from the data screening in the first stage of the project will be confirmed. Preliminary results show there is significant information for identifying several regions in France, Switzerland, Germany, United Kingdom, and Italy as being excellent. This agrees with the results of the bibliometric activity mapping.

BIBLIOMETRIC INDICATORS IN A MATERIALS SCIENCE PROJECT *(Continued)*

Development of Topics

In order to supply reliable information on the development trend toward research-relevant topics, data-mining methods are applied to the desired main topics. For example, abstracts are examined with respect to the frequency of keywords, and time profiles indicate development while normalizations mask out the general increase in scientific publications. Essentially, a large volume of data is poured into a funnel in order to generate new information contexts.

For the SMART project, the bibliometric results will help to check and prove the results of other parts of the project (e.g., evaluation by questionnaires). The answers on questionnaires regarding capacities in each field are more or less subjective and can, with methods like bibliometrics, be made more objective. This provides better understanding of the research evaluation and a more objective consideration of future possibilities.

These methods are comparable to a trend recognition system; the collection of objective and subjective data and the evaluation of these data are the first steps to a kind of science radar. Igor Ansoff, an early warning expert, says it is essential to be receptive to weak signals. Over a long period of time it was not understood how to do this. Quantitative analyses are a possible way to assemble information and to gather meta-information.

Further information about bibliometrics can be found at *www.fz-juelich.de/zb/Bibliometrics.*

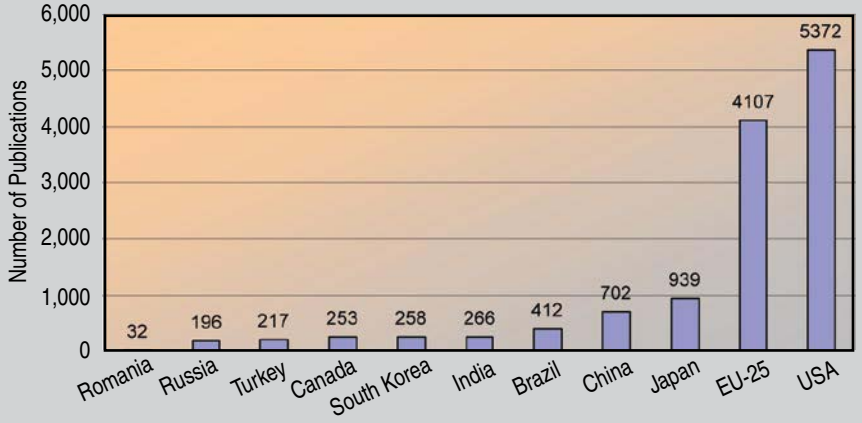

Figure B. The number biomaterials-related publications above the expected value due to GDP/capita.

DEVELOPING ROADMAPS

As mentioned previously, improving human life, increasing safety and security, and solving energy shortages are the focus fields of the SMART project. Workshops in each of these three fields will be used to produce technology roadmaps. The first workshop "Materials Powering Europe" addressed the role of materials technology in solving energy shortage problems. This workshop took place in April 2006 as part of the Materials Congress 2006 in London. The event was split into two sessions: Materials for Energy Efficiency and Materials for Sustainable Energy Technologies. More than 30 experts from academia and industry attended. The session Materials for Sustainable Energy Technologies was preceded by keynote presentations from John Kilner (Imperial College) and David Gooch (Institute of Materials, Minerals, and Mining). It was pointed out that within the next 25 years there will be a 200% increase in electrical energy consumption. Satisfying this dramatic growth in energy demand will

require revolutionary changes in energy technology and its infrastructure. The workshop participants discussed all possible technological solutions including wind, tide, geothermal over biomass, nuclear and hydroelectric power generation, and solar technology. Certain materials research topics are important in several of these energy technologies such as materials for membranes, catalysts, and bio-inspired materials. Even though corrosion research is a well-established research field in most industrialized countries, it turned out that efforts in corrosion research have to be intensified, since corrosion science is a key factor for technological breakthroughs. Lorenz Singheiser (Research Centre Juelich) pointed out in his keynote presentation in the "Materials for Energy Efficiency" session that there is an urgent need for increasing energy efficiency of fossil power plants, since about 40% of those plants will be replaced within the next 15 to 20 years and will operate for at least 30 to 40 years. Technological modifications have to be introduced before the investment takes place. Therefore R&D in fields such as ceramics for extreme temperatures, coatings technology, self-healing, and smart materials systems has to be intensified. A comprehensive workshop report will be available on the SMART web site in the first quarter of 2007: *www.smart-ssa.net*.

In October of 2006, workshops focusing on the fields of "Better Life" and "Safe Europe" took place. Currently the results of all three workshops are being combined to one overarching materials research roadmap.

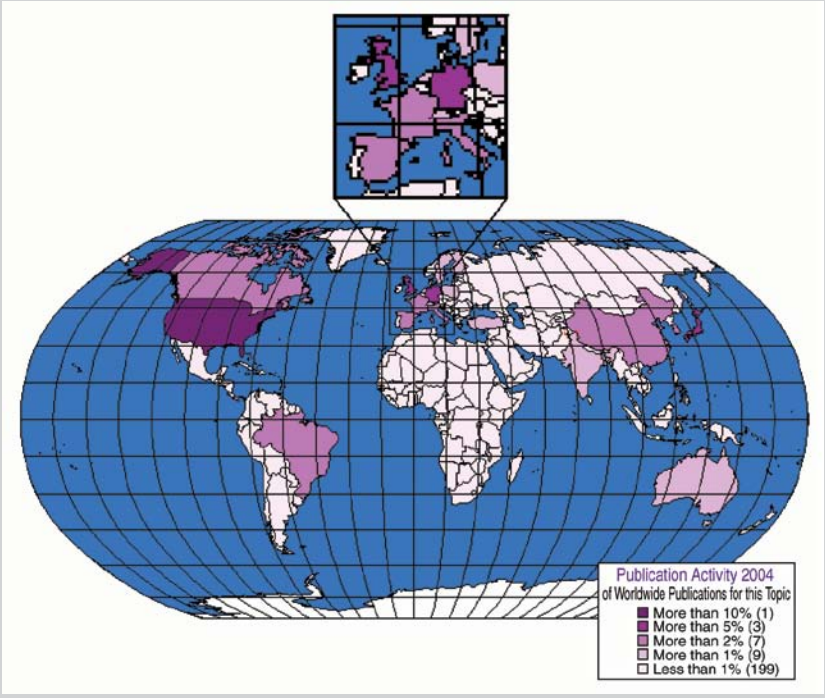

Figure 2. Publication activity mapping in the field of biomaterials in 2004 (data source: ISI Web of Science).

CONCLUSION

Materials technology will play a key role in solving society's future challenges. Even though research activities are well established in all industrialized countries and are already at a high level, it is likely that these efforts will have to be increased in the future to realize the essential technological breakthroughs required. Knowledge of excellence in materials research and roadmapping is essential in order to ensure maximum effectiveness of, and benefit from, investments in materials technology research.

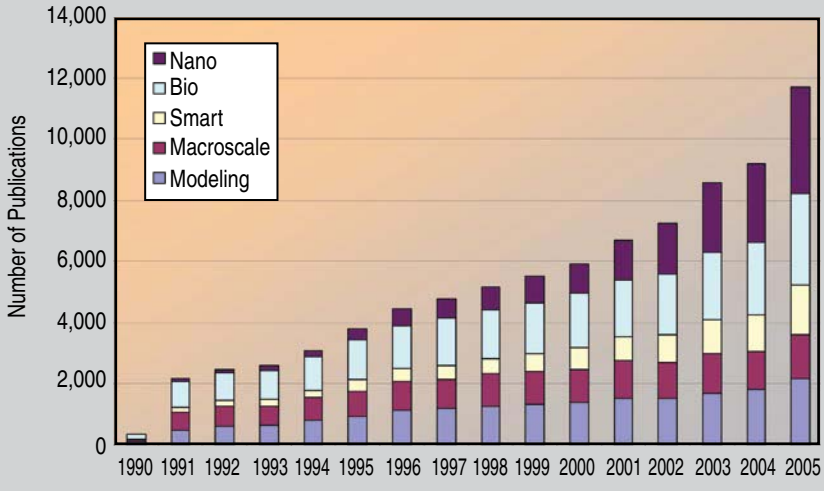

Figure 1. A timeline of the development of the five SMART Level-1 topics.

ACKNOWLEDGEMENTS

The authors would like to thank the European Commission for financial funding of the SMART project (SSA in Priority 3 (NMP) of FP 6). Also the authors thank the advisors and associated partners for their support and materials experts who took part in the interviewing and attended the workshop.

Gerd Schumacher is with Project Management Juelich, Research Center Juelich, Germany; Dirk Tunger is with Central Library, Research Center Juelich, Germany; and Alan Smith, Stuart Preston, and Brian Knott are with the Institute of Materials, Minerals and Mining in London. G. Schumacher can be reached at ptj-smart-ssa@fz-juelich.de.