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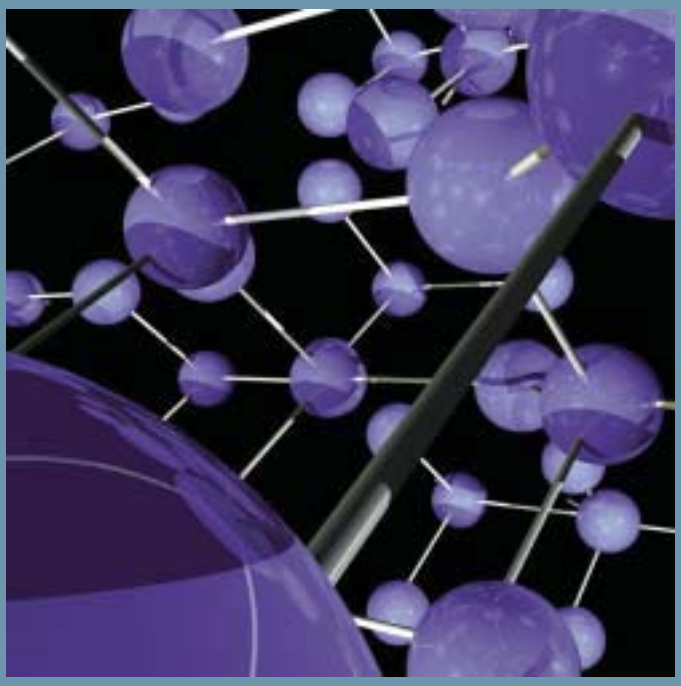
Research Programme for Electronic Materials and Microsystems 1999-2002

EVALUATION REPORT



ACADEMY OF FINLAND

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Research Programme for Electronic Materials and Microsystems 1999-2002
EVALUATION REPORT

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University of California, U.S.A

Professor Eric Larkins
University of Nottingham, England

Evaluation of Impact on Society:

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Nokia Research Center, Finland

Academy of Finland in brief

The Academy of Finland is an expert organisation on research funding. The Academy seeks to enhance the high standard of Finnish research by long-term research funding, by expertise in science and science policy, and by strengthening the status of science in society at large.

The main focus of the Academy's development activities is on improving professional research career opportunities, providing preconditions for high-quality research environments and utilising international opportunities in all fields of research, research funding, and science policy.

The Academy's operations cover all scientific disciplines, from archaeology to space research, cell biology to psychology, and electronics to environmental research. The wide range of high-level basic research funded by the Academy provides a sound basis for innovative applied research and the exploitation of new knowledge.

For more information on the Academy of Finland go to www.aka.fi/eng/.

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Preface

Strong and steady growth has occurred in the Finnish electrical and electronics industry since the 1970s. It is now Finland's leading export industry, a position traditionally held by the forest industry. In support of this trend, the Academy of Finland decided to launch a new research programme on electronic materials and microsystems called EMMA. The programme was implemented in collaboration with the National Technology Agency (Tekes). The programme committee consisted of members both from academia and industry. The budget was 5.1 MEUR and its duration three years, from 1999 to 2002. The programme was multidisciplinary and meant to strengthen collaborations between researchers in physics, chemistry and electronics.

The research proposals were reviewed by a panel including the following persons: Mr Pauli Immonen, Chair, (Nokia Research Center, Finland), Prof. Simon Middelhoek (Delft University of Technology, Netherlands), Prof. Nathan Cheung, (University of California, U.S.A), and Prof. Erik Janzen (Linköping University, Sweden). The research results were evaluated by a panel of experts who were Prof. Simon Middelhoek, Prof. Nathan Cheung and Prof. Eric Larkins (University of Nottingham, England). Prof. Juhani Kuusi (Nokia Research Center) was kind enough to evaluate the impact of the EMMA programme to society. On the behalf of the Academy of Finland I wish to thank all the experts for their highly important work. The Academy is especially grateful to Profs. Middelhoek and Cheung for their invaluable contributions both as referees and evaluators of the EMMA programme.

The experts were asked to focus their evaluation on the following issues in particular:

- To what extent the objectives of the research programme were met
- Evaluation of the research programme as a whole (e.g. relevance, effectiveness of the programme)
- Recommendations for future research programmes

I would like to see that the experience and knowledge achieved through this research programme would advance multidisciplinary basic research of electronics in future.

Helsinki, October 15, 2002

Pekka Hautojärvi
Chair of the Programme Committee of EMMA

Introduction

New research programmes are launched by the Academy every year, and their importance has grown considerably. A programme consists of a number of interrelated projects within the same target area of research. The aims are to raise the quality of research in the field, to create a sound knowledgebase, to increase networking between researchers and to intensify researcher training. Social relevance is also a very important factor when decisions are made about new programmes.

The objectives of the Research Programme on Electronic Materials and Microsystems were to promote basic research that supports new innovative applications, to support the ongoing research and development effort within the Finnish electrical and electronics industry, and to support applied research funded by the National Technology Agency and Finnish industry. At the same time the programme supported the development of research environments within university units, which is crucial in improving researcher training opportunities. A high standard of research and highly competent research personnel are crucial factors in the continued growth and development of the sector. The programme was also used to encourage broader co-operation with Finnish and international research groups.

Evaluation Procedure

The evaluation of EMMA programme was performed in two parts: the scientific evaluation by international evaluation panel and evaluation of the impact on society by a representative of industry. During the summer 2002, the evaluators received the following documents:

- English programme memorandum
- List of EMMA projects (Appendix 2)
- Applications and research plans
- Reports
- Three most important publications from each project

On 4-5 September 2002, the scientific evaluators visited the Academy of Finland in Helsinki. The evaluators were asked to find answers to the questions given in the assignment (Appendix 1) as well as to give recommendations for future research.

For the evaluation of impact on society the same material was given, but the evaluation was performed separate from the scientific evaluation.

Contents

I Scientific Evaluation of the EMMA Programme

General

The wider goals of the Electronic Materials and Microsystems (EMMA) Programme were "to promote basic research leading to new innovative applications; to support the ongoing research and development effort within the Finnish electronics and electrical industry; and to support applied research funded by the Technology Development Centre and the Finnish industry." The Programme also had important goals in the development of research infrastructures - particularly in attracting students to the physical sciences and training them to become valuable researchers. Thus, the Programme's objectives can be expressed in terms of the quality of basic research, exploitation, team-building, networking and research training. The overall scientific quality of the basic and applied research was excellent. The quality and extent of the exploitation plans varied extensively. Although much valuable intellectual property was created, further attention should be given to its identification and exploitation. The team-building was excellent for several of the research consortia, but the Academy should continue to promote the interaction between academic research groups. Some groups were practiced in national and international networking, while other groups remained somewhat isolated. The Academy should emphasize and facilitate networking, particularly through international collaborations and joint research projects. Exchange of personnel is seen to be particularly effective at building international collaborations. The research training experiences created through the EMMA Programme were seen to be of the highest international standard. The numbers of students involved was also impressive, although the Evaluation Committee would have preferred to see greater emphasis on doctoral training.

The scientific focus of the EMMA Programme was directed towards stimulating research and development on materials and technologies, with an emphasis on microsystems. The response of the Finnish scientific community to the Programme was enthusiastic, with 67 groups cooperating to produce 30 proposal submissions. The average proposal quality was very high and the competition for funding was tight. Of these 30 submissions, 17 were recommended for funding by the Evaluation Committee of which only 11 could be funded. In view of the importance of the Finnish electronics industry, the Evaluation Committee believes that a higher level of funding is imperative to support economic growth in this area. Given the limited resources available, the division of funding appears to have been well distributed, but the funding cuts reduced the scope of a number of productive research consortia. The funded projects addressed a range of relevant scientific, materials and technology issues, which included MEMS-related materials and fabrication technology, growth of novel electronic and optoelectronic materials, synthesis of functional and conductive polymers, and the development of supporting numerical modeling tools.

In view of the importance of the Finnish electronics industry, the Evaluation Committee believes that a higher level of funding is imperative to support economic

growth in this area. Given the limited resources available, the division of funding appears to have been well distributed, but the funding cuts reduced the scope of a number of productive research consortia.

Results and Outcomes

The overall quality of the research output was outstanding, with several groups achieving international stature with their results. The research results have been disseminated widely in reputable journals and important international meetings. The EMMA Programme has stimulated many of the research groups to explore the industrial applications of their research. Nevertheless, the successes of the EMMA Programme can only be regarded as a first step in the stimulation of this research area and it is important that these efforts receive continued support.

Most consortia pursued the objectives set forth in their original proposals. At the same time, a number of groups showed considerable flexibility in their research approach, allowing them to take advantage of exciting opportunities arising from their research. The Evaluation Committee view this flexibility as important for university research and found that the research consortia exercised this academic freedom responsibly.

The quality of the publications selected for consideration by the Evaluation Committee were judged to be of international caliber and the Programme generated a very respectable number of publications. The Programme also supported the education of numerous well-qualified graduates, who are clearly in demand by Finnish industry. The research consortia produced a significant amount of intellectual property and a number of patent applications have been filed. In addition, the Programme has supported the development of a number of important materials growth processes and fabrication technologies, which will be important to the success of future Finnish R&D activities. Nevertheless, paths to exploitation are not always identified by the research consortia. The Academy should provide guidelines and encourage researchers to identify and explore exploitation opportunities.

The training of researchers has been outstanding in both quality and quantity, although the Evaluation Committee feels that the Academy's goals would be better served by an increased emphasis on doctoral and postdoctoral training. Team-building is a long-term activity and the different research consortia advanced to different levels in this process. This should be an area of continued emphasis by the Academy.

Networking

The EMMA Programme has stimulated interactions between research groups across Finland, encouraging them to view their research activities in a broader context. Through these interactions, researchers have been stimulated to consider the industrial applications of their research. Several research consortia also interacted effectively with international research groups, allowing them to access their

specialist expertise. Although the networking between groups appears to be increasing, the establishment of effective and lasting networks requires time and effort. The Academy should continue to encourage the synergetic interaction of research groups.

The level of interaction with Finnish and foreign industry varied greatly between projects. Some groups were quite effective in their networking activities, while others appear to have made little effort to reach out and establish effective collaborations. The importance of the symbiotic interaction with Finnish industry is self-evident. The interactions with foreign industry / universities, however, also played an important role in several of the projects and should be further encouraged.

Coordination

The Programme Coordinator produced documentation, which clearly identified the goals of the EMMA Programme and solicited a large response from the research community. The Programme Steering Committee established and maintained effective links with the National Technology Agency (TEKES) and oversaw the proposal selection and evaluation processes. The Project Coordinator has maintained an awareness of global international developments through his attendance at key international meetings. The Programme Coordinator has organised annual meetings of the EMMA research consortia. These annual meetings provided important networking opportunities, which are seen to have been particularly valuable for students. The EMMA website is very informative and provides high visibility for both the Academy and the research teams. The website also represents an important mechanism for popularising the research activities and topics.

Recommendations

- The Evaluation Committee strongly recommends the continuation of the EMMA Programme, but emphasise the need for an increased level of funding. The goal of the Academy should be the funding of 40% of the research proposal submissions, with less than half the level of funding cuts made in the current EMMA Programme.
- Although the research output was of very high quality, the Evaluation Committee is concerned by the differing levels of funding transparency of the different research groups. In several instances, groups received funding from many sources and it was difficult to determine the added value provided by the funding of the EMMA Programme. As a result, it is difficult to compare the performance of large, well-funded research groups and smaller groups. Furthermore, insufficient funding transparency may raise concerns about the allocation and protection of intellectual property rights. The Committee appreciate that the problem of transparency is complicated by the discrepancy between the duration of the project funding and the time required for the completion of a PhD.
- The Evaluation Committee therefore also recommends that the duration of future programmes be extended to four years. This will serve the multiple

purposes, including improving the coordination between the research projects and the support of doctoral students; increasing financial transparency; and encouraging the pursuit of non-incremental research technologies.

- Although not related to the EMMA Programme, the Evaluation Committee is also concerned by the relatively long time between Calls for Proposals, which makes it difficult for researchers to respond to new research topics and ideas. We therefore recommend that the Academy consider increasing the frequency of the responsive-mode funding cycle to at least twice per annum.
- The Evaluation Committee was surprised to observe that it was common practice to support undergraduate M.Sc. students with Academy funding. Although the Committee appreciates the need to encourage students to pursue careers in the physical sciences, it was believed that such subsidies should be provided by the Ministry of Education. The limited research resources of the Academy should be devoted more towards the research training of doctoral students and postdoctoral researchers.
- The Evaluation Committee recommends regular communication and visits by the (full-time) Programme Coordinator to the individual research facilities. This should occur approximately every 6 months. The Programme Coordinator should also participate in the annual meetings of the individual consortia.
- The Evaluation Committee noted that different levels of awareness of exploitation opportunities amongst the research consortia. The Programme Coordinator should promote greater awareness of exploitation opportunities amongst the EMMA Programme members.
- The Evaluation Committee observed different levels of integration within the research Consortia. The Evaluation Committee recommends the introduction of team-building activities/mechanisms (e.g. annual retreat, cross-country skiing, ...)
- The Evaluation Committee was impressed by the EMMA website, but felt that there were further opportunities to reach out to Gymnasium students (e.g. through school visits, summer research internships, etc.).
- From a topical perspective, the Evaluation Committee noticed a lack of emphasis on systems aspects. For example, the integration of electronics with MEMS for the creation of innovative “smart” microsystems, which create added value are becoming increasingly important for modern products.

II Impact on Society

The Electronic Materials and Microsystems Research Programme targets to an area of growing importance. With a better application of materials science many limiting factors of the current electronic product applications can be pushed forward, and on the other hand also creation of totally new applications becomes possible. New functional materials and tailoring of materials for optimum performance of different functions offer possibilities in this field. New cost effective sensors and MEMS structures, when combined with advanced information and telecommunications technology, give totally new visions for information acquisition and managing of our daily living environment. Currently, in many demanding electronics applications major challenges are set for further miniaturization, higher frequencies, and high reliability, to name a few. Overcoming these needs more fundamental knowledge of materials and their properties. It is becoming also more important that electronic circuit and system design take into account the physical boundary values set by the semiconductor and packaging materials. Here important aspects are phenomena in the interface of different materials and compatibility to other materials and manufacturing technologies.

The work with materials and microsystems needs combined expertise of physics, chemistry, electronics, materials science, and computational methods. In the work of many groups of the Research Programme, this has been succesfully carried out. This way the program is also having a positive impact on creating networks of different research groups and disciplines. In the future work, this would most probably be an asset also for work with other subjects, thus creating longer term and wider impacts beyond the scope of this programme. From the industrial exploitation point of view, work with electronic materials involves co-operation of wide supply chain containing material manufacturers and electronic design providers. Thus, the economic and social effects are reflected to a wide community.

All the projects in the Research Programme have produced a large number of publications, and thus the scientific reflectance of the projects has been taken care of. Actually, some projects are reporting even incredibly high number of publications considering the time and resources, which actually gives a reason to suspect that the reported papers have partly been mixed with the outcomes obtained by other funding. Also the education of researchers has been done in an appropriate manner.

However, the number of created intellectual property should be bigger. Only one project has reported patents. Of the provided documents, it is unclear if other projects have pending patents or if the research groups are not reporting patents created during the project but owned by the co-operating companies, but as a whole more attention should be paid that in these emerging technology areas an appropriate consideration of intellectual property issues is taken in an early stage. Many of the projects have produced results which are potentially having wide industrial applications after some further development.

The portfolio of the research projects in the Programme covers well the different aspects of electronics materials and microsystems. However, the reliability and durability issues are not explicitly addressed in any project. As this is one of the important aspects to be assessed when new technologies are taken into use, it would be beneficial to have some evaluation work going on in the early research phase already.

APPENDIX 1

The Academy of Finland
Research Programme for Electronic materials and Microsystems July 26, 2002

Assignment

The Evaluation of the Electronic Materials and Microsystems (EMMA) Programme

The final evaluation of EMMA is divided into two parts: The international evaluation of the scientific quality and the reaching of the original objectives of the programme, and the self-evaluation of the relevance and effectiveness performed by the groups. The international evaluation is conducted by Professor em. Simon Middelhoek (Chair) from Delft University of Technology, Professor Nathan W Cheung from the University of California and Professor Eric C Larkins from the University of Nottingham.

The evaluation of the programme should focus on whether the goals of the programme were met, what was the contribution of the programme to the society and what was the added value of the programme to the consortia (e.g. to the scientific work and to the researcher training). The evaluation should also give recommendations for future research programmes and bring out the strengths and weaknesses of the EMMA programme and research consortia in general. The evaluation of the EMMA programme should concentrate on the whole programme and research consortia rather than on the projects and researchers individually.

The evaluation panel is expected to find answers to following questions:

- Were the objectives of the programme at different levels realistic?
- Were the common scenarios and main points of emphases of the programme appropriate?
- Was the right amount of projects funded? Was the division of the funding between selected projects optimal?
- How well did the projects fit into the EMMA programme?

- What is the scientific quality of the research results obtained (innovativeness and significance to the development of the field of research)? Have there been any scientific breakthroughs, are any such breakthroughs on the horizon? How have the other scientific objectives of the programme been reached?
- Was there productive co-operation with Finnish / foreign partners?
- How did the achieved results respond to the original research plans?

- What was the amount and quality of publications / degrees / possible patents in the programme?

- Did the selected projects meet the objectives of the research programme in terms of their plans?
- How has programme membership been reflected in the work of the research groups?

- What kind of success has the programme as a whole had with regard to integrating and synthesising the results?
- Are there scientific, social, economic or technological impacts in sight that are in line with the objectives set for the research programme? If so, what kinds of impacts?
- Recommendations how to improve and develop the research in the current field
- Any other comments

APPENDIX 2

List of Projects:

Microelectronics materials in scaled-down systems (3 200 000 FIM)
Ahopelto, Jouni (VTT Electronics)
1 100 000 FIM
Lipsanen, Harri (Helsinki University of Technology/Optoelectronics)
500 000 FIM
Pekola, Jukka (University of Jyväskylä/Nanotehcnology)
1 000 000 FIM
Tulkki, Jukka (Helsinki University of Technology/Computational Engineering)
600 000 FIM

High aspect ratio microstructures - HARMS (1 800 000 FIM)
Franssila, Sami (Helsinki University of Technology/Microelectronics Center)
850 000 FIM
Kuivalainen, Pekka (Helsinki University of Technology/Electron Physics)
650 000 FIM
Leppihalme, Matti (Helsinki University of Technology/Optoelectronics)
300 000 FIM

Interfacial compatibility and reliability of ultra-high density solderless electronics (1 800 000 FIM)
Kivilahti, Jorma (Helsinki University of Technology/Electronics Production Technology)

Fabrication of thin films for electronics by Atomic Layer Epitaxy and electrodeposition (1 700 000 FIM)
Leskelä, Markku (University of Helsinki/Inorganic Chemistry)

Multiscale processing and modeling of silicon wafers and structures (2 400 000 FIM)
Lindroos, Veikko (Helsinki University of Technology/Physical Metallurgy and Materials Science)
800 000 FIM
Kaski, Kimmo (Helsinki University of Technology/Computational Engineering)
(Modelling of electronics materials processing and microelectromechanical systems)
800 000 FIM
Nieminen, Risto (Helsinki University of Technology/Physics)
(Multiscale modelling of Si processing and Si-based microelectromechanics)
800 000 FIM

Porous silicon as material for gas and humidity sensors
Niinistö, Lauri (Helsinki University of Technology/Inorganic and Analytical Chemistry)
1 700 000 FIM

Design and fabrication of advanced semiconductor structures and devices for optoelectronics (6 200 000 FIM)
Pessa, Markus (Tampere University of Technology/Optoelectronics Research Centre)
2 600 000 FIM
Keinonen, Juhani (University of Helsinki/Physics)
(Atomistic characterization and ion beam modification of optoelectronic materials)
800 000 FIM
Nieminen, Risto (Helsinki University of Technology/Physics)
(Modelling and simulation of semiconductor materials and strucures)
1 000 000 FIM
Ristolainen, Eero (Tampere University of Technology/Electronics)
(Materials, components and microsystems for optoelectronics)
300 000 FIM
Rosenberg, Rolf (VTT Chemical Technology)
(Secondary ion and neutral mass spectrometry of impurities in semiconductors)
500 000 FIM
Saarinen Kimmo (Helsinki University of Technology/Physics)
(Materials, components and microsystems for optoelectronics)
1 000 000 FIM

Materials-based microwave filter Technologies (1 000 000 FIM)
Salomaa, Martti (Helsinki University of Technology/Materials Physics)

Characterization of defects in novel silicon-based materials systems (4 700 000 FIM)
Sinkkonen, Juha (Helsinki University of Technology/Electron Physics)
1 700 000 FIM
Lepistö, Toivo (Tampere University of Technology/Electron Microscopy)
600 000 FIM
Punkkinen, Risto (University of Turku/Electronics)
1 200 000 FIM
Räsänen, Markku (University of Helsinki/Physical Chemistry)
600 000 FIM
Saarinen Kimmo (Helsinki University of Technology/Physics)
600 000 FIM

Structural and functional approach to polymer materials (3 400 000 FIM)
Sundholm, Franciska (University of Helsinki/Polymer Chemistry)
600 000 FIM
Ikkala, Olli (Helsinki University of Technology/Materials Physics)
(Supramolecular hairy rods poymers:
Building blocs for controllable electroactive materials and Nanocomposites)
600 000 FIM

Seppälä, Jukka (Helsinki University of Technology/Polymer Technology)
(Functional polymers of electronics)
600 000 FIM
Serimaa, Ritva (University of Helsinki/Physics)
(Order in complex polymer materials)
600 000 FIM
Sundholm, Göran (Helsinki University of Technology/Physical Chemistry and Electrochemistry)
(Electrochemical characterisation of functional polymer materials and interfaces)
400 000 FIM
Wilén, Carl-Eric (Åbo Akademi/Technical Polymer Chemistry)
(Preparation of functional membranes by irradiation grafting)
600 000 FIM

High-Q micromechanical oscillators (1 600 000 FIM)
Tittonen, Ilkka (Helsinki University of Technology/Metrology Research Institute)

The scientific quality and the impact of the Academy of Finland's Research Programme for Electronic Materials and Microsystems (1999-2002) have been evaluated by international experts. The programme was carried out in 11 projects by more than 50 researchers. The scientific focus of the programme was directed towards stimulating research and development on materials and technologies, with an emphasis on microsystems.

The overall scientific quality of the basic and applied research within the programme was excellent, with several groups achieving international status with their results. Researcher training was outstanding both in quality and quantity. However, the number of created intellectual property should be bigger, and the reliability and durability issues were not explicitly addressed. These are important aspects to be assessed when new technologies are taken into use. Ongoing research and development efforts within the Finnish electronics and electrical industry need to be supported by basic research.

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