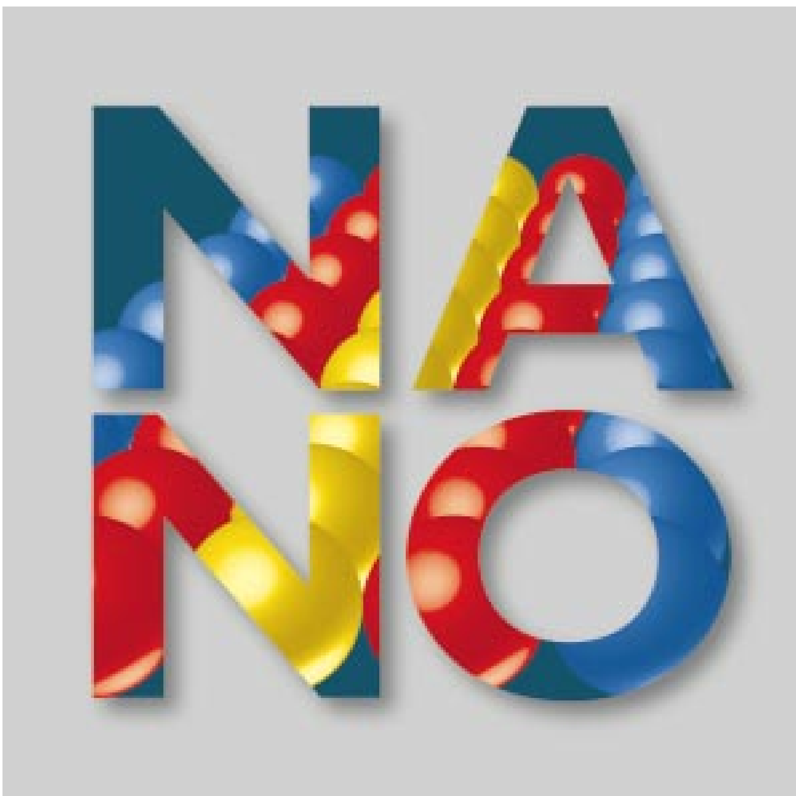
Nanotechnology Research Programme 1997–1999

Technology Programme Report 11/2000

Evaluation Report



TEKES

Nanotechnology Research Programme 1997–1999

Evaluation Report

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ACADEMY OF FINLAND

TEKES

National Technology Agency

Technology Programme Report 11/2000
Helsinki 2000

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Tekes' primary objective is to promote the competitiveness of Finnish industry and the service sector by technological means. Activities should diversify production structures, increase production and exports, and create a foundation for employment and social well-being.

Tekes supports applied and industrial R&D in Finland with about two billion Finnish marks annually. Tekes offers excellent channels for technological co-operation with Finnish companies, universities and research institutes.

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The technology programmes for developing innovative products and processes, are an essential part of the Finnish innovation system. These programmes are characterised by close co-operation between industry, the universities and research institutes. The programmes also form a solid basis for international co-operation. Currently there are more than 60 technology programmes.

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Preface

Technology programs form an essential part of the Finnish innovation system, ranging from those having a clear industrial emphasis to those that aim at very long-term objectives and address those issues in which an industrial backbone has not yet formed.

The Finnish National Nanotechnology Program clearly falls under the latter category. It was the first program to be planned and cofinanced by the Academy of Finland and Tekes and the first that addressed both scientific and technological issues. Because of this pioneering role, it is felt that this evaluation report adds insight and provides guidelines about how similar programs should be carried out in the future.

The program was initiated in 1997 and the projects completed by the end of 1999. Financing of the program amounted to FIM 43.9 million, out of which the Academy financed FIM 18.3 million and Tekes FIM 25.6 million. A total of 16 projects were financed. Industrial funding was negligible, since it was not considered to be a prerequisite.

As a multidisciplinary field, nanotechnology embraces sciences such as physics, chemistry, biology, medicine and materials science. Consequently, research tasks were organized under five headings:

1. Nanobiology
2. Self-organized structures
3. Functional nanoparticles
4. Nanoelectronics
5. Biomaterials for information technology

One of the objectives was to promote understanding and cooperation between different tasks. To a certain extent this was realized, but naturally each group had the freedom to select their partners.

Special attention was devoted to international benchmarking in the preparatory and early phases of the program. Due to the precompetitive nature of the field, international levels of research and cooperation were considered mandatory.

Tekes wishes to take the opportunity to express its cordial gratitude to program evaluators for their work, to its sister organization the Academy of Finland for its cooperation, and last but not least, to the research groups that made all this happen.

Helsinki, February 2000

Tekes, the National Technology Agency

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1.1 Introduction

1.1.1 Program background and motivation

Nanotechnology the science and engineering of extremely small (~1–1000 nm) structures has emerged in recent years as a major research theme in fields ranging from microelectronics to biomedicine to structural materials. Indeed, it is not unreasonable to assert that advanced work in nearly every field in science and engineering entails, at some level, the understanding and control of material properties at or near the nanometer scale. It is in addition widely acknowledged that various aspects of nanoscale science and technology will have a profound and far-reaching impact intellectually, technologically, and economically in the coming years and decades.

In recognition of these trends, Tekes and the Academy of Finland initiated a joint research program, the Finnish National Nanotechnology Program, motivated by the following factors:

- The intense and rapidly growing interest in nanotechnology internationally.
- The enormous industrial potential foreseen for nanotechnology.
- The need to educate researchers equipped to explore new ideas in nanotechnology to help realize this potential within Finland.
- The need to increase the prominence of Finnish research in nanotechnology and related areas.
- The desire to foster new, interdisciplinary interactions leading to new, unforeseen opportunities for creativity and innovation.
- The need to fill the gap that exists between so-called basic research (normally funded by the Academy of Finland) and applied research (normally funded by Tekes) and to find ways to increase cooperation between these organizations.

1.1.2 Program structure

This joint Academy/Tekes program on nanotechnology began in 1997 and projects funded under this program were slated for completion by the end of 1999. Total Finnish government funding for this program was FIM 43.9 million, with the Academy and Tekes contributing FIM 18.3 million and FIM 25.6 million, respectively. The Finnish National Nanotechnology Program is the first joint endeavor of this type between the Academy and Tekes. In recognition of the long-range, exploratory nature of much current research in nanotechnology, the Academy and Tekes made the unprecedented move of joining forces to initiate and structure a research program in a manner that has proven to be highly appropriate for this subject, but was not typical for either funding organization.

Even at a conceptual level the program was not typical for either funding organization. The primary role of the Academy of Finland is to promote high-quality scientific research, whereas Tekes programs normally contain a significant amount of industrial funding and a number of industrially-based projects. This high degree of involvement from industry, with a corresponding requirement of financial commitment from participating industrial organizations, was not a prerequisite for projects funded under the Nanotechnology program, in recognition of the highly exploratory nature of much of the research to be funded. Whereas the Tekes programs are usually quite rigidly structured, with a full-time program coordinator and steering committee, it was felt that this approach would not be appropriate for the Nanotechnology program. Instead, researchers for each program were given a considerable degree of independence and encouraged to take the initiative in arranging an appropriate organizational structure for their research programs. Principal investigators and researchers for each project then reported to the corresponding funding organization according to their usual procedures.

On the program level, no coordinator or steering board was nominated. The program was too small for a full-time coordinator to be employed, and coordination of the program was therefore performed in-house. A steering board would have met with considerable difficulties in trying to steer both Tekes and Academy projects spanning a broad range of disciplines, all of which contained a very substantial component of basic research. Instead, it was decided to arrange an annual seminar for each project to report their progress and major results, with representatives from appropriate industrial organizations present. The final seminars were presented at a workshop held in September 1999 that coincided with the evaluation presentations and discussions upon which this report is based. The usual industrial representatives for the program were not present at this final workshop.

1.2 Program evaluation procedure and criteria

1.2.1 Evaluation procedure

The external evaluation of the Finnish National Nanotechnology Program was conducted by PD Dr. Christiane Ziegler of the University of Tübingen (Tübingen, Germany) and Professor Edward Yu of the University of California, San Diego (La Jolla, CA, USA). Copies of reports for each project funded under the Program were provided in June 1999 to the evaluators, and the project presentations and individual meetings and discussions between the evaluators and the project investigators were conducted at a workshop in Turku, Finland on 7-9 September, 1999. At this workshop, a representative (typically the Principal Investigator) for each project presented a 20-minute summary of the project and its major results and accomplishments. Following these presentations, the evaluators met with investigators for each individual project for approximately 40 minutes per project. Prior to the workshop, the evaluators also met with personnel from Tekes and the Academy of Finland, who provided background and contextual information regarding the Nanotechnology Program to assist in the project and overall program assessments. The final report was written by the program evaluators upon their return to their home institutions.

1.2.2 Evaluation criteria

The principal criteria for assessment of the research projects funded under the Nanotechnology Program were as follows:

- How innovative were the proposed research and eventual research accomplishments of the investigators for each project?
- What were the overall scientific and technical quality and impact of the work performed?

An additional criterion that was significant but, given the exploratory nature of most of the research projects, of lesser significance than the above criteria was the following:

- What is the potential commercial applicability of the research performed?

The individual project evaluation reports directly reflect these criteria.

For the assessment of the Nanotechnology Program as a whole, the principal criteria were the following:

- How innovative were the proposed research projects and eventual research accomplishments within the program as a whole?
- What were the overall scientific and technical quality and impact of the work performed within the program as a whole?
- What was the added value provided by Tekes and Academy of Finland funding specifically under the Nanotechnology Program?

These criteria are addressed in the summary assessment of the Nanotechnology Program.

1.2.3 Assessment of the evaluation process

In general the program evaluators felt that the evaluation procedure was quite satisfactory and in particular was effective in providing important and relevant information to the evaluators in an efficient and sufficiently complete manner. The information provided by Tekes and the Academy of Finland regarding the motivation for, inception of, and execution of the program as a whole was very helpful and necessary for a complete evaluation.

The background information (project reports) provided in advance of the workshop was very helpful. However, the evaluators felt that the reports could have been more useful and effective if a more structured format had been specified for and adhered to by the project investigators. Specifically, information on the following, provided in a clear, standard format, would have been useful: the original/proposed project goals; the level of funding provided specifically through the Nanotechnology Program and the level of ancillary funding for projects in related areas; key scientific and technical contributions, and the significance of each in the opinion of the investigators; publication lists clearly delineating papers resulting from the Nanotechnology Program; and final outcomes relative to original goals. A considerable portion of this information was in fact available in the reports, but not always in the clearest and most accessible form; in fact there was a wide variation in the clarity and completeness of different project reports. In addition, the availability of preprints/reprints prior to the workshop was sporadic.

The workshop, including both summary presentations and individual discussions, was quite effective and allowed the evaluation to be conducted in a very efficient manner (from the evaluators' perspective). The poster session following the main presentations and meetings was also useful in that it allowed the evaluators to probe specific aspects of the various technical projects in greater detail than was possible, given time constraints, in the scheduled presentations and individual discussions. The total time devoted to the workshop, and its allocation among the presentations and individual meetings, was appropriate – sufficient to provide the evaluators with a good sense and somewhat detailed impression of each individual project, while short enough to maintain the efficiency of the overall process.

1.3 Overall program assessment

1.3.1 Program rationale and justification

On the whole the evaluators were quite favorably impressed with the organization, execution, and accomplishments of the Finnish National Nanotechnology Program. Nanotechnology, broadly construed, is a key area for scientific and engineering research that will have a profound impact on current and future science and technology. Scientifically, technologically, and economically it is extremely important that Finland have a strong activity and international presence in at least certain aspects of nanotechnology research, and this program represents a significant step towards achieving this status.

In many respects one of the key priorities and justifications for initiating and maintaining a vibrant research program and corresponding knowledge base in nanotechnology is to enable assessment of new scientific and technological developments at an early stage. The existence of such a program would then allow important areas to be identified at an early stage and made priorities in Finnish research and development. Similarly, many (but not all) developments that are merely faddish can also be identified as such relatively early and prioritized accordingly, but only if knowledgeable and perceptive researchers familiar with the appropriate fields are available to provide input. For areas that are identified as important priorities for Finnish research and development, an ongoing, state-of-the-art effort in nanotechnology research will ensure that a pool of qualified and knowledgeable researchers is in place and available to move into the relevant fields and make significant contributions.

1.3.2 Scientific and technical quality

The scientific quality of the research conducted under this program was generally quite good, and in some areas was clearly at or near the state of the art internationally in the relevant fields. For example, the research projects on Coulomb blockade thermometry, quantum-dot lasers, nanoparticle synthesis via aerosol processes, and polymeric nanostructures are very competitive with state-of-the-art research programs in these areas worldwide. In many cases the research programs conducted under the Nanotechnology Program, and particularly those at the state of the art, benefited from a highly developed research infrastructure that had been established previously, and from related ongoing research programs. The groups conducting research under such favorable conditions were then well positioned to build upon their established efforts and expertise to make timely and significant research contributions. This point is noted not to detract from the accomplishments of these groups, but on the contrary to highlight the importance of an ongoing, sustained research effort with a steady record of accomplishment in a given area.

Research projects such as the VTT program on low-dimensional semiconductor devices produced state-of-the-art results in selected areas and, very obviously and perhaps more importantly, played a central and vital role via the numerous interactions of the project investigators with researchers working on other projects within the Nanotechnology Program. The program on single electronics and nanolithography at the Low-Temperature Laboratory at the Helsinki University of Technology was to some degree, and certainly has the potential to be, of a similar nature. This type of synergy is essential for effective utilization of resources, especially given the size and scope of the overall Finnish research enterprise. The value of such interactions should be recognized, and their continuation encouraged.

1.3.3 Commercial impact

In a few instances research conducted under the Nanotechnology Program had already succeeded in generating commercially relevant technology and commercial spinoffs. While this should not be an essential criterion for success in long-range, exploratory research in a field such as nanotechnology, instances in which it has been accomplished should be recognized and applauded. For example, commercial interactions and spinoffs in the program on microcavity light emitters, Coulomb blockade thermometry, surface plasmon resonance techniques, aerosol generation of nanoparticles, polymeric nanostructures, fluorescence resonance energy transfer, and DNA chip diagnostics are to be commended in this respect, although in certain cases external factors such as patents present substantial obstacles to commercialization in Finland.

1.3.4 Program structure and administration

During this evaluation several aspects of the Nanotechnology Program were mentioned by the project investigators as having been particularly beneficial, and as evaluators we agree with this overall assessment and the particular points made by the investigators. Specifically, the following aspects of the program were especially valued and should be considered for incorporation into future programs of a similar nature, i.e., pertaining to long-term exploratory technology research:

- No hard requirement for industrial funding, thereby allowing high-risk/high-reward ideas to be explored more effectively.
- Joint funding between Tekes and the Academy of Finland for long-term, exploratory technology research that falls between what are traditionally considered to be fundamental research and applications.
- Flexibility in organization and management of the research programs, along with streamlined reporting requirements appropriate for longer-term, exploratory research.
- Interdisciplinary research programs that allow for and encourage interactions among normally disparate research communities.

Although the more flexible structure suggested above is indeed more appropriate for long-term, exploratory technology research than a rigidly structured program, it would be important to ensure, in conjunction, that there is accountability and feedback to encourage high-quality, soundly motivated research. Appropriate metrics for evaluation of research productivity, quality, and impact should be developed for such programs.

1.3.5 Summary of program assessment

In summary, the evaluators felt that the Finnish National Nanotechnology Program was a very worthwhile and valuable research program that yielded a variety of high-quality, scientifically significant research results and that succeeded in establishing the groundwork for a viable Finnish-based research effort in selected areas of nanotechnology. Such an effort is important in ensuring that Finland remains at or near the forefront of research in a broad range of specific fields impacted by nanotechnology, so that new developments and important areas can be identified at an early stage and targeted and pursued aggressively in a focused manner. Given the size of the Finnish research and commercial enterprise, a broadly based exploratory research effort at the state of the art combined with aggressive, targeted research and development when appropriate is probably both effective and necessary.

Aspects of the program such as joint Tekes/Academy funding, streamlined administration and reporting requirements, and more flexibility with regard to industrial participation and funding were viewed as being appropriate and valuable for the type of research undertaken in this Program, and should be continued for similar types of research.

1.3.6 Outlook and recommendations

It is the understanding of the evaluators that continuation of a dedicated nanotechnology research program is not anticipated, but that selected aspects of the program will continue to be pursued under the traditional Tekes and Academy rubrics. We feel that this should be an effective way to proceed provided that avenues remain open for the conduct of long-term, exploratory technology research, and we encourage incorporation of some of the programmatic features highlighted and recommended above. Specifically, the program rationale summarized above in Section 1.3.1 should be kept in mind in funding of nanotechnology-related projects both under existing Tekes and Academy of Finland research programs and under new initiatives in the future. The features noted in Section 1.3.4 with regard to program structure and administration appeared to contribute substantially to the enthusiasm and productivity of investigators funded under this program, and should be incorporated in future programs focusing on research in nanotechnology and similarly long-term, exploratory areas of technology.

In addition, opportunities for interdisciplinary research in both nanotechnology and other areas as appropriate should be provided. It is likely that much of the most interesting and innovative research in coming years is likely to emerge at the boundaries between traditional disciplines, perhaps most notably at the interfaces of various disciplines with biology and medical applications.

1.4 Acknowledgements

The evaluators would like to express their appreciation and gratitude to the Tekes personnel – Päivi Piironen, Oiva Knuuttila, and Jussi Kivikoski – for their invitation to participate in this evaluation, their planning of an invaluable contributions to the evaluation process, and their overall hospitality during our stay in Finland. In addition, we would like to thank the Program investigators for the time and care taken to prepare project reports and presentations and to discuss their research with us. The efforts and enthusiastic participation of all involved helped to make the evaluation an enlightening and enjoyable process for us.

2 Detailed project reviews

2.1 Microcavity light emitters (SUPREME)

Principal Investigator:
Markus Pessa
Optoelectronics Research Centre,
Tampere University of Technology

Level of support: 8,270,000 FIM (Academy)

2.1.1 Project Scope and Summary

This research project focused primarily on the development of surface-emitting resonant cavity light emitting diodes (RC-LED's), intended for applications such as plastic optical fiber communications, displays, and signal indicators. The advantages of surface-emitting RC-LED's compared to conventional LED's include higher intensity, improved spectral purity, improved beam directionality and shape (i.e. generation of a circular far-field pattern), improved wavelength stability with respect to temperature variations, higher possible speed of modulation, and suitability for fabrication in large arrays. Within the Optoelectronics Research Centre, extensive facilities are available for III-V compound semiconductor epitaxial growth, materials characterization, and device fabrication, and for optoelectronic device characterization. These were utilized extensively for this project. Particular wavelengths of interest included 650nm for plastic-fiber-based LAN's operating at 150-500Mb/sec and for displays, and 880/980nm for low-cost short-haul plastic fiber communications. The Tekes SUPREME project was an outgrowth of an EU-sponsored program under which the theory for modification of spontaneous emission in RC-LED structures was developed and demonstrated. Initial work under the EU program was conducted primarily during the period 1994-97.

2.1.2 Innovativeness

The project investigators appear to have taken primarily established ideas and implemented them, quite effectively, in the development of RC-LED structures. For example, the epitaxial layer structures and material systems employed appear to be relatively conventional. It is apparent, however, that a great deal of effort went into the design and optimization of epitaxial layer structures for emission at various wavelengths, and the ability to grow various arsenide and phosphide compounds with good control over composition, including quaternary compounds, was undoubtedly essential. Various techniques developed for vertical-cavity surface emitting lasers (VCSEL's), such as oxide aperture windows, appear to have been employed in optimization of LED characteristics under this project.

2.1.3 Scientific and Technical Quality

The work proposed for this project was well focused and motivated, and the laboratory and investigators pursuing this work were building upon a well established, strong effort in this area. Given the well defined research focus and the availability of extensive experimental facilities and a large group of personnel, the investigators were able to realize a high degree of success in growth, fabrication, and characterization of a variety of RC-LED structures. Epitaxial growth capability is state-of-the-art, employing valved arsenic and phosphorus sources for growth by molecular-beam epitaxy (MBE). The valved phosphorus source is a relatively recent development in the MBE field and allows for growth using solid, rather than gaseous, anion sources while providing excellent control over Group V alloy composition. It is interesting that the project report suggests that cracking of arsenic to yield As_2 rather than As_4 does not improve growth. Particularly in mixed anion heterojunctions, cracked as is believed to allow for better control over interface stoichiometry, which can strongly influence the emission wavelength and optical matrix element.

Electroluminescence characterization results shown in the report indicate that good control over wavelength has been achieved at 660nm, 880nm, and 1.3µm. The linewidths appear to be quite good (as stated) for these quantum-well structures. It would be interesting to determine the inherent quantum-well luminescence linewidth (without the microcavity structure) as in indicator of the material quality within the LED structure. During the evaluation it was indicated that the spectral purity achievable in the RC-LED structures was between those achievable in conventional LED's and in vertical-cavity surface-emitting lasers (VCSEL's). Demonstrated quantum efficiency was stated to be ~20%, in comparison to ~2% for conventional LED's. Modulation at 155Mbit/sec was demonstrated and 400Mb/sec is currently targeted, in comparison to ~100Mb/sec achievable in conventional LED's.

In terms of research, the investigators appear to have made substantial progress toward development of RC-LED's at a variety of important wavelengths, consistent with the stated technical focus and the proposed project goals. The publication record presented in the report confirms the nature and extent of the technical contributions arising from this project.

2.1.4 Commercial Potential

Significant issues in this project that are highly relevant for attempts to commercialize this technology are the cost-benefit ratios for MBE vs. MOCVD and for RC-LED's vs. VCSEL's. During the evaluation the investigators indicated that other organizations had observed yields of ~40% for MOCVD-grown material and ~70% for MBE-grown material, suggesting that MBE offers potential benefits in cost of production. The cost comparison to VCSEL's needs to be investigated, as the goal stated during the evaluation was to achieve costs comparable to those for conventional LED's despite requiring an epitaxial layer structure comparable to that for VCSEL's. Simpler device processing for RC-LED's compared to VCSEL's may be a significant factor here.

In terms of commercialization and general industrial relevance, the project appears to have been quite successful. ORC has generated two spinoff companies, Coherent Tutcore in 1991 and Nordic Epitaxy ~1 year ago, and these companies appear to provide good opportunities for technology transfer to industry. The investigators also stated that they were currently negotiating with various companies for commercialization of RC-LED technology for a range of applications, notably low-cost plastic optical fiber communications.

2.1.5 Additional Comments and Recommendations

The SUPREME project was well focused technically, with clearly defined research goals and methods, building upon well established ideas and technology in the field of optoelectronics and making effective use of extensive facilities and personnel in place in the ORC at Tampere University of Technology. The research conducted is in an important field within optoelectronics and focused on a problem of significant commercial interest. Most of the work done under this project appeared to be based on ideas, techniques, and materials that were already well established within the optoelectronics research community. ORC appears to have been able to reach a level of demonstrated device performance comparable to the state of the art and highly competitive for commercialization. The issues presented as subjects for future investigation – optimization of epitaxial layer design and material quality, improvement in modulation frequency, efficiency, etc., and reliability are highly relevant for commercialization for the applications envisioned. Continued comparison and evaluation of the RC-LED technology with VCSEL's based on both performance and cost will be important. For subsequent research, a significant issue will be whether to focus primarily on integration of advanced materials and device technology at the systems level, e.g., microsystems engineering for optical and optoelectronic applications, or on development of new materials, e.g. III-V nitride semiconductors, or some combination of both.

2.2 Coulomb blockade thermometry and NIS techniques

Principal Investigator:
Jukka Pekola
Dept. of Physics,
University of Jyväskylä

Level of support: 2,250,000FIM (Tekes)

2.2.1 Project Scope and Summary

This research project involved some quite novel and interesting device concepts developed by the project Principal Investigator based on quantum phenomena in nanostructures observable at cryogenic temperatures. One project component entailed the refinement of a concept for low-temperature thermometry based on the temperature dependence of electron transport in an array of nanoscale tunnel junctions. Additional project components involved the development of normal metal-insulator-superconductor (NIS) tunnel junctions for microscale cooling, and the development of highly sensitive bolometers (radiation detectors based on radiation-induced changes in temperature) for detection of x-rays and sub-mm radiation. Research sponsored under the Tekes NANO program focused primarily on the refinement of these device concepts to a degree sufficient for commercialization, or at least evaluation of commercial feasibility. Most of the basic device concepts employed were developed prior to the start of this program, and the Principal Investigator had in fact succeeded in establishing the specific topic of Coulomb blockade thermometry as an accepted niche in the field in which he was one of the expert practitioners. The NIS cooler concept was originally proposed by others in the 1980's, and a number of groups are competitors in this area. However, the Jyväskylä group is a leader in this area with significant results in both fundamental physics and applications.

2.2.2 Innovativeness

The concept upon which Coulomb blockade thermometry is based is quite innovative and interesting from a fundamental physical perspective. The Principal Investigator for this project came up with this concept prior to the start of the Tekes NANO program, and the main goal in the thermometry component of the current project was the refinement of this device concept to a level suitable for commercialization or evaluation of commercial feasibility.

The device concepts explored under this project are quite novel and represent topics that for the most part are under extensive investigation by only a limited number of other groups worldwide. Specifically, it was stated that the Chalmers group is also working on Coulomb blockade thermometry and that the leading groups in the general area of low-temperature physics of small structures included those at NIST, Harvard, Chalmers, and Rome Institute of Solid-State Electronics.

2.2.3 Scientific and Technical Quality

In general the scientific quality of the work performed under this project appeared to be quite high, and the Principal Investigator appears to be one of the originators and current leading practitioners in the field of Coulomb blockade thermometry. The publication list in the report confirms that substantial progress in refinement of this concept for thermometry was made. Substantial progress was made in the development of passivation procedures that substantially improved device lifetime and reliability. An operating range of ~20mK – 30K has been demonstrated, with accuracy in temperature measurement of ~0.5%.

In addition to the work on Coulomb blockade thermometry, it appears that substantial progress was made in demonstration of the additional device applications targeted in this research project – NIS coolers and ultrasensitive bolometers. For these technologies, current efforts are being directed towards increasing cooling power by moving to microscale rather than nanoscale NIS devices, and the implementation of these devices in space-based applications.

The Principal Investigator appears to be one of the leaders in the specific area of Coulomb blockade thermometry, and the successful release of a commercial product based on this concept by Nanoway is quite impressive. The future directions that were indicated to be of interest in the NIS and bolometer projects also appeared to be well motivated and to provide good prospects for sound technology development and application.

2.2.4 Commercial Potential

The basic thermometry technology has been transferred to Nanoway, a spinoff company from the Principal Investigator's laboratory, and a commercial cryogenic temperature-measurement system based on Coulomb blockade thermometry is now available. A simple system with one temperature sensor costs ~20-30K FIM, and a complex system costs ~40K FIM. Additional sensors are available for ~10K FIM.

Given the goal of commercialization, it would be quite beneficial to formulate a comparison of these device concepts, including both their current level of performance and ultimate potential, with other state-of-the-art devices and measurement techniques. Criteria for comparison might include sensitivity, range of measurement, precision/accuracy, robustness, time response, etc. Based on the information provided during the evaluation it appears that the Coulomb blockade thermometry system is highly competitive overall.

2.2.5 Additional Comments and Recommendations

Pursuit of many of these ideas also allows for, and requires, exploration of a variety of issues of fundamental physical interest. At this stage it appears that continued evaluation of the real commercial and/or scientific potential of specific device concepts is appropriate, to determine whether or not pursuit of commercialization is a worthwhile and feasible goal. In addition, the conception and exploration of new concepts beyond those already demonstrated and under investigation in other laboratories worldwide as has been done under this project is to be commended and should be encouraged in future work. The Tekes NANO program is to be commended for making possible the pursuit of long-range, exploratory work such as that in this project, while at the same time encouraging and facilitating interaction with and technology transfer to industry as appropriate.

2.3 Low-dimensional semiconductor devices based on nanotechnology

Principal Investigator:
Jouni Ahopelto
VTT Microelectronics Centre

Level of Support: 2,606,000FIM (Tekes)

2.3.1 Project Scope and Summary

This research project addressed the fabrication and characterization of various types of nanoscale semiconductor structures. Specific efforts included novel maskless fabrication techniques for III-V quantum wires and quantum dots; fabrication and characterization of Si and Si-based quantum point contacts and single-electron transistor structures; investigation of metal-semiconductor-metal (MSM) photodetectors; and fabrication by molecular-beam epitaxy (MBE) of Si/SiO_2 superlattices for optoelectronic applications. An additional goal of the project was the development of experimental infrastructure required for an ongoing research effort in nanoscale fabrication and characterization of semiconductor-based structures.

2.3.2 Innovativeness

The research proposed and conducted under this project was, and continues to be, very much in the mainstream of advanced work on semiconductor nanostructures. For example, most of the nanostructure fabrication techniques that were described in the proposal are relatively well established. The device applications and demonstration vehicles proposed and pursued, e.g., single-electron transistors, quantum-point contacts, MSM photodetectors, etc. are also well established and understood. However, it was reasonable to anticipate that mainstream investigations in this highly exploratory field of research would yield new insights and require substantial scientific and technical innovation. Given the stated desire not only to pursue specific research topics in nanotechnology, but also to develop the requisite experimental infrastructure, use of these structures as vehicles to confirm that one has established the key capabilities required for nanotechnology research was quite appropriate.

2.3.3 Scientific and Technical Quality

The concepts and techniques developed for maskless fabrication of quantum wires based on selective growth over regions subjected to focused-beam ion implantation were fairly novel and quite interesting. The results presented for selective growth of InGaAs/InP quantum wires demonstrated successful growth of well-defined ridges containing InGaAs wires with decent luminescence properties (as revealed by cathodoluminescence). This work represents a significant result in maskless fabrication of nanostructures using an approach that did not appear to have been previously demonstrated elsewhere.

It appeared that much of the subsequent work performed specifically under this project (as opposed to work in collaboration with other participants, which will be addressed separately) focused primarily on Si-based materials and device structures. This emphasis appeared to arise partly from the general emphasis at VTT on Si-based materials and devices, and also from a more general recent trend in nanotechnology research towards investigation of Si and Si-based nanostructures. The Principal Investigator succeeded in fabricating and characterizing quantum wires and quantum point contact structures using silicon-on-insulator (SOI) wafers, and obtained good results in low-temperature characterization of conductance properties and TEM assessment of structure. Additional work to determine strain distributions, optimum fabrication procedures, and scattering times is likely to be beneficial.

In addition to the work performed specifically under this project, the Principal Investigator and his laboratory appeared to be important participants and valuable contributors to several other Tekes NANO research projects. For example, the work on fabrication and optical characterization of strain-induced quantum dots performed in collaboration with the group of Turkka Tuomi appeared to benefit very substantially from the

Principal Investigator's participation. It is appropriate and commendable for the VTT Microelectronics Laboratory to play a significant role technically and in providing access to facilities and infrastructure for Finnish research efforts in nanotechnology.

The NANO program appears also largely to have succeeded in providing for the improvement of experimental infrastructure available in Finland generally and at VTT specifically for research in nanotechnology. For example, the acquisition of a DI Dimension 3000 scanning probe microscope and implementation of a SEM-based system for electron beam lithography are worthwhile and valuable developments. Larger-scale facilities such as TEM and production-level electron beam lithography appear either to be accessible via collaboration or to be priorities for acquisition. Further progress in the development of research infrastructure is to be encouraged. In addition, pursuit of materials characterization and of theoretical studies and modeling will be important and should not be neglected.

2.3.4 Commercial Potential

The VTT group appears to be well positioned for industrial interaction, and to have performed well in this aspect of the project. Collaborations with Okmetic for development of SOI and Si/SiGe technology were noted, as were ongoing collaborations in which Okmetic was provided access to VTT characterization facilities. In addition the VTT group appeared to be quite heavily involved in the exploration of nanoimprinting as a potential technology for fine-scale patterning. The primary emphasis of the latter project, funded through an EU program, was on assessing and improving the applicability of nanoimprinting technology to manufacturing; this effort appears likely to provide natural avenues for collaboration with and technology transfer to industry.

2.3.5 Additional Comments and Recommendations

This research program largely succeeded in realizing, at varying levels, the basic goals proposed, namely the development of epitaxial growth, processing, and characterization infrastructure for research in nanotechnology, and the investigation of specific nanoscale device concepts and fabrication techniques. Having established a sound infrastructure for nanotechnology research and having obtained a number of state-of-the-art results in research, the logical next steps will be to (a) assess the viability of specific materials, structures, and devices for real applications and pursue promising avenues, (b) continue to develop infrastructure and research facilities in appropriate areas relevant to nanotechnology, and (c) place greater emphasis on fundamental studies of novel device concepts and applications, in addition to the most promising approaches that have become well established based on research within the field. For research in nanotechnology it is necessary and appropriate to have a significant component of fundamental, exploratory research to determine the most promising concepts that will then justify more intensive investigation and technology development.

2.4 Single electron transistor and new lithographic methods

Principal Investigator:
Mikko Paalanen
Low-Temperature Laboratory,
Helsinki University of Technology

Level of support: 3,150,000FIM (Tekes)

2.4.1 Project Scope and Summary

The research proposed under this project was quite ambitious, with technical content and objectives that were largely consistent with major topics of interest in nanoelectronics during the early and mid 1990's. For example, single-electron transistors fabricated from metallic and semiconductor nanostructures had been demonstrated in the late 1980's and early 1990's and were under investigation motivated by both fundamental physical interest and potential applications in logic and, subsequently, memory. Scanning probe nanolithography was also an area of considerable interest, with promising results having been reported by a number of research groups. The group headed by the project Principal Investigator was founded at the beginning of 1996, and a major goal in the project was to establish a major new research thrust in nanotechnology and related areas at the Low Temperature Laboratory. A viable infrastructure for research in nanoscale science and technology now appears to be in place, with a variety of interesting research results having been reported.

2.4.2 Innovativeness

As noted above, the research projects proposed in this program were state-of-the-art at the time of proposal but largely reflected then-current activities in nanoscale science and technology, and particularly nano-electronics, at that time. Nevertheless, it was reasonable to anticipate that pursuit of these projects would result in a substantial amount of new science and technical innovation that could not have been foreseen at the outset.

2.4.3 Scientific and Technical Quality

The goals of this project as stated in the proposal were quite ambitious. The research results that were described in the written report and at the evaluation meetings represented reasonable progress towards some of the stated goals, and the basic infrastructure required for continued work on nanoscale science and technology appears to be in place. A considerable portion of the proposed work was most likely handicapped by reliance upon the development and routine application of proximal probe nanolithography. An AFM patterning system was indeed developed under this project, but did not appear to have been used extensively for device fabrication.

The basic research results obtained combined with the experimental facilities and infrastructure developed through this project represent a sound foundation for subsequent research on fabrication and characterization of various types of nanostructures. Among the highlights of the research performed under this project were the following:

AFM-based manipulation of nanotubes and nanoparticles is a worthwhile and interesting accomplishment, and provides a useful tool for use in fabrication and characterization of simple nanoscale structures.

Fabrication of nanoparticles with good size uniformity using aerosol techniques is a very useful accomplishment (compare Section 2.11) and makes possible the investigation of quantum size effects, single-electron charging, and a variety of other phenomena. At the review it was stated that 7-100nm Au and Ag aerosol particles had been produced, and these should be useful for a variety of investigations. For example, scanning probe manipulation of nanoparticles and transport studies should prove quite fruitful. In addition, a number of research groups in the US are now pursuing self-assembly of arrays of nanoparticles into larger 2D and 3D structures.

A nanotube-based transistor structure was fabricated by scanning probe manipulation. However, detailed electrical characteristics of the transistor structure were not described.

Work on modeling and numerical simulation of single-electron transistors (SET's) and of SET's integrated with SQUID's and conventional FET's was also briefly discussed. Noise simulations and attempts to achieve and characterize high-frequency performance are likely to prove quite interesting. Research on these topics and also investigation of nanotubes were viewed as being among the most promising avenues for future exploration.

2.4.4 Commercial Potential

The work performed under this project was considered by the Principal Investigator to have limited immediate industrial application. However, this is not unexpected and is in fact quite appropriate for much work on nanotechnology generally given the exploratory and high-risk/high-reward nature of the field. Some specific examples of work with good industrial potential included the AFM patterning system developed under this project and specific nanoscale electronic devices for specialized applications (analogous to SQUID's).

2.4.5 Additional Comments and Recommendations

As stated above, the major benefit to arise from this project was the establishment of a viable infrastructure for research on nanoscale science and technology. For example, a 350m^2 clean room facility shared between HUT and VTT has been established. Such joint enterprises are to be encouraged, as they promote greater efficiency and are likely to enhance the degree of collaboration that exists between these institutions.

During the evaluation it was stated that synthesis, characterization, and application of nanotubes was viewed as one of the most promising areas for future investigation. Carbon nanotubes are indeed likely to be an important area of research in nanoscale science and technology. Given the intense and widespread interest in these materials, however, the project investigators should make every effort to assess the field and determine what unique and significant contributions they will be able to make, and perhaps to focus on aspects of these materials that could provide opportunities for application or interaction with industry.

2.5 Quantum dot laser and related nanotechnology projects

Principal Investigator:
Turkka Tuomi
Optoelectronics Laboratory,
Helsinki University of Technology

Level of support: 1,650,000FIM (Tekes); 1,910,000FIM (Acad. of Finland)

2.5.1 Project Scope and Summary

The primary focus of this project was the epitaxial growth of semiconductor quantum-dots and of associated epitaxial layer structures, such as Bragg reflectors, required for incorporation of such quantum dots into complete laser devices. Considerable effort was devoted to the fabrication, by three-dimensional island growth in MOVPE, of quantum dot structures with narrow size distributions and good optical quality. The project report also made mention of effort that would be devoted to growth of vertically stacked quantum dots, experimental optimization of laser structures, and theoretical modeling of lasers.

2.5.2 Innovativeness

The research proposed under this project was, and continues to be, very much in the mainstream of compound semiconductor materials and device research. However, this is an active and interesting field of research and their work has resulted in significant new contributions representative of and competitive with the state-of-the-art in this field.

2.5.3 Scientific and Technical Quality

The development and refinement of techniques for fabrication of semiconductor quantum dots using epitaxial growth techniques is an activity that remains of current interest, and the results described in the research report indicate that the quantum-dot size uniformity and optical properties achieved by this group are comparable to those achieved in other laboratories working in this area. In addition, the results described pertaining to the fabrication of Bragg reflector structures indicate that growth techniques for these structures are well established and highly controllable, comparable to those of laboratories worldwide working actively in this area. The laboratory publication list is quite extensive and indicates a high level of research productivity. The publications relevant to this research project are not specifically marked, but it appears that this project has produced a number of publications in high-quality journals.

With regard to specific research results, the fabrication of semiconductor quantum dots with state-of-the-art size dispersion and excellent optical quality was highlighted as a key contribution in the evaluation meetings. The availability of these structures made possible extensive characterization and analysis of electronic and optical properties, particularly in dots created by localized stress induced within a near-surface quantum well by dots nucleated on a wafer surface via three-dimensional island growth. AFM and luminescence results confirmed the narrow size distribution and good optical quality that was achieved. The formation of quantum dots via the combination of island growth and subsurface stress propagation appears to be a new contribution from this laboratory to the field of semiconductor quantum dots.

Substantial progress towards the fabrication of laser structures was reported, with epitaxial growth of GaAs/AlGaAs Bragg reflector structures having been achieved. A high degree of controllability in fabrication of these structures and good agreement between measured and calculated reflectivity was evident. With regard to theoretical modeling of laser structures, time-resolved photoluminescence measurements for InGaAs quantum dots were reported. The information from these studies should serve as useful input for theoretical modeling and simulation, which have yet to be performed for these structures.

2.5.4 Commercial Potential

There are a number of quite obvious industrial applications for the work performed for this project. Specifically, quantum dot laser structures are potentially of interest for optical communications and possibly sensors. Some preliminary results had been obtained in growth of III-V compounds containing small concentrations of N, which substantially reduces the energy band gap and could facilitate the realization of laser structures operating at 1.3μm, the wavelength of minimum dispersion in optical fibers.

2.5.5 Additional Comments and Recommendations

The Optoelectronics Laboratory at Helsinki University of Technology is clearly well established as an active group working in and contributing to the development of technology for quantum-dot fabrication and their application in lasers. At this stage it appears that the laboratory is well positioned to continue working at the forefront of this field. It is mentioned in the report that among the future projects planned are investigation of III-V nitride semiconductors and of integrated microsystems. In addition, at the evaluation meetings it was mentioned that investigation of photonic band gap cavities would be emphasized. Research on nitride semiconductors has experienced explosive growth over the past few years, and the keys will be to establish competitive growth capability and to determine where meaningful contributions can be made at this stage, given the large number of groups working in this field. Microsystems incorporating optical and/or sensor components is a rapidly growing field and is likely to be an important area for the future. Work in this field will involve a mix of efforts at the micron and nanometer scale.

The operation of this program under the joint auspices of Tekes and the Academy of Finland was mentioned as a particularly positive aspect of this work, as it allowed very exploratory research to be conducted on quantum-dot-based lasers. Continuation of such joint activities is very much encouraged to enable a good mix of application-oriented and exploratory research projects to be pursued.

2.6 Nano-optics and -electronics

Principal Investigator:
Martti Salomaa
Materials Physics Laboratory,
Helsinki University of Technology

No information provided.

2.7 MECA-consortium

Principal Investigator:
Vilho Lantto
Dept. of Electrical Engineering,
University of Oulu

No information provided.

2.8 New structures and components in sensors based on surface plasmon resonance (SPR) and in other photoactive devices

Principal Investigator:
Helge Lemmetyinen
Institute of Materials Chemistry,
Tampere University of Technology

Level of support: 2,848,000FIM (Tekes)

2.8.1 Project Scope and Summary

The overall objective of the project was to understand the photochemistry occuring in artificially or self-assembled molecular thin films of new molecules and apply the phenomena in molecular devices. The three particular aims were (a) to develop and test new types of photoactive molecular films for SPR technology, (b) to build up a prototype of an SPR instrument, and (c) to test the suitability of a molecular opto-electronic device, developed for the measureing of photoinduced electrical signals in ultra-thin molecular films, as components of ultra-fast photodiodes and photoswitches. This project was conducted by three groups together. The organic chemistry group from Helsinki University (HU) synthesized molecules designed by the group of the Principal Investigator (TUT) which were then used by the latter group and the group from VTT Chemical Technology. TUT was responsible for the optical characterization with high time-resolution of the molecules, delivered by HU, which were studied in solution and in thin (LB) films for gas sensor and molecular device applications. For the sensor applications VTT developed a customer-friendly small SPR machine on the basis of fixed angle detection.

2.8.2 Innovativeness

The research in the three involved groups is competitive within the global scene but mainly based on conventional ideas. Dyads as photo-active molecules have been invented many years ago. The real innovations concern smaller improvements, in particular in SPM instrumentation.

2.8.3 Scientific and Technical Quality

The search for new organic molecules which may be used for new electronic or optoelectronic devices is an interesting field of research which is followed by many groups. From a basic science point of view as well as for the development of fast and ultra-fast optical devices, experiments with high time resolution are of great importance. The TUT group is one of few groups worldwide which works in this field on organic thin film materials. These activities are of high scientific value which is reflected in a number of publications in highly ranked scientific journals, alone and together with the HU group.

The newly synthesized molecules, in particular those combining fullerenes and phytochlorin, seem to be interesting candidates for fast photoswitches. However, there are no clear visions how these molecules may be implemented in a real device.

The SPR system is cheaper and much more open than the BIACORE instrument from Pharmacia, the main competitor for this kind of instrumentation.

The VTT work is, as it should be for VTT, more technology oriented if compared to the other two groups. However, original publications are present.

TUT and VTT have a variety of national and international cooperations going on which reflects that the groups are respected within the scientific community. For the HU group no specific information on this subject was delivered during the evaluation.

2.8.4 Commercial Potential

The developed SPR system, which is already in a prototype state, will be commercialized.

If the gas sensor work will be continued this has already a market. However, so far only few test measurements were performed which do not show whether the system can compete with existing sensors.

Other molecular devices are not under direct development in these groups, therefore the project as a whole is far from showing industrial applications.

2.8.5 Additional Comments and Recommendations

The field of molecular electronics, including electronic and optoelectronic applications of organic thin films, is of current interest and is likely to remain so for the foreseeable future. Continued effort in this area is to be encouraged. To be competitive within this established field of research the groups should concentrate on such areas where they make use of a very close collaboration between the groups and make advantage of combining the expertise of organic chemists, physicists, and engineers. The collaboration within the project has worked so far but could be improved. Furthermore the groups should be more focussed on defining possible applications, even if these remain on a demonstration level.

2.9 Nanostructures in molecular electronics (NANOME)

Principal Investigator:
Henrik Stubb, Heikki Isotalo
Department of Physics, Åbo Akademi
VTT Electronics/Microelectronics

Level of support: 900,000FIM (Tekes)

2.9.1 Project Scope and Summary

This research project focused primarily on the investigation of thin-film organic molecules as electronic and optical materials for a variety of device applications. The fields of molecular electronics generally and polymer or organic-based optoelectronics are of current interest and offer a variety of possibilities for scientific investigation, technology development, and commercialization. The major goals were to develop the ability to deposit and characterize – structurally, electrically, and optically various thin-film organic materials, to demonstrate patterning of these materials at the sub-micron level, and to pursue device applications at the micron to nanometer scale. The research team for this project was largely physics-based, but planned to take advantage of the ready commercial availability of the various organic molecule and polymer constituents to be employed in the proposed work.

2.9.2 Innovativeness

The production of conducting polymer lines by imprint techniques is quite new and this group appears to be competitive in this subject relative to activity worldwide. The time-of-flight (TOF) method for measurement of mobility in ultrathin films, although developed in Vilnius, was first applied to organic materials by the Åbo group. A significant innovation resulting from work at Åbo Academi was the development of a method for producing extremely thin (several monolayers) conducting polyaniline films; conventional spin casting yields film thicknesses of several tens of nm.

2.9.3 Scientific and Technical Quality

The development of techniques for controllable fabrication of extremely thin organic films enabled conductivity as a function of film thickness to be studied. Organic thin films were fabricated and conductivity measurements were performed over length scales ranging from ~50nm to 100μm. Nanoscale patterns were fabricated using electron-beam lithography. Results were presented of conductivity measurements using Au electrodes for organic films deposited by Langmuir-Blodgett techniques as a function of electrode spacing and number of organic monolayers. In the results that were presented, it was not clear whether or not contact resistance and screening effects may have been playing a significant role; while these effects were not discussed in the report or evaluation, they warrant consideration. In particular the issue of contact resistance for metal-polymer contacts is of great interest and importance in the field generally. Thin-film time-of-flight measurements were also developed and applied to characterization of these films.

In addition to conventional lithographic patterning, stamping techniques were pursued in collaboration with another Tekes Nanotechnology program participant, J. Ahopelto. This approach to patterning of polymer materials been reported by a few groups previously. Conducting polymers were also employed as compliant Ohmic contact materials for stress-induced quantum dot structures, with what appear to be good results.

Overall it appeared that a number of interesting results had been obtained over the course of this project, and the publication list presented in the project report was indicative of a substantial level of research accomplishment.

2.9.4 Commercial Potential

With regard to industrial collaborations and potential applications, the work performed under this project at Åbo Academi led to participation in an EU project application on characterization of interfaces. Additionally, the investigation of all-plastic electrically pumped lasers was suggested. For the work performed at VTT, no direct industrial collaborations were apparent but there had been preliminary discussions with Nokia and a number of small companies with regard to all-polymer electronics and applications of nanoimprinting technology.

2.9.5 Additional Comments and Recommendations

The field of molecular electronics, including electronic and optoelectronic applications of polymer and other organic thin films, is of current interest and is likely to remain so for the foreseeable future. Continued effort in this area is to be encouraged. It is likely that interdisciplinary collaborations between physics-based groups such as the one participating in this research project and chemistry-based groups with expertise in synthesis and characterization of polymers and organics will be highly fruitful. The investigators for this project mentioned as areas for future emphasis the development and application of a variety of advanced characterization techniques such as integral mode time-of-flight measurements and photomodulation spectroscopy for characterization of transport, interface properties, etc. Such studies are likely to be of fundamental scientific interest and also relevant for use of these materials in device applications.

2.10 Technology for molecular computing and color research

Principal Investigator:
Jussi Parkkinen
Lappeenranta University of Technology
since 1.1.1999 Dept. of Computer Science,
University of Joensuu

Level of support: 1,700,000FIM (Tekes);
1,040,000FIM (MATRA);
800,000FIM (Acad. of Finland)

2.10.1 Project Scope and Summary

In this project the potential of biological materials for a new generation of computer hardware ("biocomputer") should be exploited. More specifically bacteriorhodopsin was used to build a demonstrator of an artificial color vision system. The specific objectives were (a) to define a computing paradigm, natural for biomolecules, (b) to study biomolecules, which can be used for opto-molecular computing, (c) to define basic optical and photochemical properties of chosen biomolecules, (d) to demonstrate some computing functions using optically active molecules, (e) to build a prototype system for color vision based on biomolecular components, (f) to study computational models for color vision systems.

2.10.2 Innovativeness

Bacteriorhodopsin is widely used in bioelectronics. In fact it is the most popular prototype material used there. The Principal Investigator has a good background in color vision, in contrast to the competing groups worldwide. Because bacteriorhodopsin is thought to be one of the first biosystems in real use for technical optical systems it is worth to get this knowledge also to Finland. Also the color sensor is better than others in the field.

2.10.3 Scientific and Technical Quality

The group uses changes in the retinal part of bacteriorhodopsin to tune the properties of the protein. As a main result a demonstrator for a basic color matrix element and grey level digital camera based on a bacteriorhodopsin detector matrix could be built. To achieve this, the photocycles of the new materials were studied by photochemistry and modelled carefully. The optical properties for the bacteriorhodopsin used in the artificial color vision system were derived. The technology for the repeatable production of bacteriorhodopsin based devices, the software for an artificial color vision system for adaptive color recognition, a model for high level color vision, and a simulation software for a bacteriorhodopsin based color detection matrix design were developed. The results are published in different journals some of which have a high impact factor.

2.10.4 Commercial Potential

A bacteriorhodopsin based camera was developed as demonstrator. Although the pixel size is extremely large for real applications, this shows that there may be a product such as a matrix color sensor made from proteins. However, it remains unclear whether the material itself would give any advantage if compared to conventional devices.

2.10.5 Additional Comments and Recommendations

The field of bioelectronics is extremely interesting. However, there are not many groups in Finland working in this area. Therefore the critical mass is relatively low which may lead to a non-competitive situation in the future. It should therefore be explored whether a larger effort in this area, e.g. through a new special funding program, could bring Finland into a better place.

2.11 Synthesis of multicomponent, nanostructured materials with aerosol flow reactor technology

Principal Investigator:
Esko Kauppinen
VTT Chemical Technology

Level of support: 1,500,000FIM (Tekes)
2,330,000FIM (related funding)

2.11.1 Project Scope and Summary

The project aimed at the development of a gas phase synthesis method for the production of controlled single and multicomponent nanoparticles using aerosol flow reactors operating at or near ambient gas pressure. In particular a pilot scale aerosol decomposition reactor technology for the production of nanostructured, submicron to micron sized powders should be developed. In a second effort, monodispersed metallic nanoparticles of controlled size, morphology, and crystallinity to be used in SET building blocks (compare Section 2.4) should be produced. Thirdly, the basic mechanisms during particle formation both via gas phase chemical reaction-nucleation-growth-crystallization and via aerosol droplet reaction/crystallization should be studied in detail.

2.11.2 Innovativeness

The group was one of the first groups starting to produce nanoparticles by the aerosol technique. The group is the biggest world-wide and globally absolutely competitive with the other groups. Unique is the combination of high-level reactor technology and the high-resolution TEM to control the particle growth and crystallization process.

2.11.3 Scientific and Technical Quality

The technical results are on a very good level. A variety of metallic and non-metallic materials can be produced as mono-disperse powders and the reactor technology is well understood and improved continuously.

From a scientific point of few the TEM characterization of the crystal structures obtained gave a lot of new insight into the mechanism of crystal growth. The crystal growth can now be tailored for a specific shape, size, and crystal structure.

The results are published in well-known good journals. There is a huge variety of national and international collaborations which reflects the outstanding position of this group within the global scene. The Principal Investigator is in the steering committees of the ESF-Nano program and of the European Consortium of Nanomaterials.

2.11.4 Commercial Potential

The potential for commercialization of aerosol particles is high. There are cheaper methods to produce nanoparticles but the method is highly competitive in those applications where the crystal structure of the nanoparticles has to be precisely controlled. There are already big projects running for titania powders where a major manufacturing concern has now changed from their own wet process to the aerosol method because it can be better controlled. Other projects concern the use of titania in cosmetics, catalysts, and special paints as well as multicomponent particles for controlled drug delivery together with Orion.

2.11.5 Additional Comments and Recommendations

This project is a very good example that the Tekes funding within the NANO program enabled the group to make technological inventions which can now be commercialized. These efforts should be in any way continued and supported. The collaboration between this group and other groups should be highly encouraged so that not only the commercial but also the scientific potential of such nanoparticles will be utilized.

2.12 Novel self-organized polymeric nanostructures

Principal Investigator:
Olli Ikkala
Materials Physics Laboratory,
Helsinki University of Technology

Level of support: 4,500,000FIM (Tekes)

2.12.1 Project Scope and Summary

The project aimed at the development of self-organized polymeric nanostructures based on copolymers for different applications. In the first subproject in particular basic research on tailoring properties by different concepts of copolymer self-organization was performed. The second project concerned self-organized thermosets with improved mechanical properties, i.e. high strength together with toughness and flexibility. The third project aimed at polymeric nanoparticles for temperature-induced controlled drug delivery.

2.12.2 Innovativeness

There are a variety groups working with block copolymers and their structural optimzation for specific tasks. The HUT materials group is competitive in this field of research. In the case of nanoparticles for controlled drug delivery there is a huge variety of concepts for this task, many of which are based on magnetic particles or liposomes, but also on synthetic polymer basis.

2.12.3 Scientific and Technical Quality

The results for the three projects are in detail:

A concept was introduced to combine a functional polymer with amphiphiles with matching functionality to yield self-organizing block copolymer-like materials using hydrogen bonding, coordination bonding, ionic interactions, and combination thereof. Hierarchical concepts were introduced that allow functional materials.

Phenolics, which are of great importance for various companies in the chemical industry, were studied with respect to tailor the mechanical properties of such thermosets through proper self-organization to give synergistic properties, i.e. acceptably high strength and toughness. After numerous trials with cross-linkable alkylphenols, a scientifically successful concept was identified based on hydrogen bonding block copolymers cured with novolac. Cheaper solutions were under development during the evaluation process. In particular two new routed were followed: Use poly/ethyleneoxide)-block-(poly(propyleneoxide)-block-poly(ethyl eneoxide) block copolymers cured with novolacs or resols, or using mesomorphic structures of cationic starch/surfactants as templates for phenolic curing.

Several polymer materials with various architectures suitable for temperature-controlled drug release systems were synthesized. A brain model test fo biocompatibility and drug release tests in living (rat retina) tissue was developed. Biocompatibility tests were performed and a method for drug loading to the polymeric nanostructures was developed. The controlled drug release could be demonstrated in water, in physiological salt solution, and in living neural tissue. However, so far the thermal release of drugs was not very successful in oncology because only small regions can be heated which are near to the skin. Such tumors can usually be removed by an operation and are therefore no target for controlled drug delivery. For other purposes the method may be competitive.

All three groups have published their results in very highly ranked papers, including Nature and Science. The HUT materials group has also a huge variety of national and international contacts.

2.12.4 Commercial Potential

The second project is already in collaboration with an industrial partner and is therefore commercially applied. The third and first project have a potential to be commercialized. There are already discussions with a company in the pharmaceutical industry for project 3. But there will be competition with other methods of controlled drug delivery (compare Section 2.12.3). Also the method to detect free drug in tissue (project 3) may be utilized in pharmaceutical companies. There are already a lot of applications of tissue and cell based biosensors in bigger pharmaceutical companies in Europe, but most of the development is done in house and kept confidential. Therefore a direct comparison is not possible.

2.12.5 Additional Comments and Recommendations

Because of the wide applicability of tailor-made polymeric structures this subject has strategic importance for the materials science field in Finland and should be continued and supported. The field of controlled drug delivery is very important but also highly competitive. The groups should make sure that they are aware of ongoing international research in this field.

2.13 Development of a homogeneous immunoassay based on the fluorescence resonance energy transfer

Principal Investigator:
Hans Söderlund
VTT Biotechnology and Food Research

Level of support: 1,130,000FIM (Tekes)

2.13.1 Project Scope and Summary

An immunodiagnostic tool, specifically, a fluorescence resonance energy transfer (FRET) based homogeneous immunoassay in a lipid film should be developed. The basic principle utilized is that donor and acceptor labelled antibody Fab fragments laterally diffuse in liposomes and aggregate upon bonding of the antigen. The liposomes serve to immobilize the Fab fragments onto a solid support to allow the creation of a multi-analyte microarray immunochip.

2.13.2 Innovativeness

Immunosensing is an important field on which a large number of groups is working world-wide. However, the utilization of diffusing proteins in membranes for this purpose was quite new at the beginning of the project. Still there are only two competing groups working in this field worldwide, and one of those uses a different transducer principle (electrochemical detection). A patent is held by the Finnish group which covers the whole concept.

2.13.3 Scientific and Technical Quality

The aim of the project was more on technical achievements, in line with the VTT policy. Although the final goal of a functional device was not met at the time of the evaluation, all elements needed were developed and there was a good chance to get first results within the running time of the project. Within Finland, Orion Diagnostica and Vaisala followed the project and a new project together with Orion and Wallac was initiated (compare Section 2.13.4).

So far not many of the results are published. However, the two papers delivered by the group to this specific topic are of high caliber and published in journals with a good impact factor.

2.13.4 Commercial Potential

The potential for commercialization is high. The group already launched a project together with two Finnish companies (Orion, Wallac). In this 3year project a cheap, hand-held device for immunosensing will be developed.

A demonstrator does not yet exist, because at the time of evaluation all elements of the system were tested alone, and the demonstration of the system as such still has to be proven. This should be ready till the end of the year when the project terminates.

2.13.5 Additional Comments and Recommendations

This project is a good example that the Tekes funding within the NANO program enabled the group to make technological inventions which can now be commercialized.

2.14 Development of new generation DNA-diagnostic tools

Principal Investigator:
Ann-Christine Syvänen
National Public Health Institute, Helsinki
now Uppsala University, Sweden

Level of support: 2,412,000FIM (Tekes)

2.14.1 Project Scope and Summary

The objective of the project was to develop a tool for DNA analysis based on the so-called minisequencing single nucleotide primer extension method. The miniaturization of the minisequencing assay into a microarray format should give an efficient, cost-effective, and specific mutation detection system which can be used for genotyping studies.

2.14.2 Innovativeness

The minisequencing process was developed by Ann-Christine Syvänen and Hans Soederlund several years ago when they worked for Orion. The integration of this method into a chip design was straight-forward. The main problem is the difficult patent situation in this field. The patent applications for the minisequencing method were originally held by Orion, but the European rights were sold to Sangtec Medical in Sweden. Orchid Biocomputing has recently acquired all US patent rights to the minisequencing method. Furthermore Affymetrix owns a wide patent for on chip DNA detection.

The contact printing robot is an adaption of a commercially available system.

2.14.3 Scientific and Technical Quality

The main technical achievement concerns the successful miniaturization of the minisequencing technique. The minisequencing technique itself is highly competitive if compared to hybridization tests because it allows a more sensitive way to detect single mutations. Furthermore, except the PCR and the analysis not further steps are needed if compared to four or more steps used in a “conventional” hybridization test which reduces cost and time. The scientific outcome will mainly come from the genotyping work which was started during the project and will now be continued within a new project on cardiovascular deseases.

The results are published in very good journals. There are good collaborations within Finland and the work will also be transfered to Sweden due to the move of the Principal Investigator.

2.14.4 Commercial Potential

The commercialication is completely hindered by the patent situation.

2.14.5 Additional Comments and Recommendations

It is a pity that the patent was sold and that therefore Finland cannot make a profit out of this interesting technology. But there is no easy solution how to solve this problem or how to avoid a similar situation in the future.

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