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EVA_1: Evaluating nano-oriented competence centers

Scientific Report

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EVA_1

Evaluating nano-oriented competence centers

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Forschungszentrum Karlsruhe GmbH, Karlsruhe
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Disclaimer

The information presented in this report is obtained from the answers to the questionnaires between January 2005 and July 2005. In writing the report we are reliant upon accuracy of the information provided by those who kindly completed and returned the questionnaires.

In Appendix B the technology portfolio and main fields of application were obtained directly from the responses to the questionnaire. The description of the center is based on the questionnaire response and to some extent on the information publicly available on the organisations web site.

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Executive Summary

EVA_1 is a study based on a questionnaire on technological capabilities and strategies of 41 nano-oriented competence centers from 13 countries in Asia/Pacific, Europe and Northern America (i. e. U.S.A.). Besides general aspects like type and mission of the centers the study describes a simple Boston Consulting Group-like Portfolio Matrix to specifically compare different centers from different global regions. Furthermore it analyses the relevance of 89 different micro and nanotechnologies and of different application areas and industrial sectors such as micro and nano integration centers and nano-bio centers. It identifies several differences of nano-oriented centers located in the above mentioned global regions. However, with respect to the specific thematic orientation of competence centers lists of technologies have been derived that indicate the common understanding of the most relevant micro and nano technologies in these specific areas. Finally EVA_1 lists the profiles of 42 nano-oriented centers that have participated in the study.

Acknowledgements

This study would not have been possible without the support and contributions of those who responded to the EVA_1 questionnaire.

We express our deepest gratitude for their invaluable contribution!

Personally we would like to thank Peter Hocke-Bergler for his solid contributions and profound advice in developing the EVA_1 questionnaire. Furthermore Markus Dickerhof for the time he spent discussing on how to analyse the raw data in order to extract as much information as possible and finally Steven T. Walsh from the University of New Mexico whose encouragement hardly can be overestimated.

Content

1 Introduction

The present study is focussed on identifying the character and capabilities of a number of global initiatives towards a better access to nanotechnologies and its relatives. The survey was conducted between January 2005 and July 2005. Its main motivation arises from the fact that over the last three years on average every 3 to 4 weeks a new nano-oriented center, association, initiative or the like has been either announced, founded, granted or inaugurated somewhere in the world. The authors have been particularly interested in getting a better picture of the present situation of technology-oriented initiatives in the fields of nanoscience and technology, nano and microfabrication, nanomaterials, and nano-bio integration.

Among others six Nanoscale Science and Engineering Centers (NSEC) funded by the US American National Science Foundation (NSF) as well as five Nanoscale Science Research Centers (NSRC) funded by the US American Department of Energy (DOE) gained particular attention in 2004. An estimate of approximately 30 centers established in 2004 and 2005 describes a preliminary peak of a still ongoing global development towards providing centralized access to nanotechnologies. This development started in the mid 90s of the last century and is clearly continuing. Although various centers that were recently founded are still under construction and have not yet reached their full size of operation, they promise an impact on science, technology and even economics.

The motivation of EVA_1 was to identify and understand different approaches that are taken to centralize micro and nanotechnology (MNT) as well as to understand what these technologies of miniaturisation mean if one thinks of them as steadily maturing or evolving disciplines, which start suffering under a growing public expectation of commercial success. We have been interested in getting answers to questions like the following:

- Are there different types of centers, in particular commercial centers?
- What are typical aims of centers and who do they address mostly?
- Can we see different approaches in different parts of the world?
- Is there currently something like killer-application areas, everybody strives for?
- Is there a relation between technologies provided and different application areas?

EVA_1 aims at meeting the needs of people who are interested in actively exploiting technological capabilities of nano or micro processes either in order to pursue scientific work or to develop new products. Therefore it addresses mainly questions of practical interest and is less motivated to provide insight in specific topics of nanoscience, nanotechnology or microsystem technologies. Its intention is to provide a sense of what “main stream” nano-to-micro-fabrication methods might mean to different people and organisations. Furthermore the authors were interested in relating different technologies or different sets of technologies to different industrial sectors as well as to different application areas.

EVA_1 is not a roadmap type of study as it does not provide any information on any future situation. It only covers the status in the above mentioned period of half a year. It is as comprehensive as it can be given by the response to our questionnaire and the match of definition of what "nano-orientation" means to us with the expectations of the reader. Readers interested in a roadmap approach will be pleased to know that some such studies have already been carried out in remarkable diversity[1,2,3,4,5,6,7,8].

Furthermore EVA_1 does not provide a complete list of organisations that are either infrastructure centers or networks in micro or nano technology. In terms of nanotechnology there is a recently published report of the European Nanotechnology Forum (www.nanoforum.org) on European Nanotechnolgy Infrastructure and Networks covering detailed descriptions of the situation in 28 European countries, while an additional 6 European Countries do not possess any Nanotechnology related infrastructure or network[9].

EVA_1 strongly depends on the participating centers and on the accuracy of the responses. We have tried to be as careful as possible to reflect this accuracy in our work. We would be happy if we could fuel a discussion on nano and microfabrication and therefore we would appreciate any feedback to EVA_1 in order to possibly improve its relevance for the nano and micro community. Thus the study itself is intended to be subject to regular updates. Please do not hesitate to send your feedback – referring to EVA_1 – to info@nanomikro.fzk.de or using the form given in 9.2.

Due to the time passed since we finished collecting data for EVA_1 a remarkable number of nano-oriented centers have been founded, granted or inaugurated elsewhere prior to the publication of EVA_1. Logically, these centers could not become part of this first edition of EVA_1. To give a sense of what might have happened in various countries since then a brief look at Germany indicates the vitality and dynamic development of the field of nano-oriented competence centers: an additional three nano-oriented centers have been founded in Germany since mid of 2005: *Center of Applied Nanotechnology* (CAN), *Center of Nanoelectronic Systems for Information Technology* (CNI) and the *German-*

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[1] J. Elders, R. Giasolli, S. Walsh: 2nd Edition International Micro-Nano Roadmap; Micro and Nanotechnology Commercialization Education Foundation (2004) ISBN 0-9727333-1-0

[2] H. Wicht, J. Bouchaud, R. Dixon, H. van Heeren, A. El Fatatry, F. Götz (edior): NEXUS Market Analysis for MEMS and Microsystems III, 2005-2009, A NEXUS Task Force Report-Studie (2005) ISBN 2-9518607-2-2

[3] NanoRoadSME, Nanomaterial Roadmap 2015; http://www.nanoroad.net

[4] Nanoroadmap project; http://www.nanoroadmap.it/

[5] Working Group Nanomanufacturing; http://www.nanomanufacturing.eu/roadmap.php

[6] "Foresight Nanotech Institute Launches Nanotechnology Roadmap"; http://www.foresight.org/cms/press_center/128

[7] P. Alivisatos et al.; Nanoscience Research for Energy Needs; Report of the National Nanotechnology Initiative – Grand Challenge Workshop; 2nd Edition June 2005; http://www.er.doe.gov/bes/reports/files/NREN_rpt.pdf

[8] Chemical Industry R&D Roadmap for Nanomaterials by Design: From Fundamentals to Function; Chemical Industry Vision2020 Technology Partnership Energetics Inc.; (December 2003); http://chemicalvision2020.org/pdfs/nano_roadmap.pdf

[9] M. Morrison (editor): European Nanotechnology Infrastructure and Networks (July 2005) Nanoforum.org; European Nanotechnology Gateway; www.nanoforum.org

Romanian Center for Micro and Nanotechnology. Further initiatives from other European countries are for example the Nanotechnology Network (NanoNed) in the Netherlands[10] which has been inaugurated recently and the Bar-Ilan Center for Advanced Materials and Nanotechnology in Israel. Furthermore there are the Australian Research Council Nanotechnology Network (ARCNN)[11] and the Korea-China Nanotechnology Research Center[12] both exemplifying initiatives in other global regions. In addition to those public funded initiatives a US-based initiative within the frame of the Semiconductor Research Corporation (SRC) recently gained specific attention, when among others Intel, IBM, Texas Instruments and AMD founded the Nanoelectronics Research Corporation (NERC™)[13]. Even if this particular initiative does not entirely cover the scope of EVA_1 (see 3.4) it clearly indicates that also industry aims at providing resources for universities and National Laboratories in order to accelerate nanoelectronic research (at least at U.S. universities) to benefit the long term needs of the semiconductor industry.

In summary, the preceding paragraph implies the necessity to keep in mind that the picture presented in EVA_1 might be to some extent 'snapshot-like'.

Finally Forschungszentrum Karlsruhe (www.fzk.de) – as one of 15 National Research Laboratories within the Helmholtz-Association of Germany and the publishing entity of this study – is committed to the development of nano and microsystems itself by dedicating an annual budget of approximately 43 Mio. € to this topic. Within its Nano and Microsystems Programme (www.fzk.de/nanomikro) in 2006 approximately 440 people, 20 % of which are third party funded, combine the skills of 19 different scientific and technological institutes in order to pursue cutting edge science in Nanotechnology and Microsystem Technologies.

Karlsruhe, December 2006

Matthias Kautt

[10] NanoNed, the Nanotechnology Network in the Netherlands, is an initiative of eight knowledge institutes and Philips. http://www.nanoned.nl/default.htm

[11] ARCNN, The Australian Research Council Nanotechnology Network http://www.ausnano.net/index.php?page=home

[12] The Korea-China Nanotechnology Research Center inside the Korean National NanoFab Center (NNFC), http://www.nanoctr.cn/e_view.jsp?tipid=1129086736441

[13] http://www.src.org/nri/about.asp?bhcp=1

2 Goals

Behind each attempt to study a given situation in a specific area of interest most often there is a general motivation that reaches beyond curiosity. The same is true with EVA_1. We have been interested in getting a clearer picture of new and relevant trends in micro and nano technologies as well as in identifying and classifying of potential competitors and collaborators.

By inventing the LIGA process[14] in the mid 80s of last century and being among the five leading institutions in the global community of non-silicon MEMS development and manufacturing as well as by developing novel functional nanostructures (e.g. optical metamaterials[15]) or nanomaterials[16] the Forschungszentrum Karlsruhe has shaped the world of miniaturisation in the last decades and still does so. In particular by founding the Programme of Nano and Microsystems we have committed more than 400 staff to these two converging key technologies.

However, we saw the necessity of identifying general technological 'hot spots' as well as specific strategic approaches of other institutions in this rapidly growing area. In this sense EVA_1 is also an attempt of benchmarking as it helps to identify competitors, i.e. peers, and to some extent allows the classification and evaluation of their performance and goals.

An additional goal of EVA_1 is to identify potential partners for collaboration. During the last decade there is a growing expectation towards the role of miniaturised technologies in the economic growth of various industries. Beside some impressive results for both MEMS technologies and nanotechnologies there are still areas where the capabilities of MNT have to be regarded at least as still unexploited or even unexplored. There are also unfulfilled expectations. This is true for example for the role of BioMEMS and BioNEMS during the last 5 years which is significantly behind the expectations. This is in a way surprising as in most of the developed countries an aging population seems to imply a steadily growing demand for smart technical solutions in health and home care, medical diagnosis and therapy as well as in safety and comfort appliances.

EVA_1 is not a network but might help to generate insight in the necessity and of how further steps should and could be done jointly to coordinate and link different approaches, infrastructure and institutions in MNT. In this sense EVA_1 tries to support ongoing initiatives on a regional and super national level e. g. "CAPACITIES" from the European Commission and might lead to valuable proposals for further work in this areas[17].

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[14] E. W. Becker, W. Ehrfeld, P. Hagmann, A. Maner, D. Münchmeyer; Microelectronic Engineering 4 (1986), 35-56.

[15] S. Linden, C. Enkrich, M. Wegener, J. F. Zhou, T. Koschny, C. M. Soukoulis; Science, Vol. 306, 1351 (2004)

[16] J. Weissmüller, R. N. Viswanath, D. Kramer, P. Zimmer, R. Würschum, H. Gleiter; Science, Vol. 300, 312 (2003).

[17] Proposal for a COUNCIL DECISION on the Specific Programme: "Capacities" implementing the 7th Framework Programme (2007-2013) of the European Community for research, technological development and demonstration activities; COM(2005) 443 final, Brussels, 21.09.2005; 2005/0188 (CNS)

3 Methodology

3.1 A brief review on studies and roadmaps

When it comes to nanotechnology besides enthusiasm also uncertainty seems to be quite common[18]. This might be a driving force fuelling a steadily growing number of different nano-related (road)mapping and integrating activities. And this is definitely true also for EVA_1. However, there are very interesting ongoing initiatives in Europe not only mapping specific areas of interest in the field of nano and microtechnologies[19,20] but also networking different road mapping activities[21] and mapping of infrastructure[9]. In the US the Harvard University has made a compendium mainly of US and Canadian centers. This was similar to EVA_1 in that it was motivated as a fact finding exercise for the setting up of a new center[22]. Furthermore, a mapping exercise of UK nano-micro centers has been carried out by the Department of Trade and Industry (DTI; UK). This appears very thorough and well presented but exclusively focussed on industries from Great Britain as a web based UK MNT Directory[23].

In 2005 the European-funded Thematic Network on Foresight in Information Society technologies in the European Research Area (FISTERA) published a report on R&D priorities of Europe's leading public research organisations in the field of Information and Communication Technology (ICT) also claiming that in most of the classic centers such as CNRS, IMEC, Tyndall, VTT and others the R&D work they pursue is mostly clustered around quite generic technologies[24]. This strongly supports EVA_1's approach towards evaluating the technological capabilities of rather novel nano-oriented centers. While relying on a classification of technologies that was provided by Telecom Italia Labs, the authors of FISTERA acknowledge that this classification is far from being perfect due to unclear terminology or the fuzziness of the definition of some technologies. However, they state that the quality of information publicly available differs considerably from organisation to organisation as well as it was obvious that some of those classic R&D organisations were unwilling to give sufficient information because they feared that competitors could learn too much about their strategy. This clearly indicates a general barrier for evaluation that must be overcome in a way that not only public information is collected but also specific information is given on request. It is indispensable to further make it clear to participants of a study that they will also benefit from their participation.

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[18] R. Compañó, A. Hullmann: Forecasting the development of Nanotechnology with the help of science and technology indicators; Nanotechnology 13 (2002) 243-247

[19] e. g. NanoRoadSME; Nanomaterial Roadmap 2015: http://www.nanoroad.net/

[20] Outcome of the Open Consultation on the European Strategy for NANOTECHNOLOGY, Dec 2004; Nanoforum.org; European Nanotechnology Gateway; www.nanoforum.org

[21] µSAPIENT Synergetic Process Integration for Efficient Micro and Nano Manufacture; EU-funded Coordination Activity in FP6

[22] http://people.deas.harvard.edu/~jones/lab_arch/nano_facilities/nano_facilities.html

[23] http://www.mnt-directory.org/

[24] B. Dachs, G. Zahradnik: R&D Priorities of Europe's leading Public Research Organisations in the Filed of IVT, Final Report, 12th April, 2005 (IST-2001-37627 Fistera – Thematic Network on Foresight in Information Society Technologies in the European Research Area (http://fistera.jrc.es/docs/priorities%20dokument%20final.doc)

Our conclusion was: as there was obviously no general methodology for evaluating different scientific institutions regarding their strategic approaches as well as their technological capabilities on a global basis and as it might become necessary to overcome motivational obstacles we would have to choose our own straight forward approach consisting of i) a web inquiry, ii) classifying micro and nano technologies as set of 8 different classes and iii) distributing a questionnaire mostly followed by interviews that enabled us to use iv) a problem specific portfolio analysis methodology commonly used in business economics for evaluating competitors on the market. The following sections describe the methodology of EVA_1 in more detail.

3.2 The EVA_1 approach

The EVA_1 approach consists of a set of consecutive steps, which have been taken between end of 2004 and the date of publication in summer 2006. As such, the present evaluation of global nano-oriented centers also considers some centers that were being newly founded and therefore not in operation by July 2005.

The EVA_1 methodology mainly consists of seven steps:

1. Definition of the scope of centers
2. Identification of most interesting centers
3. Specification of the main points of interest and creation of a questionnaire
4. Distribution of the questionnaire accompanied with individual interviews
5. Collecting of questionnaires and analysis of data
6. Dissemination of preliminary results and start of discussion
7. Formulation and publication of the study EVA_1

Preliminary results have been published and discussed at the International Conference on Commercialization of Nano and Microsystems 2005 (COMS2005)[25].

3.3 Definition of terms

Before getting started with evaluating the technological portfolio of nano-oriented centers it seemed to be appropriate in terms of convenience to 'define' the two terms ***center*** and ***nano-oriented*** as they are frequently used within EVA_1 in the following way:

- A ***center*** is an institutional entity (mostly) consisting of different partners that either claims itself to be a center (or a network) or possesses some obvious centralized administrative business structures.

[25] M. Kautt, M. Dickerhof, S.T. Walsh, K. Bittner, P. Hocke-Bergler: Global distribution of Micro-Nano Technology and Fabrication Centers: A portfolio analysis approach; Proceedings to the 10th International Commercialization of Micro and Nano Systems Conference, Baden-Baden, Germany, August 21-25, 2005 p. 165-174

- We consider **nano-orientation** as something that is either defined as such by the center itself or comprises technologies or knowledge for structuring, manufacturing, characterization and modeling of nano and/or micro materials, structures, components or systems, including their application in various industrial sectors.

In particular the second part of this 'definition' allows different types of centers to be distinguished such as 'industrial centers' on the one hand (mainly being dedicated to product development) and 'centers of excellence' on the other (mainly providing and disseminating a sound knowledge base to industrial, academic or governmental bodies).

Admittedly the given 'definition' is not as strict and precise as one would expect from say a mathematical definition. However, this breadth allows a selection of centers to be made in a way as to find answers to the questions which triggered this study.

3.4 Thematic scope of EVA_1

The main scope of EVA_1 is on centers that are focussed towards nanotechnology, nano-science and interaction with related scientific disciplines. Thus we tried to focus on 'converging' thematic priorities such as nano-micro integration; nano and micro fabrication and any evolving orientation towards the application of nano and microtechnology in life sciences. In a preliminary step we defined four thematic areas as a starting point:

- nano-science & technology
- nano-micro integration
- nano-bio orientation
- nano materials & nano and micro fabrication

Based on these priorities a web inquiry has been made. This inquiry has lead to a number of 83 centers from 17 countries that formed the base of the study. These 83 centers have been analysed and a set of specific questions have been formulated in order to form the EVA_1 questionnaire (see 3.5).

3.5 Topics of the EVA_1 questionnaire

The EVA_1 questionnaire consisted of 18 questions that covered several aspects of those centers such as

- Type of center, mission, business structure
- Customers and manners to sustain the center
- Technological portfolio
- Application areas and industrial sectors
- Budget, turnover and scientific output

Table 3.5-1 Questions of EVA_1 questionnaire

Number	Question
1	Name of Center
2	Abbreviation
3	Year of foundation
4	First year of full operation
5	Number of employees in 2005 and in full operation
6	Please classify what fits to define the type of your center
7	What of the following could be part of your mission statement?
8	Your center is focussed on meeting the needs of which of the following groups?
9	What micro nano technology is available in your center?
10	Please indicate all manners that your center sustains itself
11	If you link different partners or institutes… …you share a common web site … you act as single unit in public relations and commercialisation *… and so on*
12	What application area or industrial sector do you strive for?
13	Please estimate your annual budget
14	Please estimate your investment costs in order to set up the center
15	Average Turnover/Revenues [per year]
16	Please approximate the average number of peer-reviewed scientific publications your center generates per year
17	Please approximate the average number of doctorate students your center employs yearly
18	Please use this space to tell us anything else about micro-nano technology or fabrication centers you would like us to consider

These questions have been selected to get a fundamental image of the specific character of a center as well as of its technological capabilities and its strategic orientation towards different fields of application. Furthermore we have asked for parameters representing the scientific productivity and the attractiveness towards additional financial resources.

In order to get an impression on the technological capabilities we have classified 87 technologies in 8 categories as follows:

1. (Nano) Materials
2. Generic Structuring
3. Nanofabrication
4. Replication
5. Microfabrication
6. Characterisation
7. Simulation
8. Quality System

This list mainly displays our understanding of technological classes (i. e. categories) and thematic clusters in micro and nano technologies. Table 3.5-2 lists technologies, processes and instruments that have been identified by the authors and related to the above mentioned 8 categories. Nano and micro systems technology is a dynamic and growing field and so such a list cannot be expected to be complete but rather to list the most important and established methods. Space was available on the questionnaire for additional technologies available in the centers which had not been included in the list. Besides completeness or comprehensiveness of this list the classification we made could be well subject of arguing. We have taken into account a number of technology reviews[26,27], initiatives[28,29] and books to classify different technologies[30] as well as roadmapping activities in nanotechnology[31]. As such we hoped that the categories as well as the technologies appeared most convenient and familiar to those who completed the questionnaire.

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[26] C.A. Mirkin, J.A. Rogers: Emerging Methods for Micro- and Nanofabrication; MRS Bulletin (July 2001) 506-507

[27] Y.Chen, A. Pépin: Nanofabrication: Conventional and nonconventional methods; Electrophoresis 2001 22 187-207

[28] R.W. Siegel, E. Hu, D.M. Cox, H. Goronkin, L. Jelinski, C.C. Koch, J. Mendel, M.C. Roco, D.T. Shaw: WTEC Panel Report on Nanostructure Science and Technology; International Technology Research Institute, World Technolgy (WTEC) Division, Loyola College in Maryland (12/1998); www.wtec.org

[29] While preparing a report on the worldwide assessment of micro-manufacturing research and development Forschungszentrum Karlsruhe has been approached by a WTEC panel which allowed us to benefit from preliminary results in 2004, Finally these have been published as: K.F. Ehrmann, D. Bourell, M.L. Culpepper, T.J. Hodgson, T.R. Kurfess, M. Madou, K. Rajurkar, R.E. DeVor: WTEC Panel Report on International Assessment of Research and Development in Micromanufacturing; World Technology Evaluation Center (WTEC), Inc. (10/2005)

[30] B. Bhushan (editor) Springer Handbook of Nanotechnology Springer Verlag (2004)

[31] http://www.nanoroad.org/
http://www.4m-net.org
http://www.microsapient.org/

Table 3.5-2 Detailed set of micro nano technologies from which a selection could be made in question 9 of the EVA_1 questionnaire

Category	Technology
(Nano) Materials	• Gas phase synthesis • Liquid phase synthesis • Materials manufacturing (mechanical process) • Biomolecular synthesis • Biological coatings • LPCVD • PECVD • Electroplating • PVD (Evaporation) • PVD (Sputtering) • Si/Polysilicon/SiO_2 • SiC • Ferromagnetics • Smart materials • PZT • Polymers • Ceramic materials • Metals and alloys • Carbon nanotubes
Generic Structuring	• E-beam lithography • UV lithography • X-ray lithography • Synchrotron facility • Mechanical µ-machining • RIE/DRIE • Wet etching • Dry etching • Laser µ-machining • Sand blasting • Maskmaking devices
Nanofabrication	• Scanning probe lithography • Interference lithography • Molecular beam epitaxy • Metal organic CVD • IBAD • STM • AFM • SPM • Dip-pen nano lithography • Mechanical nanomachining • Self-assembly • Template assisted manufacturing • LADI

Replication	• Nano imprinting • Micro contact printing • Nanotransfer printing • Hot embossing • Micro casting • Thermo injection molding (TIM) • CIM • MIM
Microfabrication	• Bulk µ-machining • Surface µ-machining • Annealing • Oxidation • Doping • LIGA • UV-LIGA • HARPSS • HRMST • HEXSIL • Wafer bonding • Silicon direct bonding • Adhesion bonding • SMD • Packaging • Flip chip
Characterisation	• AFM • Auger electron spectroscopy • Ellipsometry • FIB • Nanointendation • SEM • SFM • SPM • Scratching measurement • Tribology • X-Ray diffraction/XPS
Simulation	• FEM • ANSYS • Reliability tools • CAD • Process simulation • Monte Carlo
Quality System	• FMEA • Process control • Specifications • ISO certified

The data generated from question 9 provides access to technological capabilities and the technological plurality of nano-oriented centers. As such it is an indispensable prerequisite of a portfolio analysis in order to compare different centers with each other. The portfolio-analysis of EVA_1 (see also section 2.4) consists of two dimensions where 'technological plurality' is only one of them. Whereas technological plurality is mainly specific to the internal structure of a nano-oriented center a second dimension is necessary that resembles mainly the external relationship.

Table 3.5-3 Industrial sectors and application areas as mentioned in question 12 of the EVA_1 questionnaire

Industrial sector	1. Food industry 2. Life sciences 3. Biotechnology 4. Pharmaceutical Industry 5. Chemistry 6. Defence 7. Energy 8. Automotive 9. Consumer industry 10. Information technology 11. Automation 12. Microelectronics 13. Equipment engineering
Application area	1. Security 2. Environment 3. Metrology 4. Analytics 5. Sensorics 6. Diagnostics 7. Wellness 8. Health care 9. Medical devices 10. Implants 11. Therapy 12. Science in general 13. Materials 14. Manufacturing

We have chosen industrial sectors and application areas as measure for the external relationship, i. e. the 'market attractiveness' of those centers. In order to get information on what application areas or industrial sectors those centers are striving for we offered 13 industrial sectors and 14 application areas from which a selection could be made. There might be apparent inconsistencies with the definition of industrial sectors as were given in recent documents of OECD and European Commission[32,33,34]. Furthermore industrial sectors are missing (such as

[32] http://www.uibk.ac.at/physics/info/oecd-macroth/es/1052.html

glass, wood and construction and others) due to the fact that in first instance we did not particularly focus on these industries.

However, table 3.5-3 lists industrial sectors and application areas as were offered in question 12 of the EVA_1 questionnaire. In addition we have given space for further industrial sectors to be named if they appeared to be relevant to the person completing the questionnaire. The data received from question 12 allowed the definition of ‘application plurality’ as the second dimension in our portfolio matrix.

3.6 Portfolio-Analysis method – EVA_1 approach

Even if the present study exploits a number of different methods for generating information out of the raw data sets a portfolio analysis method seemed to be most obvious to meet our requirements. Portfolio-Analysis methods are common instruments in order to compare different competitors. There exists a variety of different approaches to portfolio-analysissuch as from the Boston Consulting Group (BCG) and by General Electric/Shell. We have decided to stick to the Boston Consulting Group type of portfolio-analysis in general as it seemed to be one of the most accepted methods and also seemed to be easily adjustable to our needs[35,36].

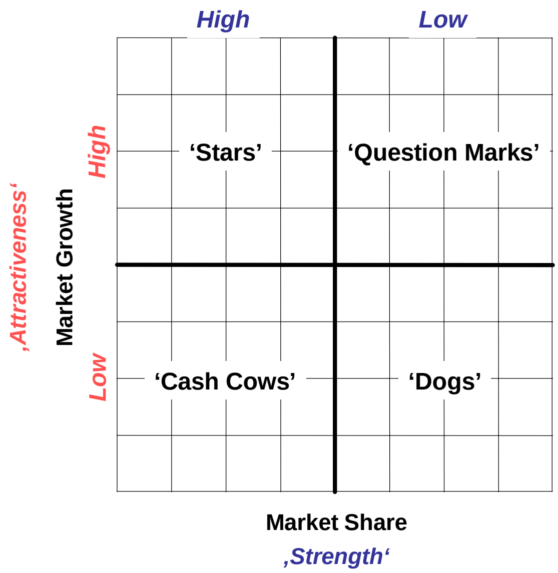

Figure 3.6-1 Boston Consulting Group (BCG) like port-folio matrix

[33] Commission staff working document; Annex to the Communication from the Commission “Implementing the community Lisbon Programme: A Policy framework to strengthen EU manufacturing – towards a more integrated approach for industrial policy” COM (2005) 474 final

[34] Commission staff working document: European Industry: A sectorial overview; SEC(2005) 1216; Brussels 5.10.2005

[35] B. Henderson; Strategic and Natural Competition (1980) in C. Stern, M. Deimler (Hrsg.); The Boston Consulting Group on Strategy: Classic Concepts and New Perspectives, 2nd Edition, John Wiley & Sons Inc (2006)

[36] B. Henderson; The Anatomy of Competition; Journal of Marketing, Vol 47, 7-11 (1983)

In general, in BCG portfolio analysis method the first step would be to identify various Strategic Business Units (SBU's) in a company portfolio. Such a SBU is a unit of a company (in our case: a center) that has separate objectives and that can be planned independently from the other business units. In a company a SBU can be a division, a product line or even individual brands, depending on how the company is organised. In EVA_1 we have replaced the term of a business unit with technology unit, i. e. the center.

By using a so-called BCG Box or portfolio matrix (see fig. 3.6-1) a company would classify its SBU according to two dimensions. Where the horizontal axis serves as a measure of SBU strengths in the market and the vertical axis provides a measure of market attractiveness. We have done it in quite a similar way by transferring the horizontal axis as a measure of 'technology strength' and the vertical axis as a measure of 'application attractiveness'.

Figure 3.6-2 shows the modified BCG approach as is used in EVA_1. It can be seen that the basic rules and intentions of a BCG portfolio matrix are still valid. But in EVA_1 SBU are interpreted as technological units that are not economically active and therefore do not apply to 'market share' as a measure for strength or to 'market growth' as a measure for attractiveness. Therefore these two dimensions have been replaced by 'application plurality' as a measure for attractiveness and by 'technology plurality' as a measure for strength.

Figure 3.6-1 also shows that there are in general four areas defined by the matrix. SBU's are classified in a way as is highlighted by the terms 'stars', 'cash cows', 'questions marks' and 'dogs'. This specific classification is not suitable to the EVA_1 as it mainly refers to economical and less to technological aspects but in general it shows that a BCG portfolio matrix allows distinguishing different types of SBU – in terms of EVA_1: different types of nano-oriented centers. This is exactly our motivation for choosing the portfolio approach.

Comparing figure 3.6-1 with figure 3.6-2 it can be seen that we have changed the orientation of strength so that the axes of the matrix will seem more familiar to the reader. This means that higher values of 'technology plurality' are drawn to the right. Consequently any 'stars' (i. e. nano-oriented centers with high technological strength and high application attractiveness) would be located in the upper right area of the EVA_1 portfolio matrix.

But as we did not want to overstrain the BCG concept we avoided classifying centers in the above described manner. However the EVA_1 approach also allows classifying of technology oriented centers. This is indicated by the terms 'diversified', 'focussed', 'dedicated' and 'comprehensive' describing the situation in different centers with different values of plurality. There are also four cases or types of centers that can be distinguished.

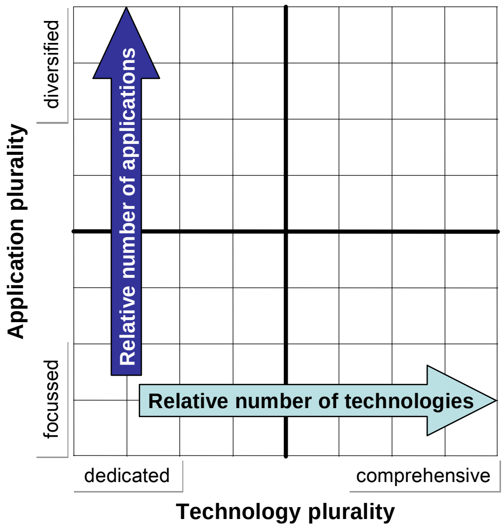

Figure 3.6-2 BCG-like port-folio matrix as used in EVA_1. Coloured arrows indicate higher values of pluralities.

Case 1 ***(high values of technology plurality/high values of application plurality)*****:**
The centers comprise a comprehensive set of micro-nano technologies and are engaged in a large variety of different (i. e. diversified) applications and industrial sectors.

Case 2 ***(high values of technology plurality/low values of application plurality)*****:**
These centers comprise a comprehensive set of micro-nano technologies and are focussed to meeting the needs of a rather low number of applications or industrial sectors.

Case 3 ***(low values of technology plurality/high values of application plurality)*****:**
These centers comprise a smaller set of micro-nano technologies. However, they are striving for a large variety of different applications and industrial sectors.

Case 4 ***(low values of technology plurality/low values of application plurality)*****:**
These centers comprise a rather small set of micro-nano technologies and are focussed at exploiting this dedicated technological capability in a precisely defined set of application areas and industrial sectors.

It is important to notice that the number of technologies available within the frame of the centers – whether it is a high or a low number – clearly does not imply any information on the quality of the particular technologies, processes and service provided by the center as well as the plurality of applications does not imply any judgement regarding specific application knowledge of the center.

4 Statistical aspects of the EVA_1 study

In order to allow an estimation of the overall quality of the statistical base of EVA_1 we provide some statistical background. Regarding the overall quality of the study it seemed important to consider at least the following two factors: the response-factor and the quality of the persons who responded to the questionnaire. Whereas the response factor is related to the attractiveness of the subject of the study to those being evaluated, the quality of the persons who responded to the questionnaire allows an assessment of the relevance of the derived information.

4.1 Response

83 centers were identified during a web inquiry and approached by the questionnaire as well as by telephone calls or interviews. The distribution of the centers according to country is shown in fig. 4.1-1. In most cases the person in the most senior management position was approached with the questionnaire. In general during telephone interviews there was mostly a good feedback indicating that the study's focus lies within the fields of interest of the management of the centers.

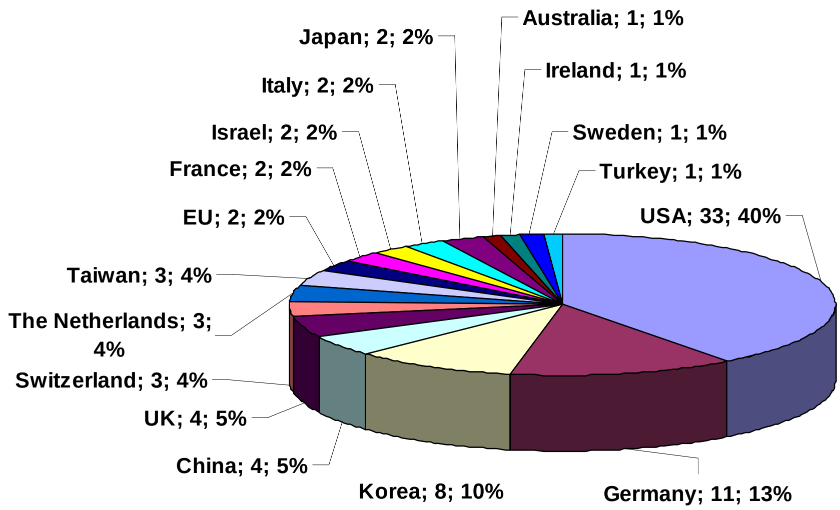

Figure 4.1-1 Distribution of 83 centers that have been identified as those who seemed to fit best to the definition given in 2.1 and to whom a questionnaire was sent.

The good feedback given in telephone interviews led to a response of 41 completed questionnaires defining a remarkable response factor of 49 %. The distribution of these 41 centers again according to country who returned a completed questionnaire is shown in fig. 4.1-2. By comparing this distribution with those in fig. 4.1-1 it can be concluded that the response is roughly representative to the initial distribution even if there is a slight over representation of European – namely German – centers. In spite of this US American centers dominate the picture of nano-oriented competence centers. With coverage of 29 % from US and 17 % from Asia/Pacific the regional spectrum of responding centers can be judged as reasonably well balanced.

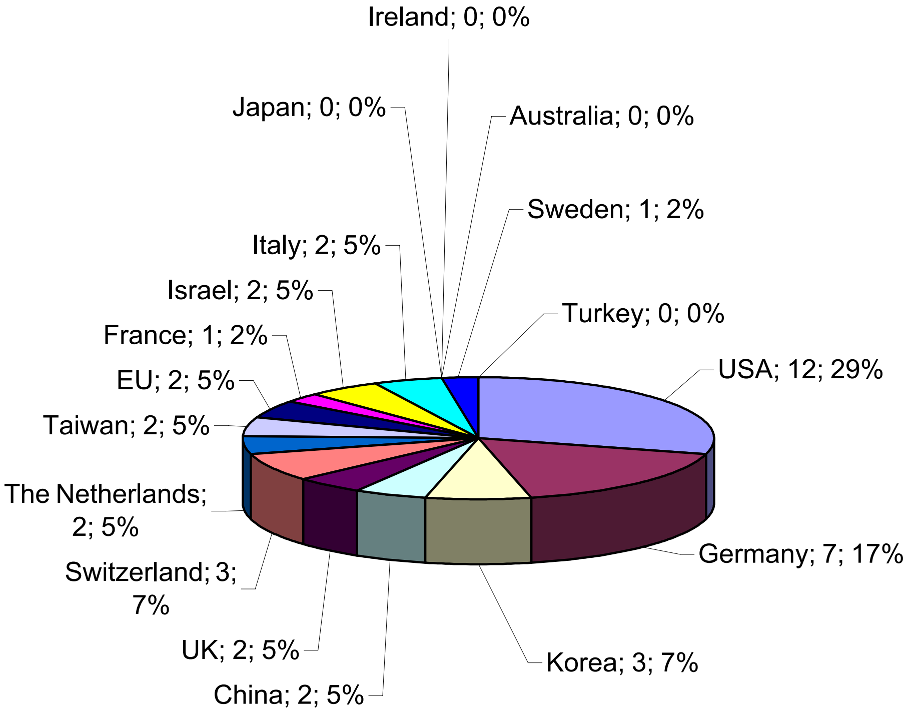

Figure 4.1-2 Distribution of 41 centers that returned the completed questionnaire.

4.2 Quality

60 % of the questionnaires have been completed by the directing persons of the centers. Another 40 % of the completed questionnaires derive from upper management such as personal assistants to the director, deputy division directors, programme coordinator, senior technical staff or the like.

Regarding the completeness of the returned questionnaires we can state that there is a remarkable high number of questionnaires that have been returned completely answered. It might be of interest to know that particularly those questions regarding the annual budget, investment costs, turnover, average number of publications as well as number of doctoral students (i. e. questions 13 to 17) have been neglected. Nevertheless there is a reliable statistical base that clearly allows some conclusions to be drawn regarding the items addressed in questions 13 to 17.

In summary, these findings indicate a rather good overall quality of the EVA_1 data base.

4.3 Additional comments to the questionnaire

Question 18 dealt with general expectations of the approached centers and with any aspects that the persons in charge would have liked us to consider. The question was intended to provide a space for relevant additional information about micro-nano technology or fabrication centers.

There was only one additional hint given regarding national nano-fabrication centers in Korea, which we greatly appreciated.

The absence of those comments are not taken negatively but rather as an affirmation that the content of the questionnaire was designed to cover most of the relevant aspects concerning those centers who responded. Unfortunately we do not have sufficient information from those centers that declined to complete the questionnaire. Many of them were approached by phone several times and mostly time constraints seemed to have prevented participation.

5 General Aspects of Nano-oriented Competence Centers

There are some general aspects of the evaluated centers that are mostly independent of the type, mission and technological orientation of these centers. These aspects are discussed in more detail in the following sections. First we have been interested in the age of those centers and their size. This is shown in figures 5 and 6 respectively. There seems to be a clear starting point for the trend of founding nano-oriented centers by funding agencies: the turn of the century 2000/2001. But it is also noteworthy that even before the mid nineties pioneering institutions established nano-oriented centers. The number of centers in fig. 5 indicates those centers that have responded to the questionnaire. So even if this means that fig. 5-1 mainly mirrors the situation represented by the 'EVA_1-centers', by assuming that the basic data set of EVA_1 is considerably representative of the global situation, we conclude that establishing centralized access to nanotechnology (and its relatives) is more or less a first common strategic trend in promotion of science in the new century.

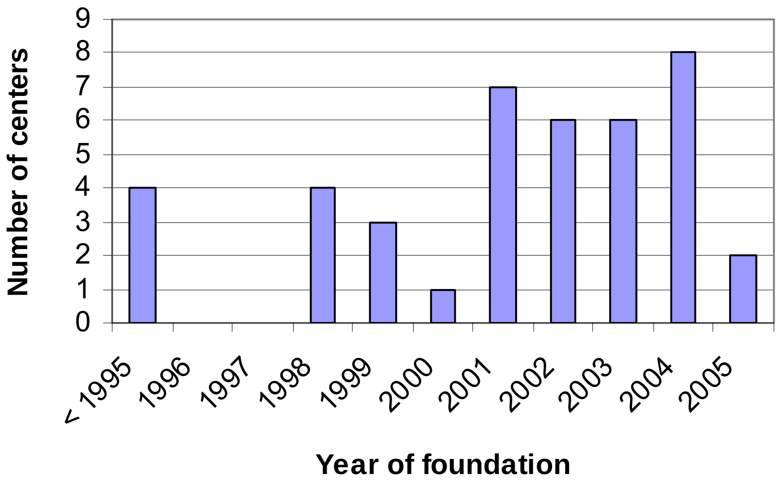

Figure 5-1 Year of foundation of nano-oriented centers which returned the EVA_1 questionnaire

Estimating the size of an average nano-oriented center proved to be one of the most difficult things for two reasons. First the number of employees is a fluctuating parameter as centers might get additional funding for various additional projects. Secondly a significant number of centers get funding for only a small managing entity, which mainly consists of a director, some senior technical staff and probably some assistants; summing to something between 3 and 6 person years. But most often partners additionally contribute to the overall staff involved in the center's work but do not participate from the center's funding. Nevertheless we were fortunate enough to receive a sufficient number of well distinguishing answers regarding this aspect so that we are able to count people involved in the center's work as a whole regardless if they are on the pay role of the center or of the center's partner organizations. Referring to this definition, fig. 5-2 shows the number of employees of the centers which responded to the questionnaire.

A majority of the centers have less than or a maximum number of 20 employees. Only a few centers are bigger than 100 employees with namely MINATEC in France as the one heading for a staff of more than 3000 after its completion. This is shown in fig. 5-2. We expect the average size of centers to increase by the next years due to the fact that recently founded centers will start full operation soon.

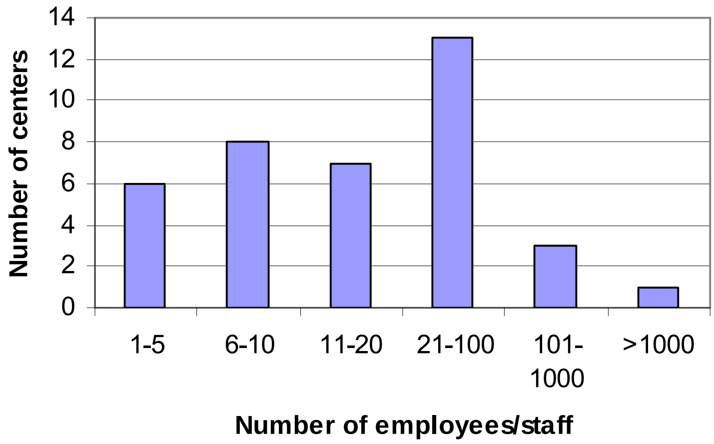

Figure 5-2 Size of nano-oriented centers (in terms of number of employees) which returned the EVA_1 questionnaire.

A side aspect is shown in fig. 5-3: the time it typically took from foundation to operation. It is apparent from the answers that once the foundation and respectively the funding is agreed upon the operation of a new center can take place within a few months. As we have asked for the time of 'full operation' – which we expected also to include investments for buildings and establishing facilities like clean rooms and the like – we have been surprised by this relatively short time frame. However, we can not rule out some sorts of misinterpretation as there might have been given also some feedback on the time of the 'start of operation' rather than of 'full operation'.

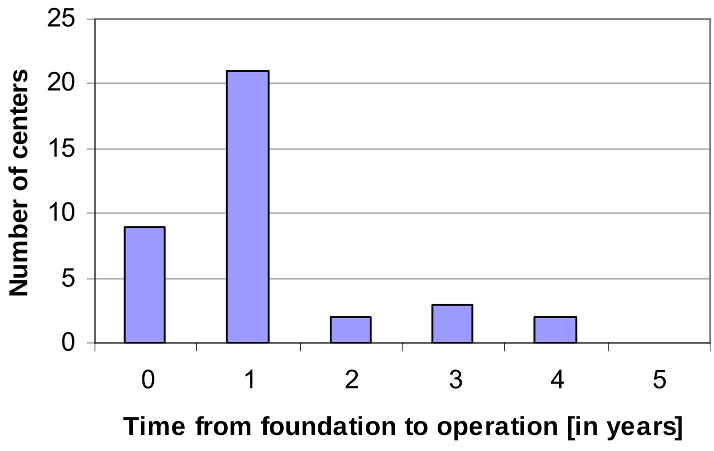

Figure 5-3 Time from foundation to operation

5.1 Type of center, mission, target groups and relationships between partners

Providing a deeper insight in the characteristics of the nano-oriented centers first leads us to the question of whether there are different approaches concerning the main strategy and thematic focuses as well as different targeted groups. Furthermore we have been interested in evaluating the relationship among the partners of a center in a way to identify potential benefits from a more hierarchical or equitable management structure, probably leading to different types of relationships between partners. The results are discussed in the following sections.

5.1.1 Type of center

In order to get basic information on the type of the centers we provided a selection of six different types, where more than one type could be selected. The selection comprised

- **R&D project:** Center fulfils a specific or specified R&D task
- **Science Center:** Center focuses on generating basic science
- **Infrastructure Center:** Center provides services and access to standardised technologies
- **Network:** Center provides access to other key players in the field and acts like a communication platform
- **Industrial Center:** Center tries to make profit
- **Association or Initiative:** Center covers someone other's interests

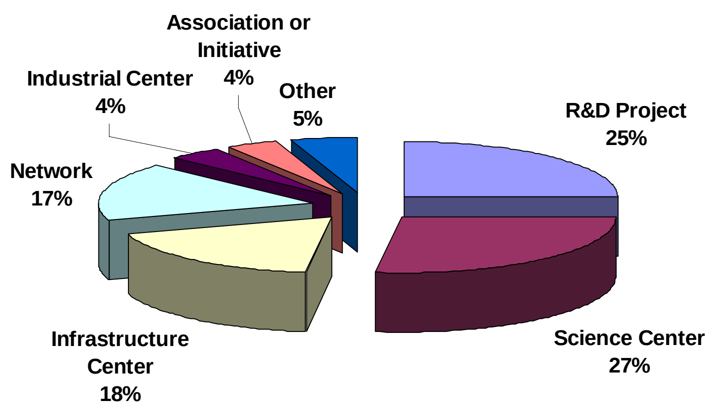

Figure 5.1-1 Distribution of answers concerning the type of nano-oriented centers. It is obvious that it's most probable to find an R&D-oriented center (52 %).

In addition a tic box has been kept free for additional types that have not been taken into account while preparing the questionnaire. One of the very rare examples of such a type was a "public/private partnership" as applies for CNT in Dresden/Germany.

Fig. 5.1-1 shows the result of question 6 ("Please classify what fits to define the type of your center"). It can be seen that there are mainly four different orientations of nano micro centers that contribute to the mission of an individual center:

1. **R&D-orientation:** Adding the respective values for "R&D project" and "Science Center" the proportion accumulates to 52 %
2. **Knowledge-orientation:** Adding the values for "Network" and "Association or Initiative" the proportion accumulates to 21 %
3. **Infrastructure:** There is a remarkable share of 18 % for providing access to technologies and processes
4. **Industry-orientation**: With only 4 % profit making industrial production does not appear to be a priority of the centers.

These findings indicate that beside various optimistic market expectations for micro and nanotechnologies the field still seems to be in a premature state where lots of R&D work and dissemination of knowledge as well as access to infrastructure – probably provided by nano centers – is necessary. This is in good accordance also with findings from Knol, who found that in universities as well as in laboratories of companies activities on micro and nanotechnology are strongly related to exploration rather than to exploitation[37].

It is remarkable that centers with a pure industry-orientation are at least quite a rare species among nano-oriented competence centers. Furthermore, a relatively high proportion of centers aim to serve as an open source for infrastructure (i.e. technologies, processes and the like) clearly indicating that "bottle necks" for manufacturing and characterisation of nanostructures, components and in future also systems are most likely not to occur. It would be interesting to evaluate whether these infrastructure centers could serve as incubators for commercial nano foundries or whether these would inhibit the development of nano foundry concepts. But this was out of EVA_1's scope.

5.1.2 Mission

Evaluating the mission statement provides access to the main intentions of a nano-oriented competence center.

By offering a selection of possible phrases for a mission statement we tried to approve the results derived from classifying the type of centers as is described in 5.1.1. Fig. 5.1-2 relates the number of scores to the different phrases. It is apparent that industrial manufacturing and production by far is the least probable

[37] W.H.C. Knol: Micro and Nanotechnology commercialisation: balance between exploration and exploitation; Proceedings to the 9th International Commercialization of Micro and Nano Systems Conference, Edmonton, Canada, August 29 – September 2 (2004) 215-220

intention of the centers. Even if this finding is in excellent agreement with the finding from characterising the type of the center it does not necessarily imply the role of industry as less important to those centers. In order to get a deeper insight into the role of industry we also asked for industry as target groups.

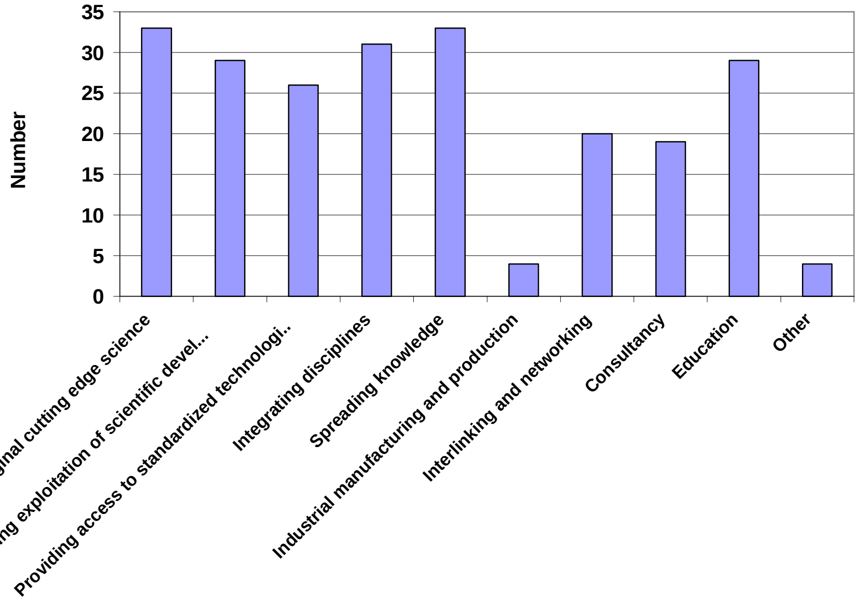

Figure 5.1-2 Distribution of scores for different phrases that could have been part of the mission statements of nano-oriented centers.

5.1.3 Target Groups

We have offered five different target groups from which more than one could be selected:

- Scientists
- Large industry
- Small and medium sized enterprises (SME)
- Associations
- Government employees

There was a spare box to be ticked in case that other target groups would have been addressed by the centers. In fact, most of the centers addressed Scientists (see fig. 10). Surprisingly “large industry” and “SME” (see the red columns in fig. 5.1-3) are significantly addressed and by summing their values they exceed even the value for scientists”. This means that “industry in general” seems to be the most frequent targeted group rather than scientists.

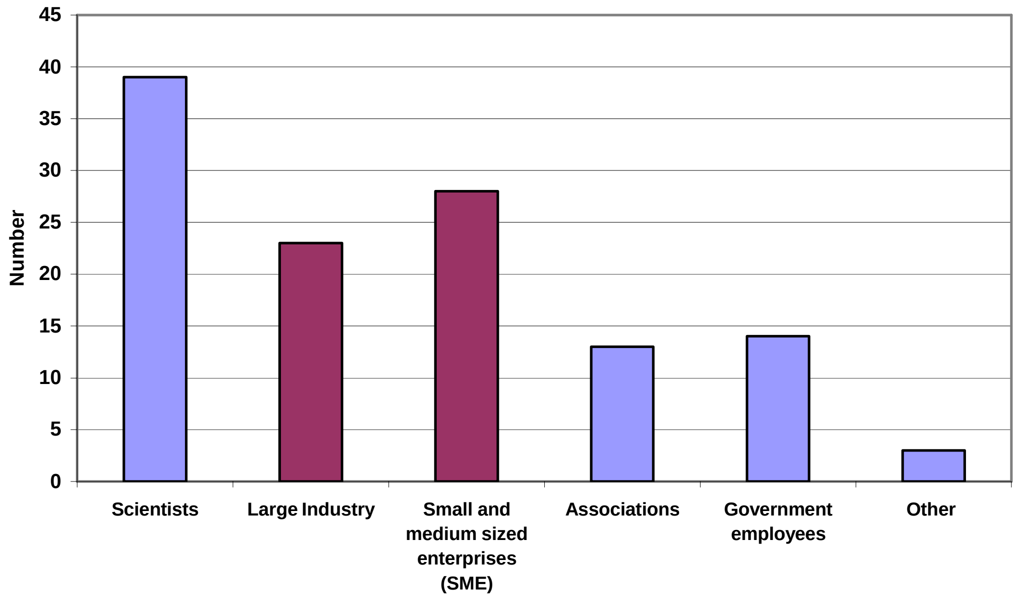

Figure 5.1-3 Number of scores for different groups of interest that are targeted by nano-oriented centers

Taking into account that most of the centers seem to be rather R&D-oriented and also following missions that are characteristic for R&D institutions (as shown in 5.1.1 and 5.1.2) the strong proportion targeting industrial groups is surprising. If this reflected the true situation it could be explained as a significant interest of industry to share responsibilities in product development among institutions from different sectors (i. e. scientific, commercial, public or other sector). In other words: indeed, industry might be the main targeted group even of mainly science-oriented centers as in case of collaboration the industrial partner saves effort and resources for fundamental R&D in specific areas of interest without losing touch to fundamental innovations in this field that might be of highest importance to the development of business and new products to the company. On the other hand, even science-oriented centers can significantly benefit from a co-payment model for industrial joint projects, opening access to additional funding resources besides public funds. However we have no data on the actual number of industrial partners and thus cannot verify that the openness towards industrial target groups expressed in these figures is realised in actual industrial cooperation. A certain proportion may account for as "wishful thinking" on the part of the centers. However, even if the statistics do exaggerate the reality, the results reflect a readiness for cooperation between the centers and industry.

5.1.4 Relationships between partners

Coordinating different skills, technologies and disciplines as well as different partners requires a certain frame within which management and decision making processes are made. As for coordinating different partners we have been interested in information regarding the hierarchical structure and the management plan behind different types of centers. As such we have counted the number of nominations for different propositions as is shown in fig. 5.1-4. These propositions show a different understanding of coordination in a way as it is a more passive approach (e. g. by simply sharing a common website) or a more active approach (e. g. by business processes and structures). We have identified science-oriented centers and have related them to four centers that are characterised as industry-oriented. Industry-orientation means that they either have characterised themselves as an industrial center or at least serve as an infrastructure center (fig. 5.1-1). Keeping in mind that by far most of the centers belong to science-oriented centers whereas only 4 centers could have been identified as industry-oriented the following conclusions have been drawn carefully.

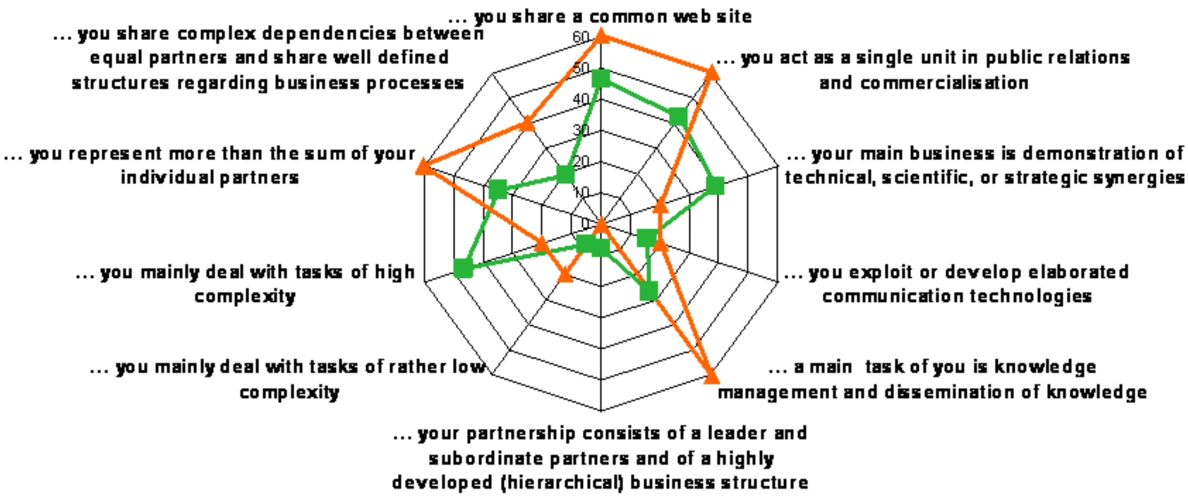

Figure 5.1-4 The polar diagram compares the relevance of different phrases to either industry-oriented (orange ▲) or science-oriented (green ■) centers on a relative scale

The polar diagram of fig. 5.1-4 shows two curves, one of which is for industry-orientation (orange) and the other one for science-orientation (green). The axis is normalised to 100 % as maximum value for each type of center (either industry-oriented or science-oriented), if all of the centers would have agreed to the proposition respectively. In other words: as 60 % of all industry-oriented centers answered that they share a common website, the displayed value is “60”.

There are issues that are of almost the same importance to the two different kinds of centers such as ‘sharing a common website’ and ‘acting as single unit in public relations’. However, there seem to be significant differences when it comes to a number of propositions like ‘dealing with tasks of high complexity’ (seems to be more relevant to science-oriented centers), ‘dissemination of knowledge’ (seems to be more relevant to industry-oriented centers) and ‘demonstration of synergies’ (which again seem to be more relevant to science-oriented centers). In addition, there seems to be a number of propositions that are of almost no relevance to the centers such as ‘highly developed hierarchical structure with a leader and subordinate partners’, ‘dealing with tasks of rather low complexity’ and ‘developing elaborate communication technologies’. Table 5.1-1 briefly characterises the two different types of centers.

Table 5.1-1 Some characteristics of industry-oriented and science-oriented centers regarding the relation among partners

Type of center	Feature
Industry-oriented	• Complex dependencies between equal partners • A main task is management and dissemination of knowledge • Tendency towards representing more than the sum of individual partners • Sharing a common website and acting as a single unit in public relation
Science-oriented	• Dealing with tasks of rather high complexity • A main business would be demonstration of synergies • Sharing a common website and acting as a single unit in public relation

5.1.5 Types of Center as related to location

In 3.3 center was defined “an institutional entity (mostly) consisting of different partners” and therefore does necessarily consist of a single organisation at a single location, but may have several partner organisations which might well be located in different locations. During the compilation of this report our interest was aroused as to what extent the centers which answered the questionnaire are based in a single or several locations. Actually, we noticed that most of the centers were from a single location and did not have partners from other locations. This was definitely different not only to our expectations (see also our ‘definition’ in 3.1 that implies that centers mostly consist of partners from several locations) but also varied from the idea of center as expressed in European-funded Networks of Excellence or German BMBF-funded competence centers, regional clusters and the like. The following paragraph highlights some findings concerning four types of centers in terms of their location:

- **single location**: partner organisations from a single site
- **regional**: partner organisations in a particular region, typically but not necessarily from within the same country
- **national**: partner organisations from within the same country
- **international**: partner organisations from more than one country

An analysis of the centers according to these categories reveals that a majority of the centers (23) are based at a single location i.e. they occupy a single site (fig. 5.1-5). Some of these centers describe themselves as a national center i.e. as a center which serves the whole country but are however based at a single location. Regional centers network organisations in the immediate vicinity for mutual gain. All centers described as nationally located (7) – not to mix with those claiming to be a national center but occupying only partners from a single site – are “centers” which consist of several partners being based in different locations within the same country. It is noteworthy that four of these are German Competence Centers.

Both of the centers which we describe as international are European-funded Networks of Excellence (NoE) [Frontiers and 4M]. Due to the strong weighing of the statistics by NoE’s and the BMBF-funded German Competence Centers a short description of these two types of networks is given below.

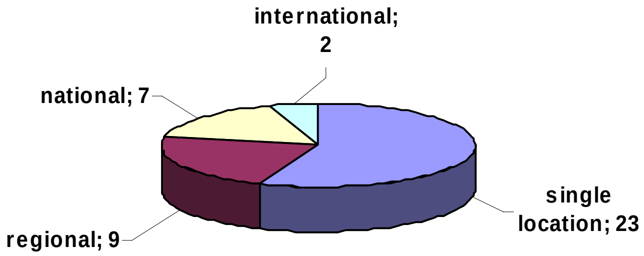

Figure 5.1-5 Distribution of nano-oriented centers as related to the location of the partners they cluster

Networks of Excellence are funded under the sixth Framework Programme of the European Union http://www.cordis.lu/fp6/instr_noe.htm and are likely to be a feature of the seventh Framework Programme. Funding is intended to overcome fragmentation in research i. e. to provide a structure where research that is being carried out in research institutions can be integrated for the benefit of all partners. It is the activities to overcome the fragmentation (both geographical and logistical) which are funded rather than research itself. In NoE’s research is funded from existing sources, the EU grant covers the expenses of networking the research. The expectation of the European Commission is the networks will develop a sufficient level of integration so that they will last beyond the end of the funding period.

BMBF-funded German Competence Centers have a strong thematic focus on a regional or national basis bringing partners together from both science and academia. The centers encourage close communication between the partners from which cooperative projects can arise. However, the centers tend to act as a network or a platform for outreach activities such as workshops, exhibitions, knowledge dissemination on their area of expertise rather than major on presenting a research infrastructure for use by partners or outside organisations. There are some centers which will endure beyond funding – such as NanoMat that started without BMBF-funding – but there might be a significant number which won't exist beyond funding.

5.2 Financing I: Investment cost and budget

Fig. 5.2-1 shows that establishing a nano-oriented center could become quite expensive but nevertheless this is not always the case. Even if approximately one third of all centers returning details on their investment costs have spent over 20 Mio. USD, there is a significant number of nano-oriented competence centers with investment costs below 1 Mio. €. The remaining 50 % of centers have moderate investment costs in the range of 1.1 and 20 Mio USD.

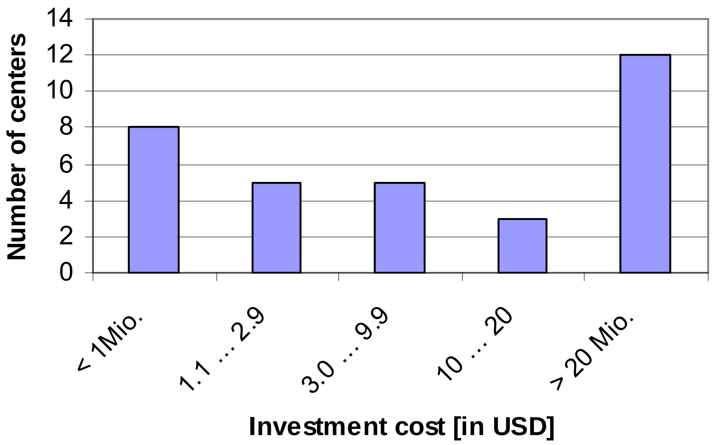

Figure 5.2-1 Investment cost for nano-oriented competence centers as indicated by answers to the EVA_1 questionnaire

Before discussing these findings it is worth considering that only ca 60 % of centers that responded to the questionnaire also provided detailed information on investment costs. However, fig. 5.2-1 seems to indicate that there are probably two extremes of nano-oriented centers with regard to investment costs: i) centers with rather low investment costs ii) centers with high investment costs. Centers with rather low investment cost would fit to associations, networks and other knowledge-oriented type of centers. Centers with a significant requirement on investment money would be high-tech centers with a comprehensive set of technologies or infrastructure.

A closer look at the returned questionnaires reveals that centers with high investment costs are indeed large science and/or infrastructure centers which may also have a networking or association role such as NNFC or MESA+. Amongst the low "set up" cost centers there are as expected centers with the expected purely or predominantly networking or association roles such as KoNTRS the Korean Nanotechnology Research Society or the German Nanoclub. However, also belonging to this low "set up" cost group are centers which have a role as a science and infrastructure center; examples here are JASMIN, NSEC, NCCR and CMNT. This may be initially surprising; however the question as to how it is possible to set up such an infrastructure on a relatively low budget is answered by the development, use and coordination of pre-existing facilities.

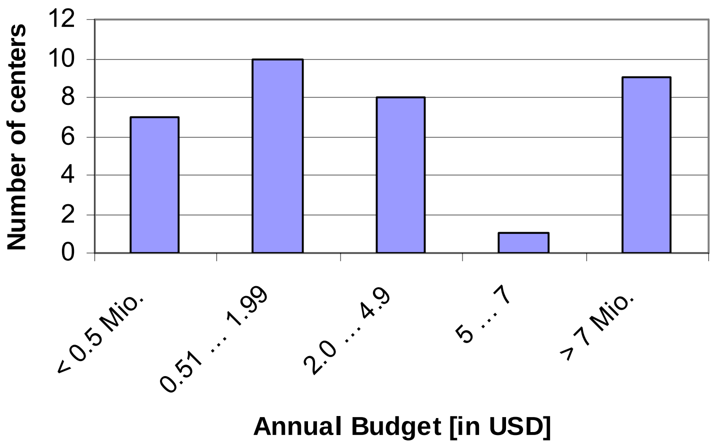

Figure 5.2-2 Annual budget of nano-oriented competence centers as indicated by answers to the EVA_1 questionnaire

Concerning the annual budget the picture is somewhat clear as more than 70 % of the centers have an annual budget less than USD 5 Mio. However, more than a quarter of the nano-oriented centers spend more than USD 5 Mio. This number comes close to the number of centers with investment cost exceeding 20 Mio but we found that high investment costs are not strongly correlated to high annual costs.

5.3 Financing II: Turnover and manners to sustain

By concluding that establishing nano-oriented competence centers isn't necessarily an expensive investment, the question is whether there is any chance of being a profitable investment at all. Therefore we have asked for some information on the annual turnover and also on the manners those centers sustain themselves. As with investment cost and budget also with revenues only some 60 % of all centers provided information on the annual return on investment. However, fig. 5.3-1 shows a decreasing dependency between increasing turnover and the number of centers with higher turnover. In other words: it appears that generating significant revenue is by far out of the scope of most of the centers. Taking into account that infrastructure-oriented centers tend to have high investment cost as well as high annual budgets it is clearly visible that it is almost unlikely to generate a turnover that allows commercial exploitation of the centers technological portfolio. However, this does not mean that we state that there is no chance for commercial success and successful business models in nanotechnology; but rather that the mission of the centers tends to be science-oriented with a solid base of expensive technologies and processes at hand: i.e. profit making is not a major goal. We have to state that commercialisation of nano and microtechnology is subject to other initiatives.

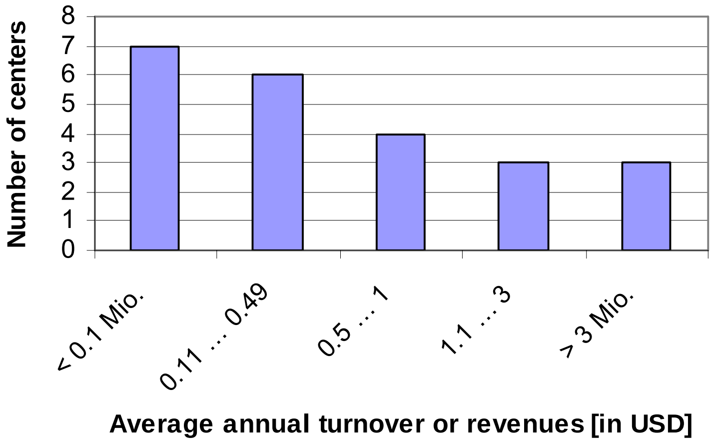

Figure 5.3-1 Average annual turnover of nano-oriented competence centers as indicated by answers to the EVA_1 questionnaire

Even if there is a clear indication of rather low annual turnover and revenues – in particular if it is compared with the investment costs and the annual budget - we have been interested in getting information on how a return on investment could be generated or even more precise: on how the centers sustain themselves. The situation is shown in fig. 15. There are three main ways of sustaining a micro-nano center:

1. Obtaining additional funding
2. Exploiting a fixed annual budget
3. Providing access to technologies for paying customers

While also 'dissemination of knowledge' contributes significantly to an annual turnover, the industry-like 'generating of sales and profits' has been ticked only one single time. So in terms of manners to sustain themselves micro-nano centers seemed to be merely focussed on public funding rather than on private sources. This also indicates R&D work as main business and is in good accordance with the most frequently chosen types of the centers and their mission statements (see also 5.1.1 and 5.1.2). Furthermore it also covers the finding that mainly industry is targeted (5.1.3) if one assumes that 'paying customers' - as indicated by the first column in fig. 5.3-2 - are likely to be industrial partners.

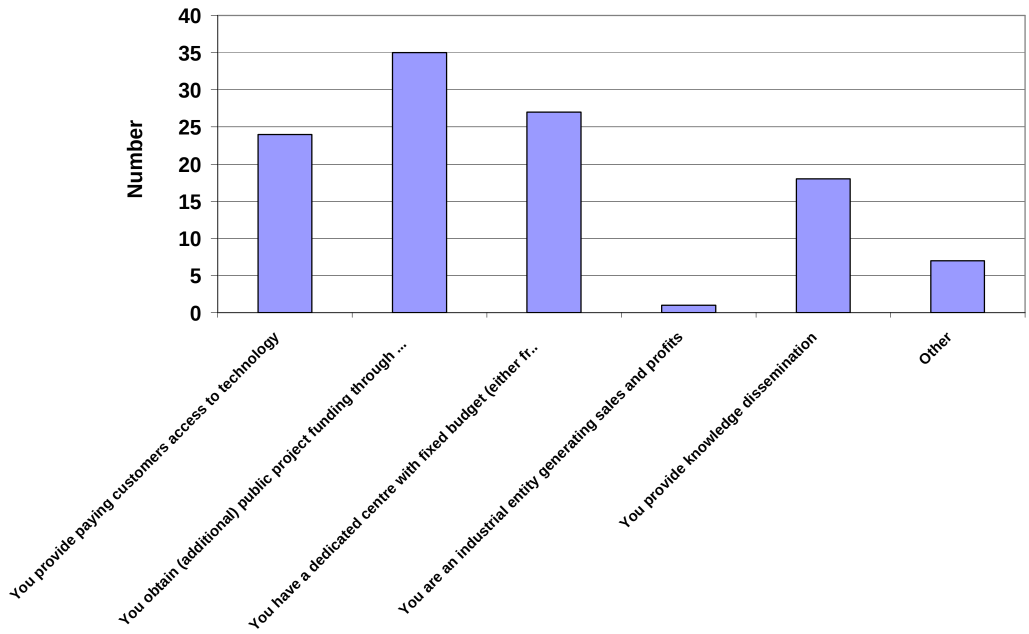

Figure 5.3-2 Manners of how nano-oriented competence centers sustain themselves

5.4 'Scientific performance'

EVA_1 also tries to evaluate nano-oriented centers in terms of their scientific performance as was mentioned in chapter 0. As such we defined three parameters as performance indicators:

- Average number of doctoral students
- Average number of peer-reviewed publications per year
- Average number of peer-reviewed publications per doctoral student.

Admittedly these performance figures (number of doctoral students, number of peer reviewed publications) do not fit each type of micro-nano centers. However, we regard their use as justifiable since they are widely accepted indicators of performance. As is discussed in 5.1.1 there are a few centers which claim to be an association or an infrastructure center. Most likely these kinds of centers wouldn't have the same tendency to doctoral students than those which are science-related. However, from the data of the questionnaires we were able to calculate an average number of 46 doctoral students per center. Unfortunately this number comes with a standard derivation of almost 62. This indicates that simply estimating the mean value doesn't help much to understand the role and importance of doctoral students to the nano-oriented centers. Fig. 5.4-1 shows roughly the distribution of typical numbers of doctoral students among these centers. It is evident that the largest fraction of centers (> 40 %) has less than 20 doctoral students. On the other hand it can also be seen that most of the centers (> 50 %) have more than 20 doctoral students with a significant number of centers that have even more than 60 doctoral students.

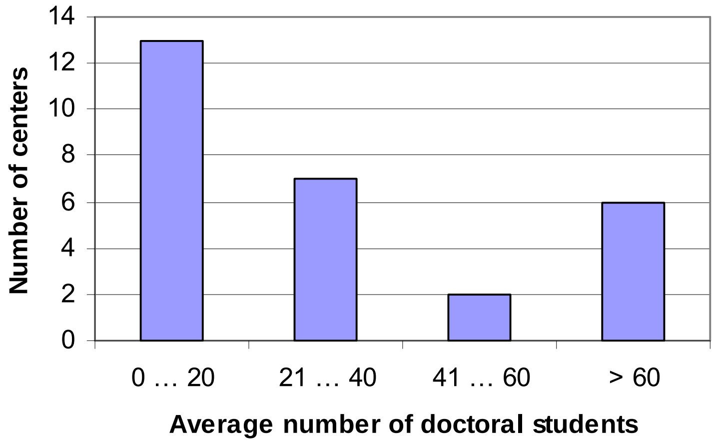

Figure 5.4-1 Distribution of doctoral students of nano-oriented competence centers as indicated by answers to the EVA_1 questionnaire. In average nano-oriented competence centers have 45.9 ± 61.6 doctoral students. The significance of this value is discussed in more detail in the text.

The mere number of doctoral students mainly lays a claim of a center for being innovative. In contrast the number of (peer-reviewed) publications as well as the relative number of such publications per doctoral student would indicate the publication performance. An average number of 84 ± 103 publications per year also indicates again that estimating the mean value does not reflect the real situation. This is also derived from an average number of publications per doctoral students which comes to 3.5 ± 3. If we look closer at the data we conclude that there seem to be two types of nano-oriented centers in terms of publication: highly and medium active centers. So, if we split the data into two fractions we could calculate that there a 16 nano-oriented centers with almost 2 ± 0.7 publications per doctoral student and 8 nano-oriented centers with 7 ± 2.8 publications per doctoral students.

Even if we take into account that a publication rate of 7 per doctoral student is a somewhat virtual number - as it is highly unlikely that a doctoral student will ever publish 7 peer-reviewed papers per year - it shows that nano-oriented centers are among the most productive scientific units.

6 Micro and nano centers

Some people regard Nanotechnology as a kind of a younger relative of Microsystem Technologies and others even predict the convergence of these two technologies. Therefore we have been interested particularly in evaluating those competence centers that try to link these two disciplines. We were fortunate enough to have questionnaires returned from the following 11 (including ourselves: 12) centers that are dealing with Nanotechnology and Microsystem Technologies:

- **CMI** (Ecole Polytechnique Federale de Lausanne (EPFL) Center of Micro Nano Technology, Switzerland)
- **CMNS** (Center for Micro and Nano Systems at the Chinese University of Hong Kong, China)
- **CMNT** (Center for Microtechnology and Nanotechnology at Lawrence Livermore National Laboratory, USA)
- **CMNP** (Center for Micro and Nano Processing at Case Western Reserve University; USA)
- **JASMIN** (John A. Swanson Micro and Nanotechnology Laboratory at the University of Pittsburgh, USA)
- **KTH/KI NMTC** (Kungliga Tekniska Högskolan/Karolinska Institutet Nano and Microtechnology Center, Sweden)
- **MESA+** (MESA+ Institute of Nanotechnology at the University of Twente, The Netherlands)
- **MINATEC** (Commissariat Energie Atomique (CEA) Laboratoire d'Electronique de Technologie de l'Information (Leti) Center for Innovation in Micro & Nanotechnology, France)
- **MNT Euregio** (Micro and Nanotechnology Network Euregio Bodensee, Switzerland)
- **MNRC** (The University of Birmingham microengineering and Nanotechnology research center, England)
- **NANOMIKRO** (Nano and Microsystems Programme at Forschungszentrum Karlsruhe, Germany)
- **ONAMI** (Oregon Nanoscience and Microtechnologies Institute, USA)

As such, integrating Nanotechnology and MEMS technologies or exploiting MEMS technologies to nano-scale applications have proven to be one of the most relevant specific thematic focuses for nano-oriented competence centers. However, this isn't surprising as we have looked specifically for micro and nano technology-centers while selecting those centers to approach with the EVA_1 questionnaire (see 3.4).

6.1 General remarks

By assuming that the presently discussed 12 micro and nano centers are primarily involved in practical R&D work rather than in networking we felt that there is a sufficient data base for extracting leading micro and nanotechnologies (MNT) as well as potential ‘killer applications’ or main industrial sectors where exploitation of MNT is advanced. The following two sections mainly deal with answering generic questions such as “Are there different approaches in integrating nano and micro technologies?” “Are there predominant technologies in MNT?” “Do different industries have different preferences for MNT?”. By dealing with questions of this kind we have been less interested in an analysis of individual centers. If the reader is interested in individual information he or she is recommended to go to the set of data sheets we have attached to the study in Appendix B starting at page 90.

6.2 Portfolio analysis

By exploiting the modified BCG-like portfolio analysis method (for further details please see 3.6) we portrayed the situation of micro and nano centers in a way as to show their technological capabilities (technological plurality) as well as their tendency towards a multitude of different applications (application plurality). This is shown in fig. 6.2-1. The portfolio analysis method was chosen as a valuable tool not only to compare with direct competitors but also to get information on strategically relevant developments in a specific area. Sometimes portfolio analysis also helps in identifying peers to some degree as individual segments (e. g. strategic business units) or detailed information on technologies and application areas and the like are observable and accessible.

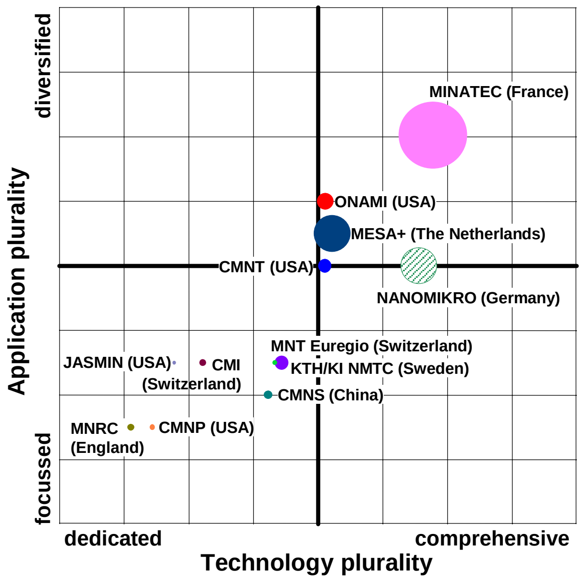

Figure 6.2-1 Portfolio matrix for micro and nano-oriented centers. The size of the bullets indicates the size in terms of staff, e. g. MINATEC: 2000; MESA+: 450; ONAMI: 90; CMNS: 20 (as of 2005)

By displaying the plurality of technologies available at a specific center versus the plurality of application areas and industries that are targeted by that center fig. 6.2-1 in general shows an almost linear dependency. Furthermore there are centers located only in two out of four possible quarters, indicating that there might be mainly two general approaches dominating the business strategy of micro and nano centers:

1. Centers located in the lower left quarter: These 7 centers exploit a rather limited number of MNT. However, we assume that this set is well defined towards meeting the needs of a specific application. To stick with the characteristics as shown in fig. 6.2-1 they operate a dedicated set of technologies and are focussed towards specific applications.
2. Centers located in the upper right quarter: These 5 centers develop, operate and maintain a rather high number of MNT, i. e. a comprehensive set, and seem to be open towards various different applications. They operate a comprehensive set of technologies and are able to meet the needs of diverse applications and industrial sectors.

To avoid any misinterpretation it has to be stated that a lower value for "technology plurality" does neither imply a lower quality of technologies available at those centers nor a lower applicability. It only shows a more dedicated and focussed business approach. As already mentioned, fig. 6-2.1 shows that the majority of those micro and nano centers are focussed with a dedicated set of technologies. This could be explained by the fact that it is quite expensive to install, operate and maintain a high number of micro and nano technologies.

In general it is to be expected that centers with a comprehensive set of technologies are larger than centers with a dedicated and therefore smaller set of technologies. This is exactly what we find in fig. 6.2-1. Larger centers (indicated by bigger dots) are located towards the right part of the diagram, i. e. towards a higher plurality of technologies, which to some extent seems to be highly reasonable. By far the largest center is MINATEC in France heading from a staff of 2000 in 2005 to some 3500 in the next years. Due to the strong micro-electronic and micro-technological fundament it is one if not *the* leading center in Silicon-based micro and nanotechnology not only comprising an impressive set of technologies but also targeting a huge variety of applications. However, there are other centers in other countries with a different strategy to exploiting micro and nantechnology which are also driving the edge of knowledge forward. As MINATEC will be inaugurated officially in September 2006 the authors are looking forward with great interest to this remarkable effort.

6.3 Most common technologies in micro and nano centers

By using a portfolio analysis approach, section 6.2 shows the technological potency as well as it shows the broadness of applications that are targeted by the centers. However, it does not give information on specific technologies. Therefore we have developed three-dimensional 'technology-maps' indicating the relative importance (i. e. occurrence) of 89 micro and nano technologies with regard to their use in different application areas or industrial sectors.

6.3.1 How to read 'technology maps'

The following diagrams show the number of scores that a specific technology has gained in relation to the fields of application or industrial sectors that was ticked by the center in the completed questionnaire. The height of the peaks mirrors this number which is also indicated by different colours in a way that darker colours show low numbers and light colours show high numbers of scores. The x-axes is divided by 89 technologies from 8 categories ranging from (Nano) Materials to Quality System (see also tab. 3.5-2). By drawing these technologies against either 14 fields of application or 13 industrial sectors the relation between distinct technologies and single application fields or industries can be derived qualitatively. So there are two different types of technology maps:

1. Technology vs. application-maps
2. Technology vs. industry-maps

They do not have necessarily different meanings but it might be of additional value to the reader if information regarding the relevance of different micro and nano technologies is available not only for different application areas but also for specific industrial sectors.

By evaluating a horizontal 'line' in such a technology map (i.e. a single application or industry) row of light-coloured peaks indicate that the specific application or industry represented by this row is either regarded as a relevant application area or an industry that is well under way to exploit the potential of MNT. The absence of peaks at least indicates that the specific application area or industry obviously does not interact with the nano-oriented centers.

By evaluating a perpendicular 'column' of a technology map (i. e. corresponding to one of 89 technologies) light-coloured peaks show those technologies that are obviously of high relevance to the R&D work done in specific applications or in collaboration with industrial partners from different industrial sectors. In contrary dark colours indicate low numbers and less relevance of specific technologies to application or industry.

Please note that we have tried to show significant results as clear as possible. This urged us to normalize each of the technology maps individually to the highest number of scores in that specific area. Unfortunately being as clear and distinctive as possible within an individual technology map meant, that it might be misleading if one tries to compare different maps by height and colour. In other words we have had to change the scale of our maps. Therefore the maximum value (i. e. white colour) is different for different sets of centers that we have evaluated – strongly correlating with the number of completed questionnaires we have received for this specific area (e. g. nano-bio, micro-nano and the like). This might be apparently for 'nano-bio' centers (see 7.3), where we could only work with 5 centers whereas we could relay on 20 centers in case of 'Europe' (see 8.1).

By drawing the number of scores for different technologies in relation to different fields of application as well as to different industrial sectors we received two of the above mentioned 'technology maps' shown in fig. 6.3-1 and 6.3-2. Fig. 6.3-1 shows the relation of 89 micro and nano technologies with 14 applications whereas fig. 6.3-2 shows the relation of again 89 technologies with 13 industrial sectors. Comparing the number of scores for different technologies allows an evaluation of technological classes as well as of distinct technologies with regard to their relevance to the field of MNT.

6.3.2 Micro and nano technologies in relation to application areas

As mentioned above the following figure (fig. 6.3-1) relates the number of scores for a particular micro and nano technology to different application areas. In general the diagram shows a surprising trend towards an almost uniform technological pattern. This pattern seems to be independent of specific applications. In other words: there seems to be a set of technologies that are of relevance to micro and nano centers irrespective of the particular application. This generic set of micro and nano technologies leads to the question “Are these main stream micro nano technologies consisting of the most relevant technologies?”. From a general point of view we could clearly identify significant differences between the eight different technological categories. The following categories are of high relevance as is indicated by a high number of scores:

- Characterisation
- (Nano) Materials
- Generic structuring
- Silicon-based micro-fabrication technologies

However, there are also technological categories that clearly don’t contribute to the same extent to the technological portfolio of micro and nano centers. These are the following categories:

- Nanofabrication, except AFM and STM techniques
- Replication
- Quality system

A more precise picture regarding the relevance of individual technologies is gained if the relative commonness of individual technologies is drawn in a way as to show the most common technologies on top and the least relevant at the bottom of a row. This is shown in fig. 6.3-2 and 6.3-3. Fig. 6.3-2 clearly indicates the top and bottom end of technologies in micro and nano centers. Whereas operating synchrotron facilities and using nanotransfer printing are almost of no relevance to micro and nano centers there is a set of technologies that seem to be of a rather high relevance to those centers. This is shown in more detail in fig. 6.3-3. Almost all of the micro and nano centers (in numbers: 90 % of the centers that returned our questionnaire) use AFM, SEM, FE-Methods and wet etching. In terms of structuring and characterisation there is still a remarkable agreement regarding the relevance of technologies. The set of technologies is dominated by classical Silicon and semiconductor technologies such as dry etching, bulk micro-machining, surface micro-machining, annealing and the like. However, we see a significant relevance – at least to 70 % of the centers – of further materials such as metals and alloys and polymers.

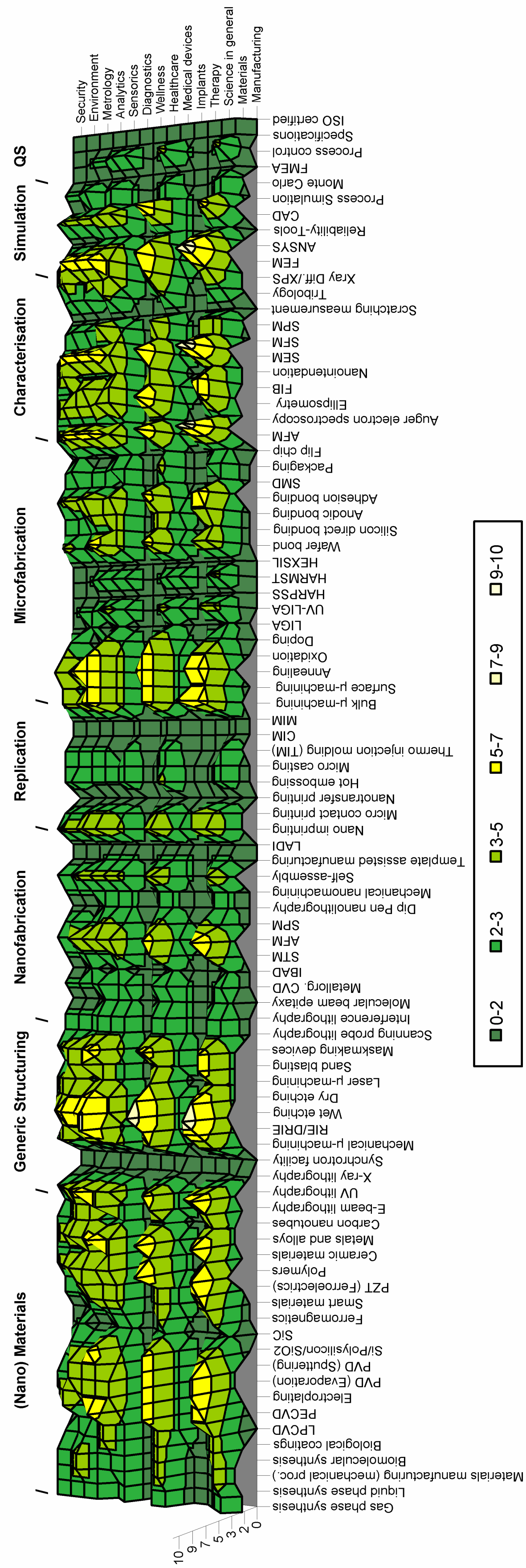

Figure 6.3-1 Technology vs. application-map of micro and nano centers

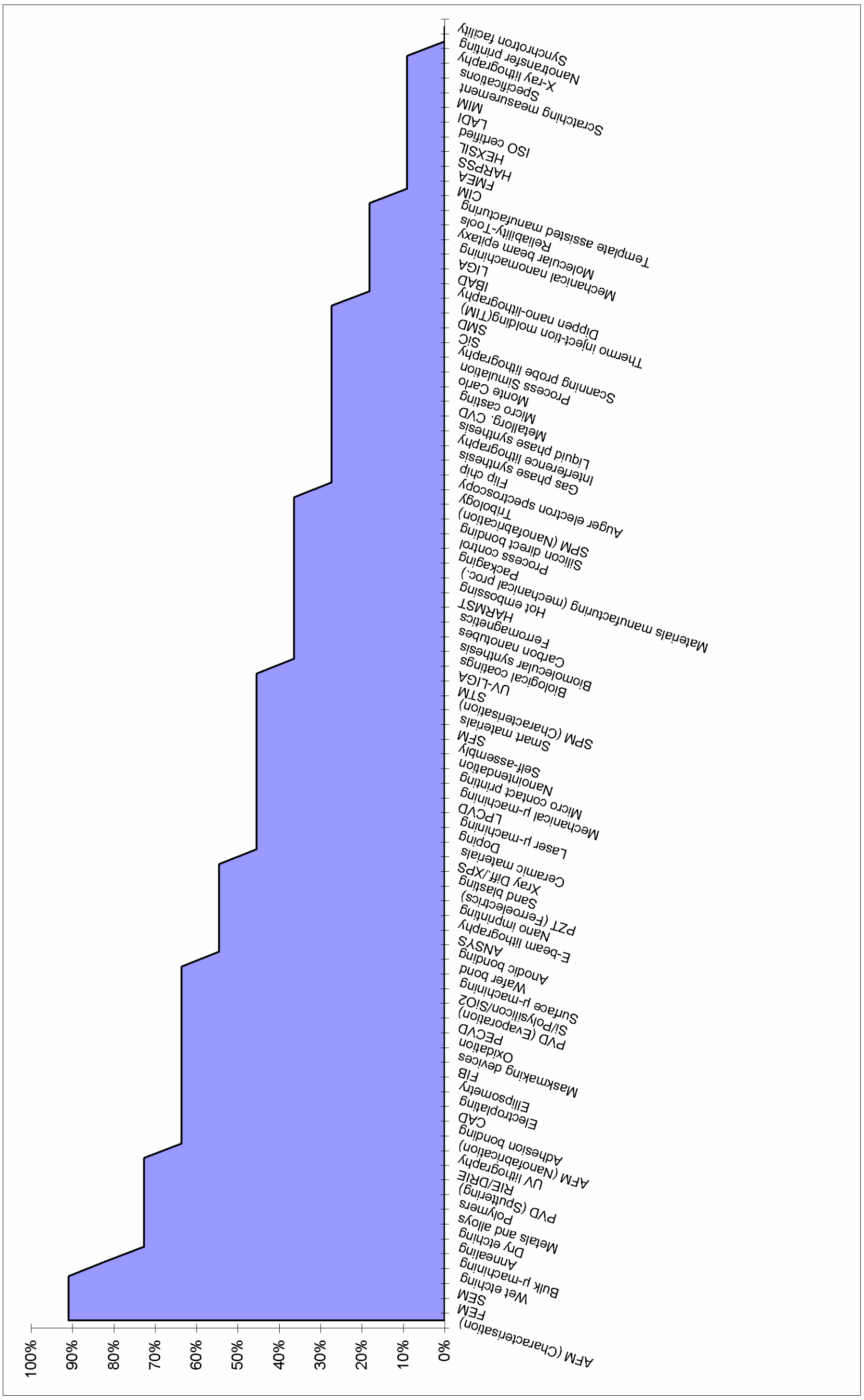

Figure 6.3-2 Relative commonness of micro-nano technologies in micro and nano centers as derived from the returned EVA_1 questionnaire

By evaluating the occurrence of different technologies that are typical for systems integration we have tried to get an impression of the capabilities of micro and nano centers in integrating nanoscale components and structures into hierarchical systems. Both figures (6.3-2 and 6.3-3) show that there is at least a reasonable chance for getting access to classical systems technologies: Some

60 % in case of wafer bonding and anodic bonding and 30 % for flip chip technologies and SMD. However, we expected the necessity for novel handling methods and integration technologies in case of nano components and materials to be integrated into systems. Unexpectedly we haven't received any hint for those methods or almost any other new technology for handling and integration of nano components and materials.

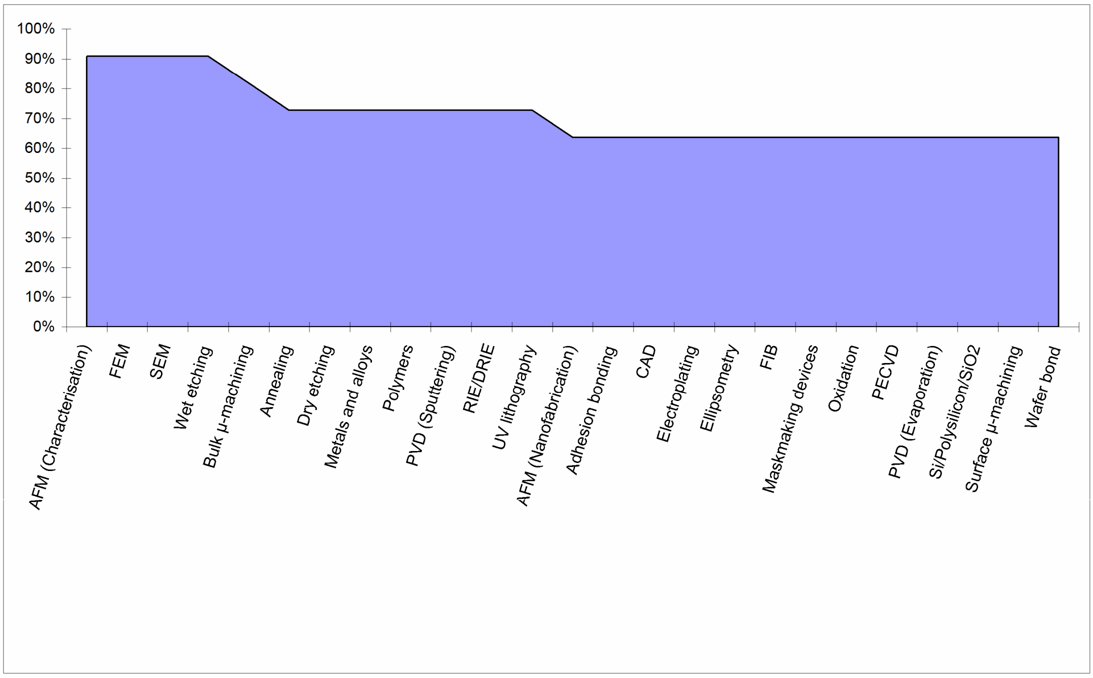

Figure 6.3-3 Most relevant technologies of micro and nano-oriented competence centers

Returning to fig. 6.3-1 also allows identifying the relevance of various application areas. Following horizontal lines that represent the technological situation for different application areas significant valleys can be observed. These indicate almost no activity of the micro and nano centers in these specific application areas, namely:

- Implants
- Therapy

However, there are some horizontal lines indicating that micro and nano technologies are of high relevance to various application areas such as:

- Science in general
- Materials
- Medical devices
- Analytics, Sensorics, Diagnosis and Metrology

Concluding these findings we could well argue that these are applications that are widely regarded as so-called killer-applications[38] and that we are in good accordance with this. However, we are not fully convinced of the independency of the strategic orientation of nano and micro centers in a way as they might not only rely on their own practical experience from real collaborations with industrial or even academic partners but probably also rely on forecasts and market predictions which again direct micro and nano centers toward these killer-applications. This might lead to the situation of a so-called self fulfilling prophecy. As it is somewhat impossible to identify the extent to which centers are relying upon forecasts or own experience we have to leave the reader with this situation.

Furthermore the role of “science in general” as one of the most ticket application areas (even if this is obviously the opposite of an application area) strongly supports the more general findings in 5.1, where we found that R&D-orientation is the most probable type of a nano-oriented center.

6.3.3 Micro and nano technologies in relation to industrial sectors

Fig. 6.3-2 shows a technology map where we have drawn the above mentioned 89 technologies against 13 different industrial sectors. Concerning the technologies we find that the picture is somewhat comparable to the above mentioned derived from fig. 6.3-1 leading to generally relevant micro and nano technologies.

However, there are significant differences among the different industrial sectors that are targeted by the micro and nano centers. A comparison of the different horizontal lines representing different industrial sectors reveals that there are a few industrial sectors that appear to be highly targeted by the micro and nano integration centers such as:

- Life Science
- Biotechnology
- Chemistry
- Energy
- Microelectronics

On the other hand there are industrial sectors that seem to be of lower relevance to micro and nano integration centers:

- Pharmaceutical Industry
- Automotive
- Consumer Industry
- Information Technology
- Automation

[38] I. Malsch, M. Oud: Outcome of the open consultation on the European Strategy for Nanotechnology; Executive Summary, page 14-22, December 2004, nanoforum.org European Nanotechnology Gateway, www.nanoforum.org

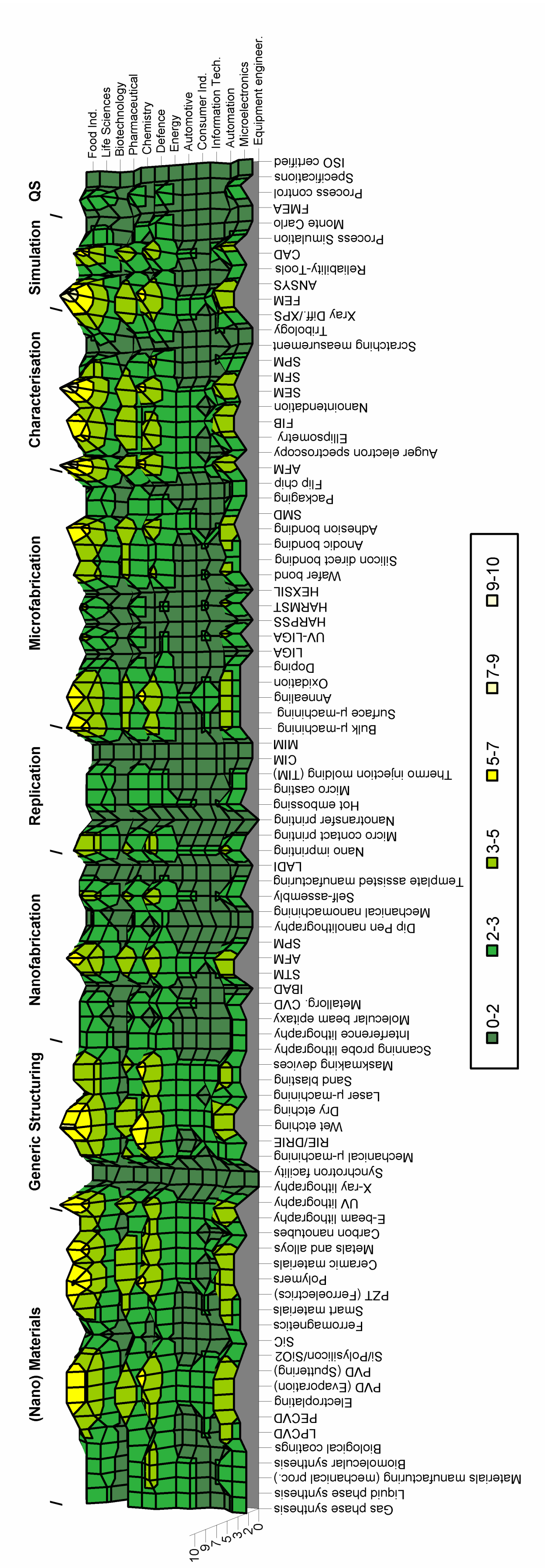

Figure 6.3-2 Technology vs. industries-map of micro and nano centers

This is rather surprising, especially when considering automotive industry as one of the favourite examples of politicians and scientists for illustrating the future importance of nanotechnology and MEMS technology in our daily life. Expectations are also strong that the pharmaceutical industry, consumer industry and information technology will be strongly influenced by advances in MNT. A possible explanation for our findings that little relevance was attributed to these industrial areas by the nano and micro centers is that much of the research occurs within the industry itself rather than in research centers or that it is done in other centers (e. g. nanoelectronic centers). Another explanation the market relevance of nanotechnology in the automobile industry is currently estimated as low because of long innovation and development times for technology development[39].

[39] VDI/VDE Technologiezentrum; Innovations- und Technikanalyse: Nanotechnologie als wirtschaftlicher Wachstumsmarkt (November 2004) ISSN 1436-5928

7 Nano-bio centers

If we consider the integration of Microsystem Technologies and Nanotechnology as a somewhat natural development in miniaturisation the exploration of molecular structures and components also might lead to convergence of Nanotechnology with traditional scientific disciplines such as chemistry or physics at the inanimate end but in context of this section even more interesting with animate science or simply: biology. Driven by both the necessity to better understand processes at the interfaces of biotic and abiotic systems as well as the demand for additional functionalities in technical systems there seems to be a general tendency for a specific part of nanoscience in orienting towards biology. Until now, already some remarkable successes for joint developments between nanotechnology and biology have been reported such as cancer diagnosis and treatment (e. g. with functionalised nanoparticles) or biomimetics, when technical (nano) materials are developed reflecting principles of natural materials. However, there is no doubt that the field of nano-biology, nano-biotechnology as well as of nano-bioengineering is at least as wide as it is undefined. We do not intend in defining these disciplines but we felt that it might be particularly of interest to the reader to identify specific technologies or applications that are of higher relevance than others to this growing field, even in its current premature state.

7.1 General remarks

Our conclusions can only be drawn from a rather limited set of nano-oriented centers that we could identify as acting in the field of nano-biology. This might be due to the novelty of the topic; however, we are convinced that it does not mirror the priority of biological or medical applications for the field of nano-oriented centers. Otherwise we would have had difficulties to explain how ‘Life Science’ and ‘Biotechnology’ are targeted by micro and nano centers as most relevant industries – as was discussed in 6.3.3. We could well argue that the strategy not only to target ‘biological’ industries would allow nano-oriented centers to be more flexible. But there is no evidence in our data for any conclusions like this. So keeping in mind that only 5 centers have returned a completed questionnaires that could be allocated to nano-biology we have been interested in the relation between and the types of these centers.

7.2 Portfolio analysis

Portfolio analysis was pursued mainly to show the situation among the five centers that returned the questionnaire. Even if the number is insufficient from a statistical point of view we have tried to extract some qualitative conclusions. If we apply the portfolio analysis method as described in 3.6 we get a picture as shown in fig. 7.2-1.

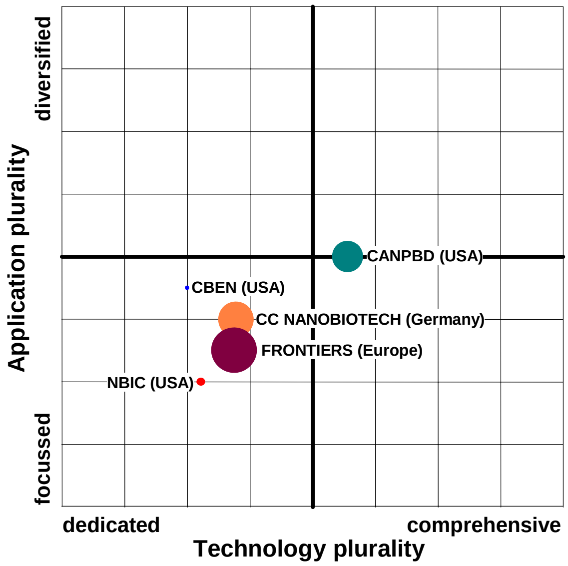

Figure 7.2-1 Portfolio matrix for nano and bio-oriented centers. The size of the bullets indicates the size in terms of staff, e. g. NBIC: 22; FRONTIERS: 200 (as of 2005)

Fig. 7.2-1 shows four centers that are mainly exploiting a more or less dedicated portfolio of technologies for meeting the needs of a focussed set of applications indicated by their location in the lower left quarter. At a first look there might be relative differences but these are not overly significant. So basically the centers CBEN, NBIC, CC NANOBIOTECH and FRONTIERS seem to follow comparable strategies. However, there seem to be different approaches if one compares the size of the two US American centers with the size of the two European centers. As the two European centers are either a competence network (CC NANOBIOTECH) or a Network of Excellence (FRONTIERS) they mainly are focussed in facilitating interaction of preferably a large number of scientists rather than on pursuing specific and focussed R&D. In other words, they are large but basically knowledge-oriented (see 5.1.1). From this point of view it is not surprising that the size or number of members of these centers exceed the size of the R&D-oriented centers in USA, where mainly science centers are founded. Furthermore the size of the US American centers to some extent will increase due to further growing of the center (NBIC has been founded as recently as in 2004) or due to additional measures and collaborations (probably as in case of CBEN, which started an initiative in 2004 called the International Council on Nanotechnology (ICON)[40]). ICON intends in tackling environmental and health aspects as well as standards for nanomaterials and the like. So even if CBEN (and NBIC) appears to be rather small, the center themselves are highly vital and active in its field.

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[40] http://icon.rice.edu/

Beside those 4 centers in the lower left quarter of fig. 7.2-1 there is another center shown in the upper right quarter indicating a center with rather more comprehensive technological capabilities exploiting a large variety of potential applications. This is the Center for Affordable Nanoengineering of Polymer Biomedical Devices at the Ohio State University in Columbus, Ohio (CANPBD). CANPBD is one of six NSF-funded Nanoscale Science and Engineering Centers (as also CBEN is) and seems to be already well developed with a staff of over 80 and an impressive set of technologies available. It also targets a larger set of applications than the other centers. This set is even larger than CBEN's, which – as is shown in its name – targets not only Biological Nanotechnology but also Environmental Nanotechnology.

There are two generic conclusions that could be drawn in addition to the above mentioned:

1. We could not identify a nano-oriented competence center that also deals with biology from Asia. Of course this does not necessarily mean that there is no specific interest in exploiting the potential at the interface of Nanotechnology and biology in Asia. But probably there are different approaches. However, we do not deduce any regional specificity. An impressive approach for an existing Asian strategy in this field might be Singapore's Institute of Bioenengineering and Nanotechnology (IBN)[41]. Even if we thought it would not fit to our definition of a nano-oriented competence center it is a substantial example for world leading R&D work at the interface of Nanotechnology and Biology.
2. By reviewing the three US centers there is a common source of funding for them. This is the National Science Foundation which is not overly surprising but as also the Department of Energy has funded 6 Nanoscale Science and Research Centers (NSRC), it appears to be obvious that biological topics are funded only under NSF's Nanoscale Science and Engineering Centers (NSEC). In order to avoid misunderstanding: NBIC is also NSF funded but has been set up already in 2001, three years before the NSF initiative towards establishing six NSECs.

Finally there is a hint on specific technologies used in the name of one of those US American centers: It is 'polymer' in CANPBD's name indicating that polymer materials might play a vital role in the field of biological or more precise biomedical applications leading to the expectation that the bio-nano interface might be likely to favour different technologies than traditional semiconductor technologies. This leads to the question what would be key technologies for nano-bio centers.

7.3 Key technologies for 'nanobiology'

In order to answer the questions raised above we have drawn the previously mentioned 89 micro and nano technologies versus the application areas that were targeted by the five nano-bio centers and obtained the situation as shown in fig. 7.3-1.

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[41] http://www.ibn.a-star.edu.sg/

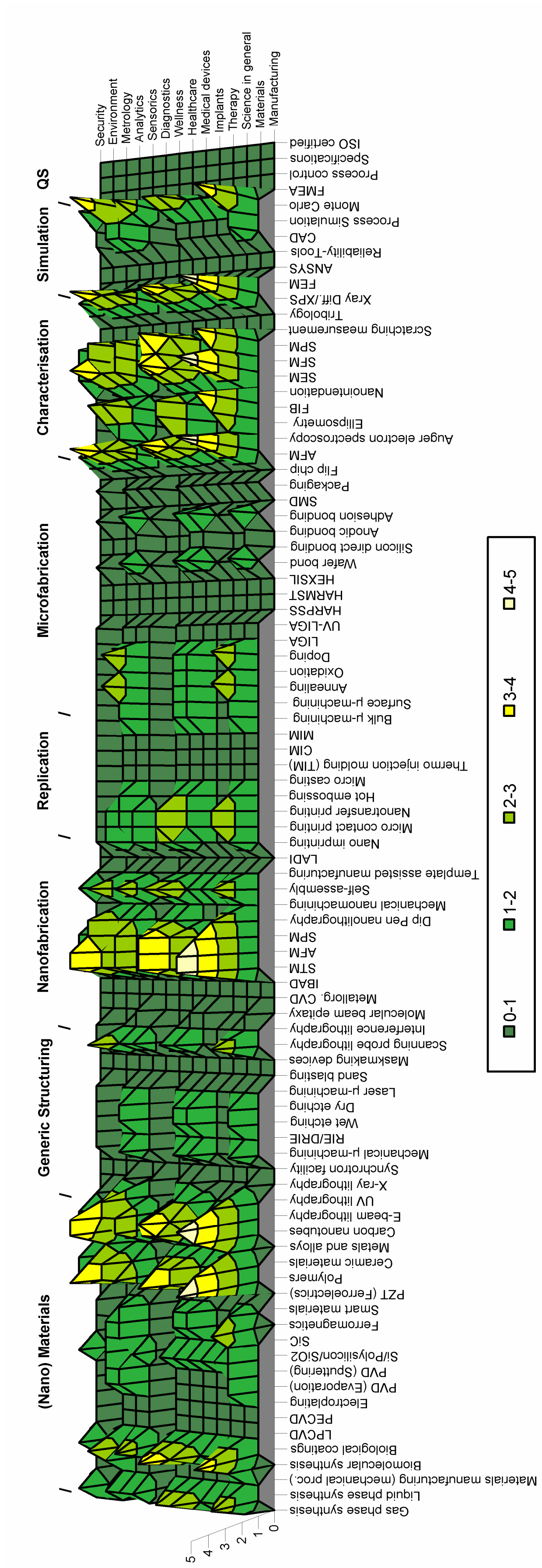

Figure 7.3-1 Technology vs. application-map of nano-bio centers

Firstly fig. 7.3-1 shows no uniformity regarding the relevance of different technologies. There are technologies which seem to be of high relevance whereas other technologies don't seem to have any relevance at all. However, it should be stated that the statistical relevance of the dataset is not sufficient to draw final conclusion but we are fortunate enough to feel able to draw some qualitative conclusions.

If we compare the situation shown in fig. 7.3-1 with the technology vs. application map in fig. 6.3-1 (technology map for micro and nano centers) we get a somewhat different picture. There are some apparent differences which might be significant even if we still keep in mind that we are working with a rather small data set. However, there are at least four qualitative conclusions to be drawn:

- In nano-bio centers several technologies are over expressed in a way as they have been almost invisible in micro and nano centers. These are: Liquid phase and biomolecular synthesis as well as biological coatings. Also scanning probe lithography, AFM/STM methods and Monte Carlo methods are of much higher relevance than in micro and nano centers.
- From a point of materials there is a clear indication towards 'non traditional' micro materials leading to almost negligible occurrence of semiconductor technologies. Those non traditional or novel materials are: Polymers, ceramic materials and carbon nanotubes
- Technologies which have preserved their relative relevance are e-beam lithography (high relevance), self assembly, nano imprinting and micro contact printing (medium to lower relevance) and characterisation in general (high relevance)
- In terms of application areas there is not a clear picture favouring a small group of applications. However, there is a group consisting of analytics, sensorics, diagnostics, medical devices and science in general that leads the applications targeted by the nano-bio centers.

So, if it comes to biological questions various molecular methods are gaining importance as well as particularly novel materials and with them probably a different profile of technologies for structuring appear. To us this seems to be reasonable in a way as it is expected that for example carbon nanotubes are expected to play a central role in novel diagnostic devices providing access to new and better transducer principles in biosensing or as transistors in electronic devices and the like.

In fig. 7.3-2 (more detailed also in fig 7-3-3) we have arranged the different technologies according to their relative commonness starting with micro and nano technologies and skills which seem to be important to either all of those five nano-bio centers (i. e. 100% relative commonness) or at least to 4 out of these 5 centers (i. e. 80% relative commonness) and ending with technologies and skills with obviously lower or even no relevance to nano-bio-centers. The situation for highly common technologies is focussed on fig. 7.3-3.

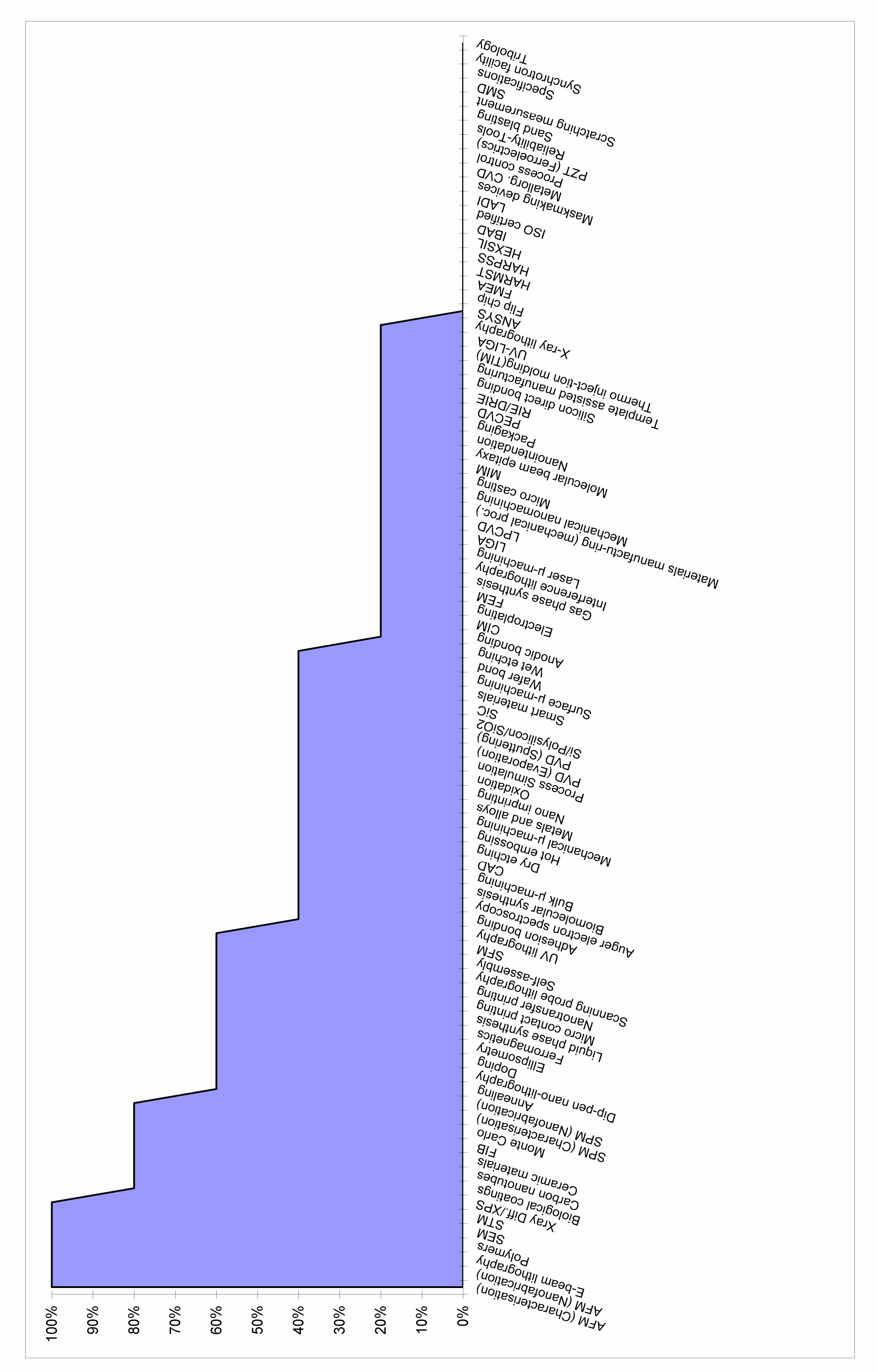

Figure 7.3-2 Relative commonness of micro-nano technologies in nano-biocenters as derived from the returned EVA_1 questionnaire

Fig. 7.3-3 shows the most common technologies in nano-bio centers which - due to our interpretation – resemble also the most relevant micro and nano technologies for bio-oriented nano-centers. As mentioned earlier, we try to avoid to over estimate this picture as it is derived from a limited data set. However, the situation is remarkably different from the situation given in fig. 6.3-3 therefore demanding a certain amount of attention.

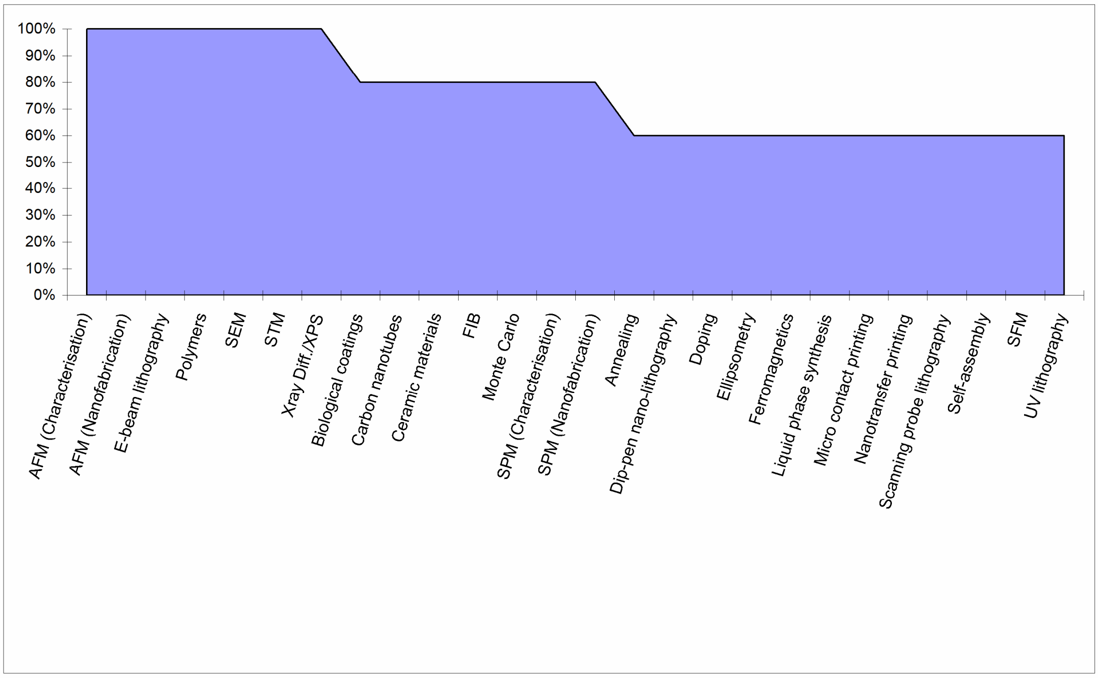

Figure 7.3-3 The most relevant technologies of nano-bio-oriented competence centers

While micro-nano centers (see fig. 6.3-3) tend towards a technological portfolio that is dominated by classical semiconductor technologies such as wet etching, bulk micro-machining annealing and dry etching and the like, these technologies are significantly lower expressed in nano-bio centers. However, AFM (characterisation mode) and SEM technologies are almost of the same relevance in both types of nano-centers. While also "polymers" defends its position in this kind of ranking, numerous other nano technologies like liquid phase synthesis and micro contact as well as nanotransfer printing and self assembling replace classical Silicon-based micro nano technologies. Also AFM in nanofabrication mode gains significantly higher attention most likely indicating molecular fabrication trends in nano-bio-oriented centers. Furthermore systems technologies such as assembling and bonding also seem to be of lower relevance to nano bio centers indicating a trend towards investigation and verification of single effects rather than towards development of higher integrated technical innovations. This science-oriented approach also appears if we compare the types of nano-bio centers as was requested in section 5.1.1. In 4 out of 5 cases we found that the nano-bio centers prefer to be recognized as science-oriented centers (i. e. science center or at least an R&D project-type of center), with only CC NANOBIOTECH (Germany) stating to be rather an association and an infrastructure network.

We would like to leave it open to the readers to what extent the above mentioned bio-specific technological portfolio is representative for bio-oriented competence centers or at least to nano-bio-oriented entities in general. However, without too much doubt the present finding of significantly different technological patterns for "inanimate" and "animate" science centers might be worth considering if existing technological capabilities should be enforced or if completely new technological capabilities would be created in a highly application-specific way. Consequently this indicates specific sets of technologies for specifically oriented competence centers which as well might be called “main stream nano-bio technologies”.

7.4 Industrial sectors with relevance for nanobiology

By drawing the number of scores for 89 technologies versus the targeted industrial sectors we derived the picture shown in fig. 7.4-1.

This figure mirrors quite a clear situation: Only three out of thirteen industrial sectors seemed to be targeted by nano-bio centers: ‘Life Science’, ‘Biotechnology’ and ‘Chemistry’. There are some scores also for ‘Food Industry’, ‘Consumer Industry’ and ‘Microelectronics’ but this is far from being significant so that we could not draw any conclusion hereof. However, this result isn’t surprising at all as it shows the expected thematic focus.

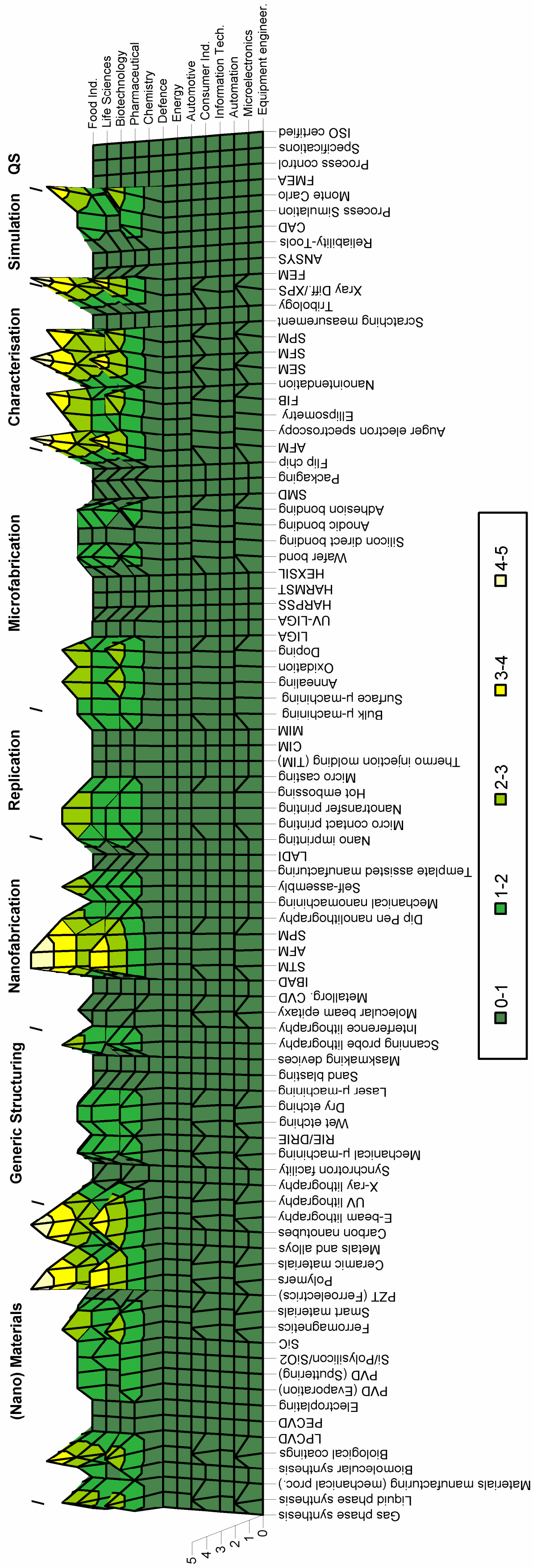

Figure 7.4-1 Technology vs. industries-map of nano-bio centers

8 Centers in different geographic regions

The following chapter focuses on the question “are there identifiable regional or cultural differences between centers based in the geographical regions of Asia/Pacific, Europe, U.S.A. i.e. North America?”

As such it analyses the specific situation in three global regions individually: Asia/Pacific; Europe; U.S.A. (i. e. North America); in alphabetical order. Starting with portfolio analysis from each of the region’s centers we proceed with an evaluation of micro and nano technologies available in these centers, and end with comparing industrial sectors.

8.1 Comparing the portfolios of centers in different geographic regions

The following three portfolio-matrices show the situation of nano-oriented centers regarding their technological capabilities as well as the plurality of applications they are targeting for Asian/Pacific region, Europe and U.S.A. (i. e. Northern America) respectively. The present discussion does not distinguish between centers focussed towards different scientific or technological disciplines such as nano-micro integration or nano-bio orientation. As such we have been interested in gaining a general impression on possibly different strategic approaches in dependence of the regional location of nano-oriented centers.

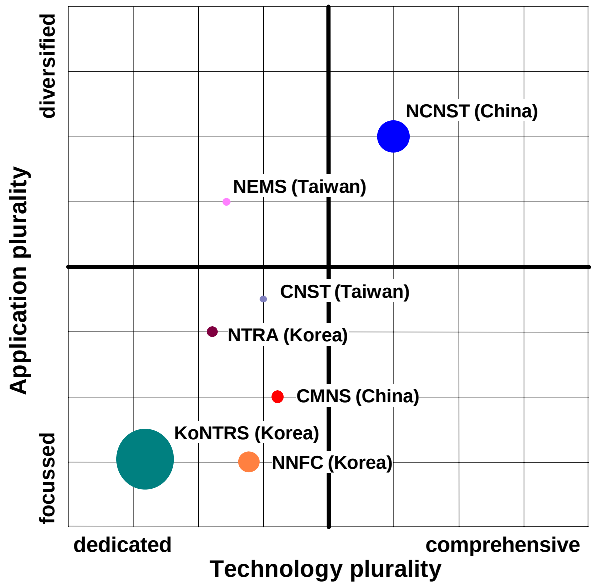

Figure 8.1-1 Portfolio matrix for nano-oriented centers from China, Korea and Taiwan[42]. The size of the bullets indicates the size in terms of staff, e. g. KoNTRS: 500; NCNST: 50; NEMS: 6 (as of 2005)

[42] ‘China’ stands for the ‘People’s Republic of China’. ‘Taiwan’ stands for ‘Republic of China’ on the island of Formosa;

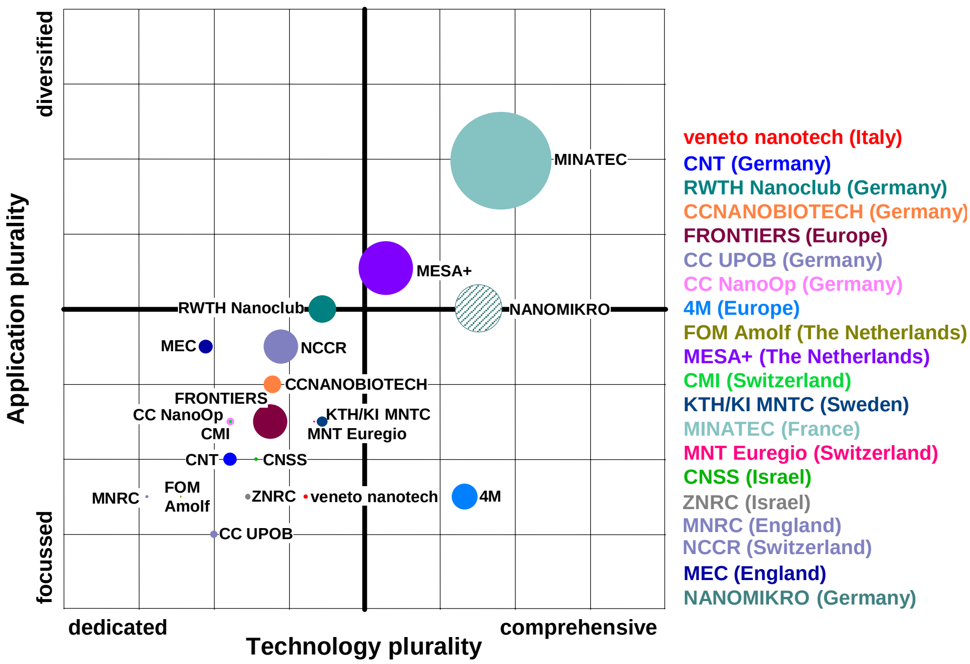

Figure 8.1-2 Portfolio matrix for nano-oriented centers from Europe. The size of the bullets indicates the size in terms of staff, e. g. MINATEC: 2000; MESA+: 450; FRONTIERS: 200; CNT: 75; veneto nanotech: 22 (as of 2005)
We have added a legend to the figure as it was not possible to show the country in detail within the chart.

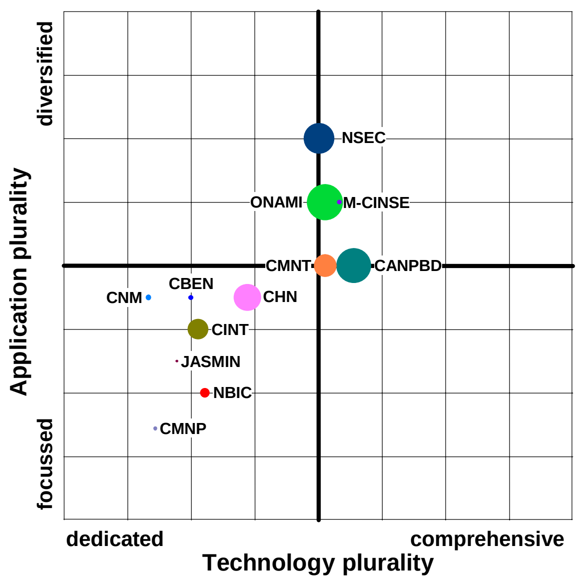

Figure 8.1-3 Portfolio matrix for nano-oriented centers from the United States of America. The size of the bullets indicates the size in terms of staff, e. g. ONAMI: 90; M-CINSE: 8; CHN: 68 (as of 2005)

Comparing fig. 8.1-1, 8.1-2 and 8.1-3 derives the same general pattern as was also observed in 6.2 in case of micro and nano oriented centers. Out of four possible quarters the centers are generally located only in two of them. And again these are:

1. Centers located in the lower left quarter: these centers exploit a rather dedicated set of technologies to meet the needs of a small multitude of different applications; in other words: these centers are thematically focussed
2. Centers located in the upper right quarter: these centers present a rather comprehensive set of technologies and seem to be open to a variety of different applications

Furthermore, there seems to be a general trend for larger centers with a higher number of employees being located towards the right side, indicating the operation of a comprehensive set of technologies, whereas smaller centers are located to the left. However, we found that M-CINSE (Maryland Center for Integrated Nano Science and Engineering, U.S.A.) indicated a size of only 5 employees which to us seemed to be overly modest compared to the claimed plurality of technologies.

In addition, it is quite unlikely to find a center that either operates only a limited number of different technologies declaring to target a diversified set of applications. The only example we found was NEMS in Taiwan. There is also only one example where a rather comprehensive set of technologies is not linked to the claim of a highly diversified application plurality: it's the European Network of Excellence in Multimaterials Manufacturing (4M).

However, comparing the three figures indicates that there doesn't seem to be general differences in strategies of individual centers from the three locations. It is noticeable that centers exhibiting a more comprehensive approach are traditional European institutions and national laboratories such as CEA Leti/France, University of Twente/The Netherlands and Forschungszentrum Karlsruhe/Germany. Their nano-oriented centers or programmes consist of up to 18 individual scientific institutes (Nano and Microsystems Programme, NANOMIKRO) and typically a rather large number of staff. MINATEC in France expects to grow from today's 2000 employees to a number of 3500 within the next few years. As such they are traditional national laboratories and seem to exploit a long-term basic funding from their governments. We have been impressed by the obvious absence of such rather large entities dedicated to nano science and technology in other regions, particularly in the U.S.A.. So even since former President Clinton in his 21 January 2000 speech at the California Intsitute of Technology announced a national initiative towards nanotechnology as well as President Bush increased funding and signed into law the 21st Century Nanotechnology Research and Development Act in 2003[43] no large entity such as MINATEC has been established. There clearly seems to be a different strategy towards funding a palette of smaller and focussed centers rather than a

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[43] Public Law 108-153, 108th Congress, Dec. 3, 2003 - [S. 189], An act to authorize appropriations for nanoscience, nanoengineering, and nanotechnology research, and for other purposes http://frwebgate.access.gpo.gov/cgibin/getdoc.cgi?dbname=108_cong_public_laws&docid=f:publ153.108

low number of diversified centers. However, diversification is assured by the high variety of such small centers, which are mostly focussed towards different application areas. So even if there are no diversified nano-oriented centers the high variety of individually focussed centers together resemble a rather powerful force for exploiting the future potential of nano science. It is beyond the scope of this study to evaluate the extent to which this strategy avoids duplication of work as well as to the extent to which established networks (NNUN and NNIN) are successful or sufficient to coordinate the work done in the centers and encourage and direct the interest of industry.

The picture of Asian/Pacific centers in general shows the same tendency as those derived from the other regions. However, KoNTRS in Korea seems to differ from the picture in a way as it is a large center but only operating a small set of technologies and being focussed to a small number of applications. This apparent contradiction can be explained by the fact that KoNTRS is an association that has a large number of members – not employees. As such it basically does not operate a single technology by its own. This would be the business of its member organisations.

Regarding the strategies exploited by nano-oriented centers in the three global regions we can draw the following conclusions:

- Independent of the global region there are either focussed centers with a dedicated set of technologies or centers with a comprehensive set of technologies aiming at a large variety of applications of nano science and nano technology
- The more comprehensive the technology portfolio is the larger the centers are
- A feature of the European situation is the presence of rather large national infrastructure centers with comprehensive sets of technologies such as MESA+, MINATEC and NANOMIKRO, which are complemented by a significant number of networks and knowledge-oriented centers.
- The U.S. American situation seems to distinguish in a way as it is dominated by a high variety of individually focussed centers exploiting a dedicated set of technologies and being coordinated in a nation-wide network. Nevertheless, this multitude of different centers in total builds the technological base of meeting the needs of a high variety of different application areas.

8.2 The most relevant micro and nano technologies for centers in different geographical regions

The above portfolio analyses and discussions do not provide detailed information on the nature of the individual technology portfolios of the centers or examine the relevance of specific micro and nano technologies (MNT) for those centers, with respect to their geographical location. Furthermore, section 8.1 does not reflect the role of different application areas and industrial sectors that are expected to be affected by nanotechnology in the future. Therefore we have drawn 89 individual micro and nano technologies versus 14 application areas for each of the three global regions. This is shown in fig. 8.2-1, 8.2-2 and 8.2-3 for Asia/Pacific, Europe and U.S.A. respectively.

In order to facilitate the comparison of the technology maps representing the three global areas we have adjusted the scale such that the colour code is related to the maximum possible number of centers coming from each area: hence a maximum number of centers from the Asia/Pacific area would be 7 centers. When considering the centers from the USA however a maximum of 12 centers was possible.

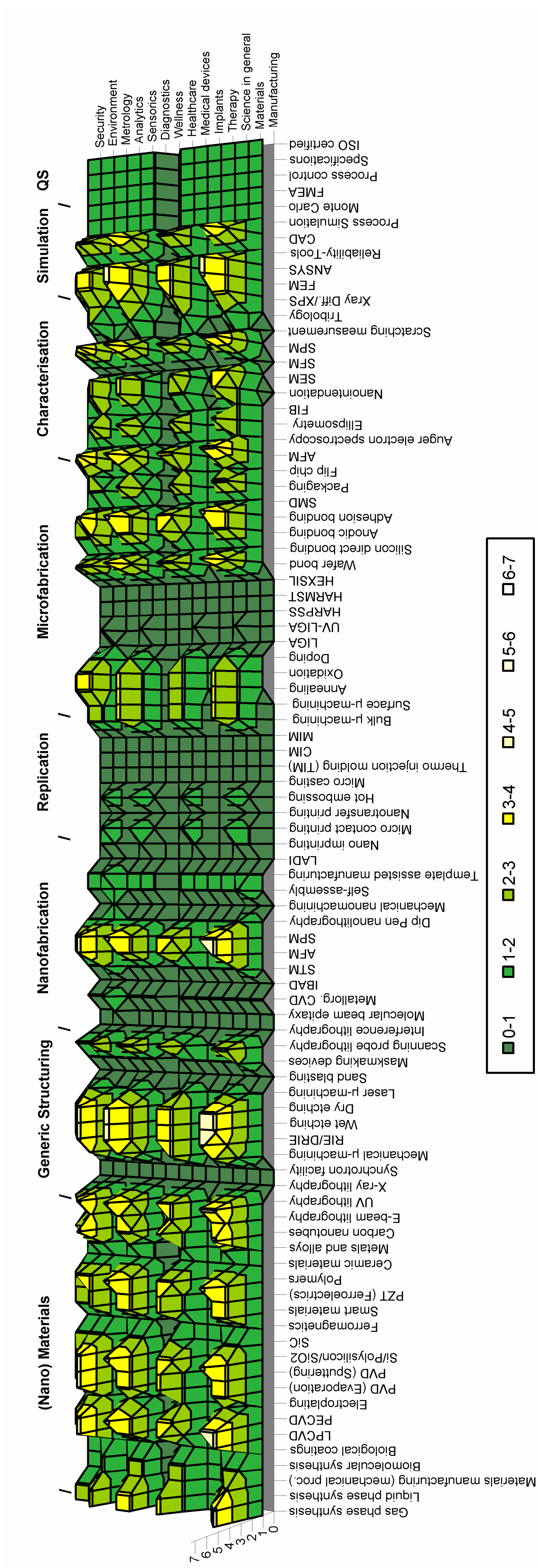

Figure 8.2-1 Technology vs. application-map of Asian nano-oriented centers

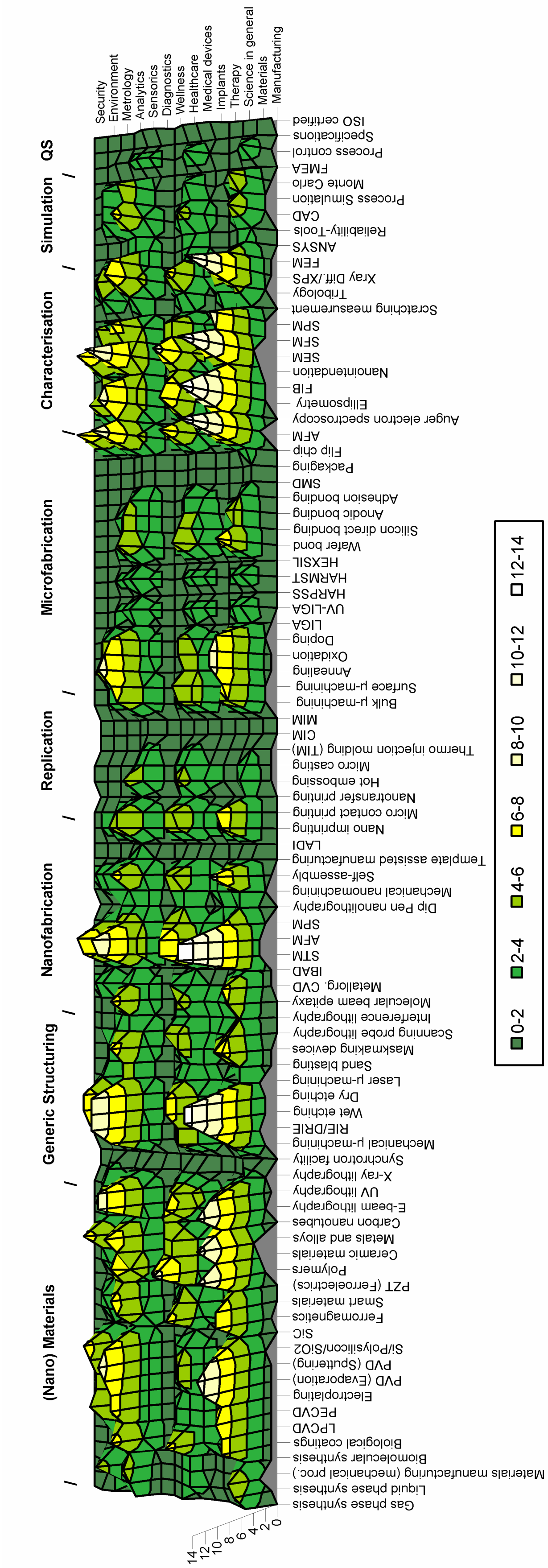

Figure 8.2-2 Technology vs. application-map of European nano-oriented centers

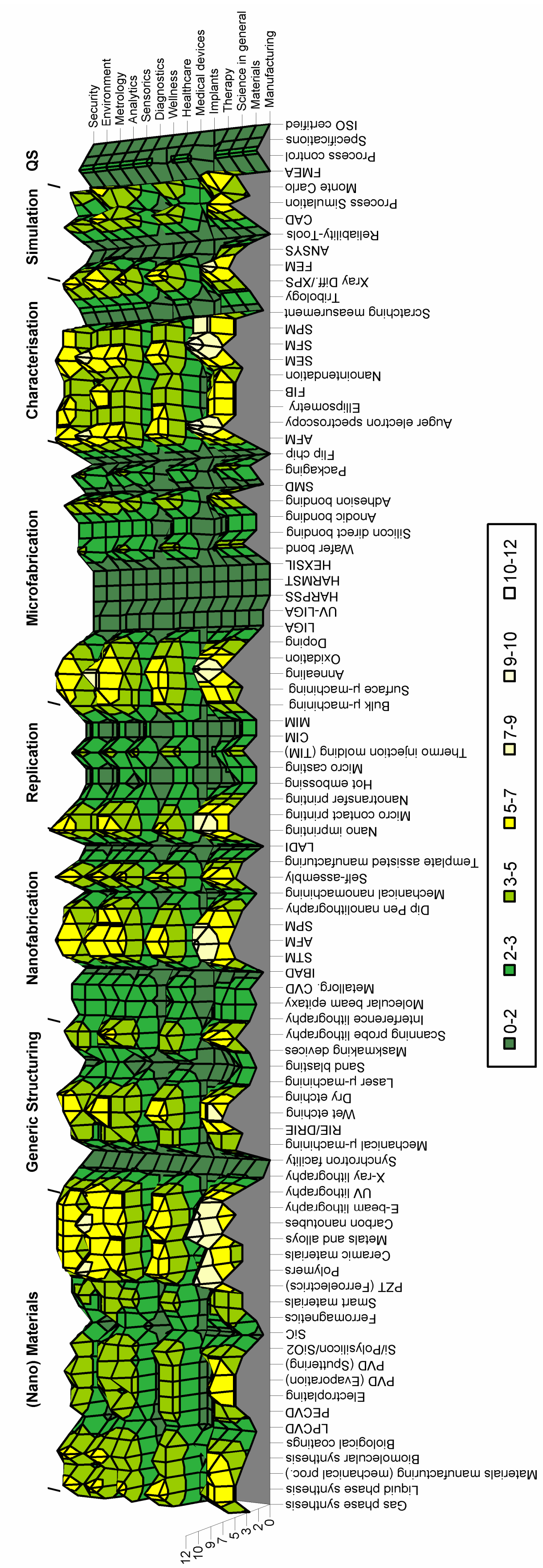

Figure 8.2-3 Technology vs. application-map of US American nano-oriented centers

In order to gain an overview of the global spread of the 89 individual technologies in the 41 centers which responded to the EVA_1 questionnaire we compared the technology maps for the three geographical regions. Our first observation was that the distribution of the technologies relating to application areas across the three global regions Fig's 8.2.1-3, matches closely the distribution of the technologies relating to industrial areas for the global regions. The following discussion relates firstly to the general global picture of the spread of technologies across the regions and secondly to the technologies as related to the application areas targeted in regions. A discussion of the technologies according to industrial sectors is given in 8.3.

A study of the maps shows that in general the US appears to operate the most comprehensive technological portfolio. The focussing and dedication of centers which is highlighted in the matrix analyses discussed above summates into an almost complete palette of technologies and application areas when viewed on the technology maps. It is simpler to describe the few exceptions which are in replication technology and in non-Silicon micro-fabrication technologies than the many strengths. The true picture could indeed reflect an even more comprehensive picture as not all centers are represented in the returned questionnaires.

The Asia/pacific map shows a well defined pattern, with uniform, almost regimented rows of peaks and troughs. Broad ranges of peaks of intense activity and plains of areas of less relevance for the region can be seen. The strengths of the Asia/pacific centers are found in simulation, nanofabrication using AFM and SPM, generic structuring and technologies for the production of nanomaterials. Molecular positioning and Monte Carlo are less employed than in US/Europe

European strengths are characterisation methods (maybe illustrating a strong research basis), nanofabrication using AFM, SPM and STM and generic structuring. Technologies for the production of nanomaterials are not as completely represented as in the US, particularly gas and liquid phase synthesis and biomelecular synthesis are noticeably lower. HARPSS, HARMST and LIGA appear to be European specialities.

A more detailed listing of the role and relevance of specific micro and nanotechnologies is given in table 8.2.1

It is worth noting that regardless of the location of the centers "Characterisation", "Materials", "classical silicon-technology", a rather small set of "Generic structuring methods" and an even smaller set of "Nanofabrication methods" seem to dominate the centers' technological portfolio. In order to compare the relative commonness of micro and nano technologies regardless of location, application areas and specific strategy of the centers the frequencies for the occurrence of the technologies has been ranked. This is displayed and discussed in section 8.4.

Besides differences in relative commonness of specific technologies also differences in the relevance of various application areas can be observed within the three global regions. As such, European centers for example rarely exploit MNT for security and environmental applications whereas these application areas are well under development in Asian and in particular in U.S.A.. This could reflect differences in national strategies for example to security research. Security research may in some countries be carried out in specific agencies which were not identified as nano or micro centers and are therefore not represented in this survey. It may be also a reflection of the outlook of the centers surveyed, as to which applications they see as important. The low importance attributed to research for environmentally relevant applications by European centers appears to be an anomaly in view of the strong environmental lobby in Europe. “Manufacturing” doesn’t seem to get the same attention from Asian and European centers as it gets from U.S. American. However, there are application areas like “Implants” and “Therapy” that do not seem to be of higher interest to nano-oriented centers, regardless of their location.

“Materials” and “Science in general” are the most common application areas indicating that although nano and microtechnolgies are already of interest in specific application areas there is still much work being carried out in the areas science in general and materials where the applications are not yet defined.

Table 8.2-1 Brief characterisation of the role and relevance of specific micro and nano technologies (MNT) or categories for nano-oriented centers in the global regions Asia/Pacific, Europe and U.S.A. (representing North America) as derived from figs. 8.2-1/2/3.

	Characteristic		
Category of MNT	**Asia/Pacific**	**Europe**	**U.S.A.**
Nanomaterials	In general of high relevance; biomolecular synthesis, biological coatings, Electroplating, SiC, ferromagnetics, ceramic materials and metals are below average	In general of high relevance; Gas phase synthesis, biomolecular synthesis, SiC and PZT are below average	In general of high relevance; highest activity compared with other regions; LPCVD, PECVD, SIC, ferromagnetics are below average
Generic structuring	High relevance for E-beam lithography, mechanical µ-machining, RIE/DRIE and other etching processes	High relevance for E-beam lithography and various etching processes	High relevance for E-beam lithography, mechanical µ-machining, RIE/DRIE and other etching processes
Nanofabrication	Dominated by AFM and SPM; no self assembly	Mostly AFM and STM; to some extent also self assembly	Dominated by AFM, STM and SPM techniques as well as by self assembly
Replication	Almost of no relevance	In general of rather low relevance but dominated by nano imprinting, micro contact printing and to some extent hot embossing	In general of rather low relevance but dominated by nano imprinting, micro contact printing and nanotransfer printing
Micro-fabrication	Classical Si-technologies of moderate relevance; Non-Si-micro-fabrication technologies of almost no relevance; packaging and flip chip technology	Dominated by classical Si-technologies with some activities in non-Si-micro-fabrication	Classical Si-technologies of high relevance; Non-Si-micro-fabrication technologies of no relevance
Characterisation	In general of high relevance; Dominated by AFM, SEM, SPM, Ellipsometry and X-ray Diffractometry	Seems to be of almost the highest relevance of MNT categories; Dominated by AFM, Ellipsometry, SFM, FIB and X-ray Diffractometry	Seems to be of almost the highest relevance of MNT categories; Besides tribology and scratching measurement all other techniques are well represented
Simulation	In general relevant whereas FEM, ANSYS and CAD are of significant relevance; *Monte Carlo methods do not occur*	In general moderately relevant whereas FEM dominate the techniques. Monte Carlo and Process simulation are contributing, but below average	In general relevant whereas FEM, ANSYS, CAD and *Monte Carlo methods are of significant relevance*
Quality system	Not relevant	In general quite low relevance with only process control means contributing significantly	In general quite low relevance with only process control means contributing significantly

8.3 Comparing industrial sectors that are targeted by nano-oriented centers in different geographical regions

The following section follows almost the same methodology as the previous one. We only replaced 14 “application areas” by 13 “industrial sectors” in order to identify possible differences in the relevance of micro and nano technologies (MNT) for various industrial sectors. As such we gained the diagrams shown in figs. 8.3-1, 8.3-2 and 8.3-3 for Asian/Pacific, European and U.S. American centers respectively. We identified qualitative differences regarding the relevance of MNT for distinct industrial sectors shown in tab. 8.3-1. Additionally we note that irregardless of location “Consumer industry” “Food industry” and “Pharmaceutical Industry” didn’t seem to be in the focus of nano-oriented centers. In a way this might seem surprising as recently published documents e.g. dealing with the impact of MNT on Food and Nutrition[44], and agriculture and food[45] indicate a higher relevance of MNT for food industry. These reports had not been available in 2005. Relevance for micro and nanotechnology to the food industry e.g. in sensors and nanoparticles, therein described probably might not have been widely known throughout the nano and micro research community.

Table 8.3-1 Qualitative “rating” of industrial sectors regarding their relevance to nano-oriented centers in Asia/Pacific, Europe and U.S.A. (representing North America) as derived from figs. 8.3-1/2/3.

Relevance	Asia/Pacific	Europe	U.S.A.
High	• Automation • Biotechnology • Chemistry • Information Technology • Life Sciences • Microelectronics	• Biotechnology • Chemistry • Life Sciences • Microelectronics	• Biotechnology • Chemistry • Defence • Energy • Life Sciences
Moderate	• Automotive • Energy • Equipment engineering	• Energy • Information Technology	• Microelectronics
Low	• Consumer Industry • Defence • Food Industry • Pharmaceutical Industry	• Automation • Automotive • Consumer Industry • Defence • Equipment engineering • Food Industry • Pharmaceutical Industry	• Automation • Automotive • Consumer Industry • Equipment engineering • Food Industry • Information Technology • Pharmaceutical Industry

The three industrial sectors that are mainly targeted by nano-oriented centers in all of the three geographical regions are : “Biotechnology”, “Chemistry” and “Life

[44] http://www.minacned.nl/nl/activiteiten/roadmap_mnt_food_nutrition.php (in Dutch language)
[45] T. Joseph, M. Morrison: Nanotechnology in Agriculture and Food; April 2006 report www.nanoforum.org, Institute of Nanotechnology

Sciences”. In this context it might be interesting that with “Defence” and “Energy” two industrial sectors – representing two of the basic social requirements “safety” and “wealth” – seem to be highly relevant only to U.S. American centers.

The technology maps plotting technology vs industry provide an interesting pictorial view of the situation.

Again noticeable from the Asia/Pacific map is the strong uniformity of technologies and industries relevant to this geographical region. The map shows neat blocks of active and inactive areas. Assuming that there is no overall planning for micro and nano technologies which covers the whole of this culturally and politically varied geographical area, spanning China, Hong Kong, Taiwan and South Korea, there is a remarkable consensus in the technologies applied and the industrial areas targeted. More specifically the Asia/Pacific region shows a strength in the silicon technologies with a relevance in most industrial areas in particular for life sciences, information technology and automation.

The U.S. American technology map reflects a particular emphasis for the industries: ‘Life science’, ‘Biotechnology’, ‘Chemistry’, ‘Defence’ and ‘Energy’ with some activity in microelectronics. Other industries are of less interest to the nano centers.

The technology map for Europe as relevant to industrial sectors shows interest mainly for the industries of ‘Biotechnology’, ‘Chemistry’, ‘Life sciences’ and ‘Microelectronics’. Reference to tab. 8.2.1 shows a high relevance of characterisation methods and microfabrication dominated by classical silicon technologies.

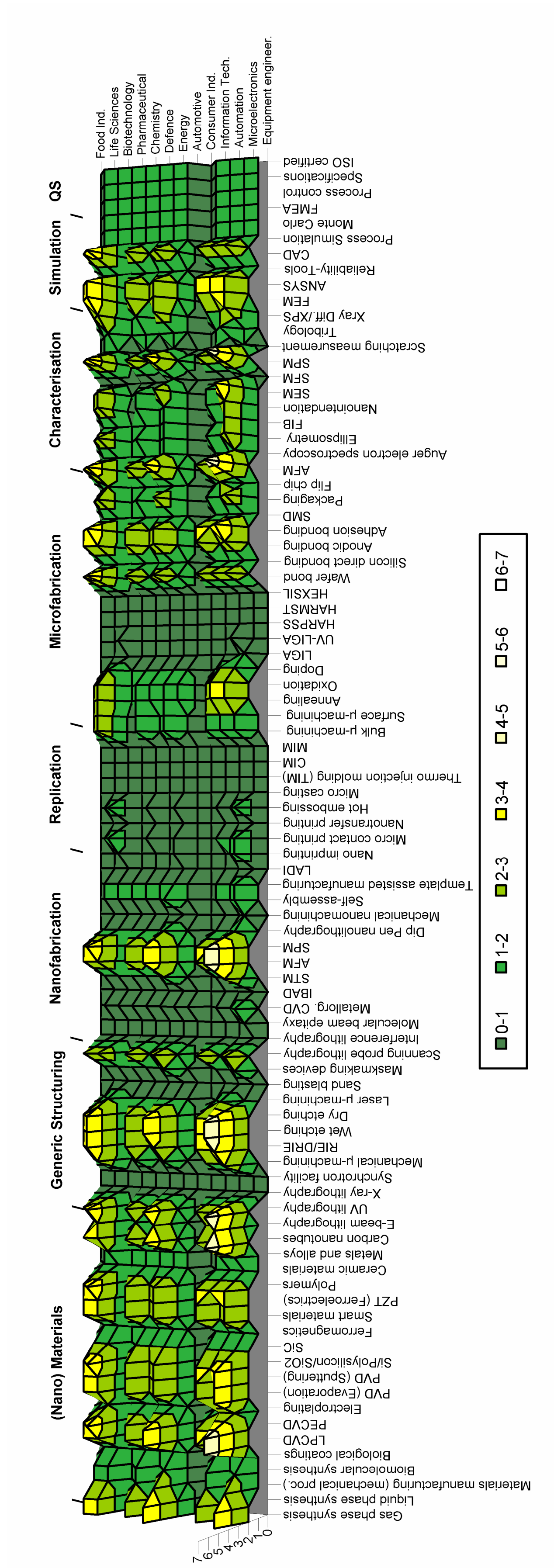

Figure 8.3-1 Technology vs. industries-map of Asian nano-oriented centers

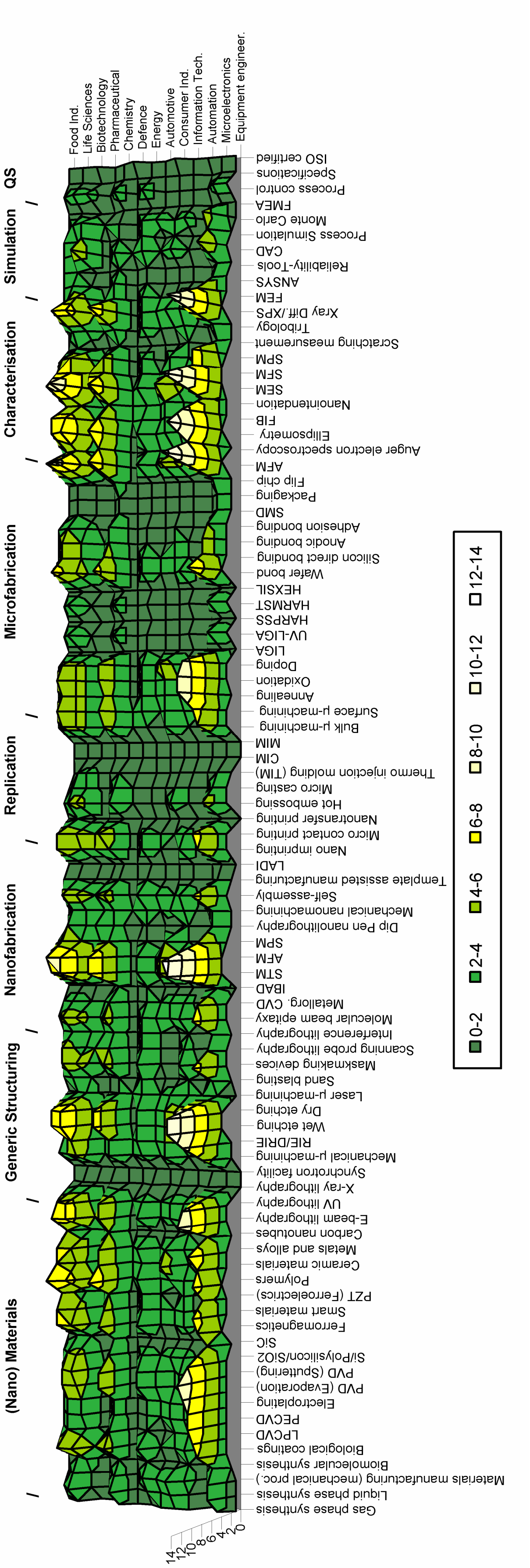

Figure 8.3-2 Technology vs. industries-map of European nano-oriented centers

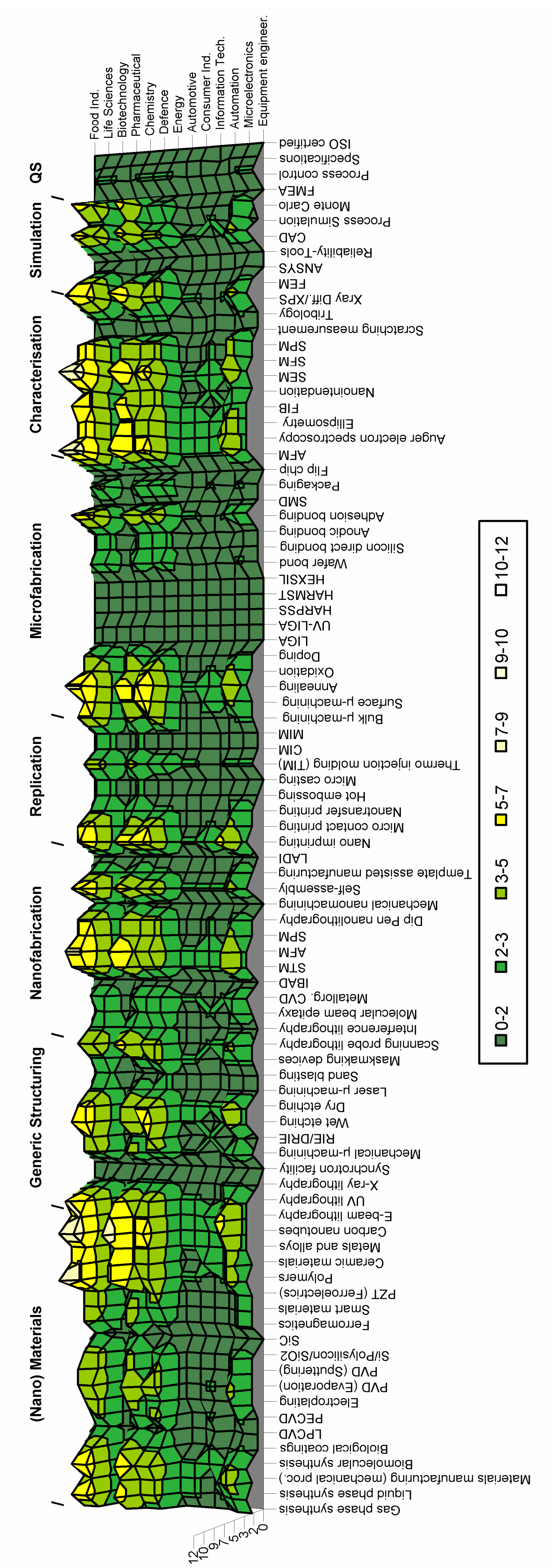

Figure 8.3-3 Technology vs. industries-map of US American nano-oriented centers

8.4 General technological aspects of nano-oriented centers

Towards the end of section 8.2 and due to some obvious global trends in the appearance of specific micro and nano technologies we raised the question whether it would be feasible to rank the relative commonness of micro and nano technologies in a more general way, i. e. regardless of their location and of the application areas and specific strategies of the nano-oriented centers. This then would give a unified as well as averaged but hopefully not indifferent picture of the relevance of specific micro and nano technologies either relative to each other or with regard to specific application areas and industrial sectors. In other words: it could lead to a canon of MNT that by distinguishing between most common and least common technologies would show the relative relevance of different technologies. The top ranked MNT then would resemble mainstream MNT – at least those that are operated/maintained in nano-oriented competence centers worldwide according to the response to our EVA_1 questionnaire.

Fig. 8.4-1 shows the relation between 89 different micro and nano technologies and 14 application areas. The layout of the diagram is identical to those in sections 6.3, 7.3 and 8.2 respectively. We only merged the database in a way to include all relevant responses to our questionnaire leading to a comprehensive and global picture of the relevance of micro and nano technologies (MNT). There are a few characteristics that have been described in detail in the above mentioned sections with regard to different orientations of the nano-oriented centers. Therefore we only highlight the most important findings:

- Independent of the application area there are MNT that are significantly over and under expressed leading to almost the same technology pattern for different applications. The relative commonness – as a convenient measure for the relative relevance – of MNT is shown in a hierarchical way in fig. 8.4-2 with AFM and SEM techniques as leading technologies which are offered by almost 90 % of the centers.
- Different categories of MNT seem to have a different relevance. We identified “characterisation” and “nanomaterials” as categories with undoubtedly the highest relevance. “Generic structuring”, “Nanofabrication” and Silicon-based micro-fabrication technologies are also of high importance to nano-oriented centers whereas the situation for “Simulation” is rather spotty. However, “Replication” seems to lack significant relevance which is also true to some non-Silicon micro-fabrication technologies and “Quality system”.
- There are various application areas that seem to be of significantly high relevance to nano-oriented centers. These are “Materials”, “Science in general”, “Medical devices” and “Healthcare” as well as “Sensorics”, “Analytics”, “Security” and “Environment”. Other application areas seem to be either of lower or of even no relevance to nano-oriented centers – such as “Implants” and “Therapy”.

In particular, the finding of comparable technological patterns for different application areas strongly supports the idea of mainstream MNT. Even if we could prove differences in the most common technologies for either micro and nano integration centers (see 6.3) or nano-bio centers (see 7.3) and also depending on geographical location (see 8.2) to some extent there seems to be a common understanding, of what MNT is. This is shown in fig. 8.4-2 in detail.

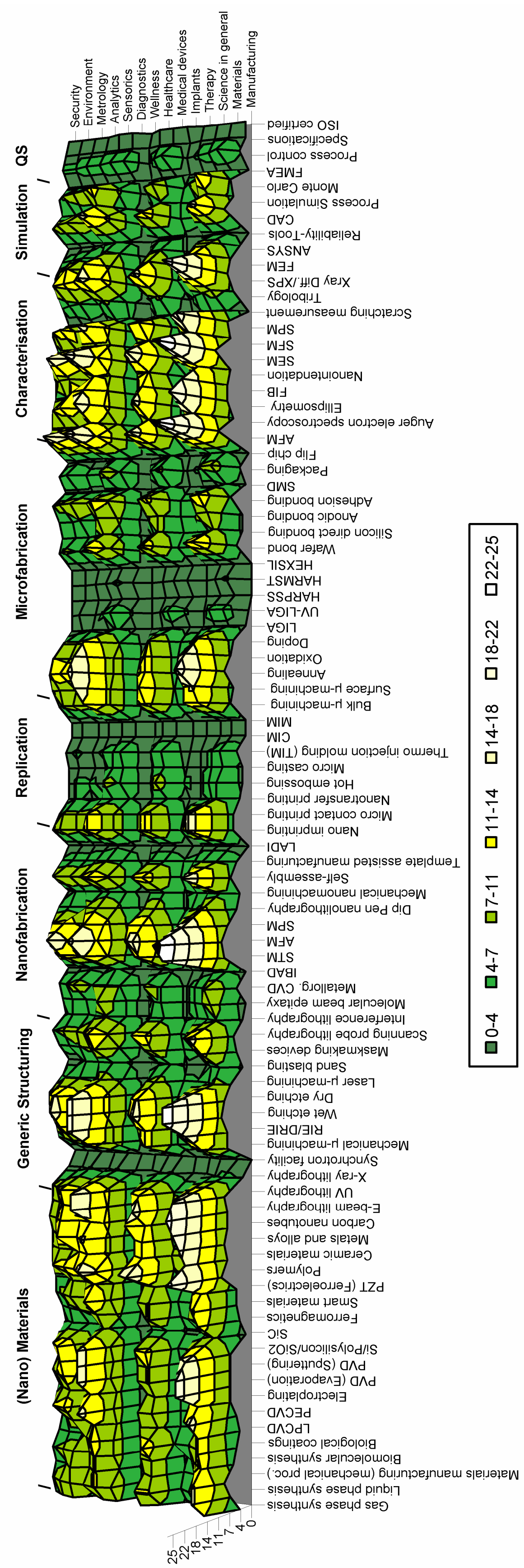

Figure 8.4-1 Technology vs. application-map of all nano-oriented centers that have responded to EVA_1 questionnaire, indicating a general view on technologies from the focus of application areas

Fig. 8.4-2 lists the MNT in a hierarchical way by starting with those that are offered frequently by nano-oriented centers and ending with those that do not seem to be of relevance to nano-oriented centers. Fig. 8.4-3 extracts those technologies which seem of highest relevance to nano-oriented centers, indicated by a relative commonness of 50 %.

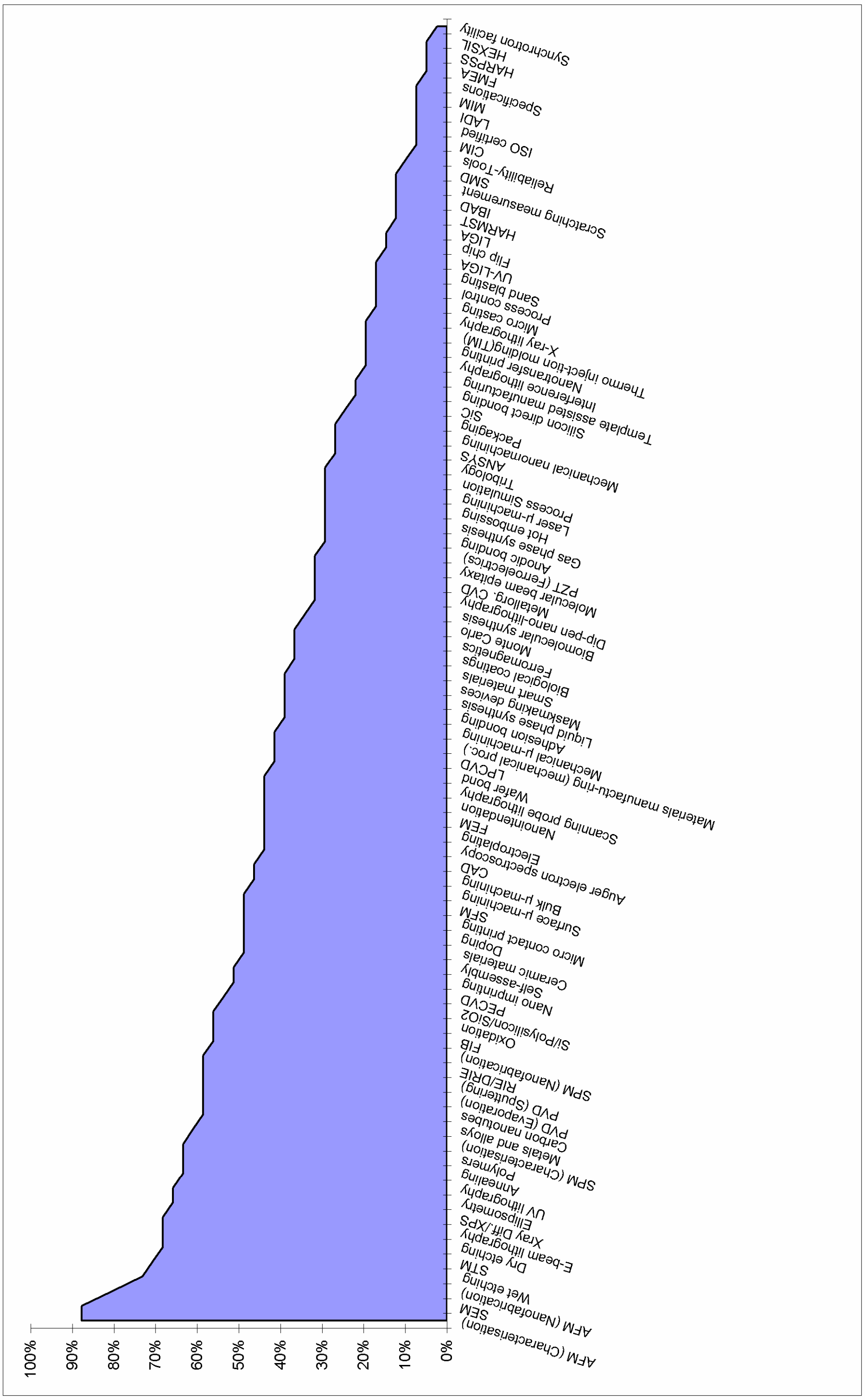

Figure 8.4-2 Relative commonness of micro and nano technologies as derived from all relevant responses to the EVA_1 questionnaire. The diagram indicates a global view on MNT from the focus of different application technologies.

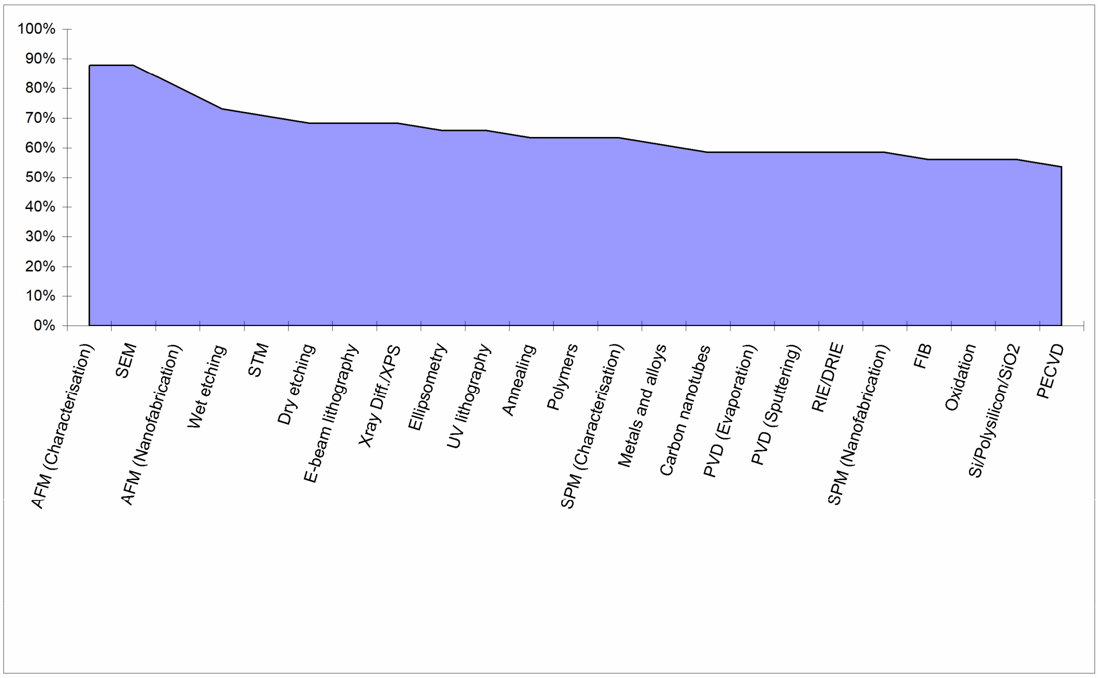

Figure 8.4-3 The "most common" technologies offered (operated and maintained) by nano-oriented competence centers irrespective of geographic aspects or any specific thematic orientation. The diagram extracts those technologies from fig: 8.4-2, that have been nominated by more than 50 % of all centers.

Fig. 8.4-3 clearly indicates the outstanding role of "Characterisation": 5 out of the ten most common micro and nano technologies are characterisation techniques with AFM (characterisation mode) and SEM heading the global MNT list. Second in terms of relevance are AFM (fabrication mode) and "Silicon-based micro-fabrication" closely followed by three "Nanomaterials": polymers, metals and alloys and carbon nanotubes. As could have been expected, E-beam lithography turned out to be *the* standard for generating primary structures.

Besides technological details we have been interested in the role of specific industrial sectors to nano-oriented centers. As such we have drawn 89 technologies against 13 different industrial sectors leading to fig. 8.4-4. This figure indicates that from a global point of view there are five industrial sectors that seem to have the closest relation to micro and nano technologies – at least to nano-oriented centers:

- Biotechnology
- Chemistry
- Energy
- Life Sciences
- Microelectronics

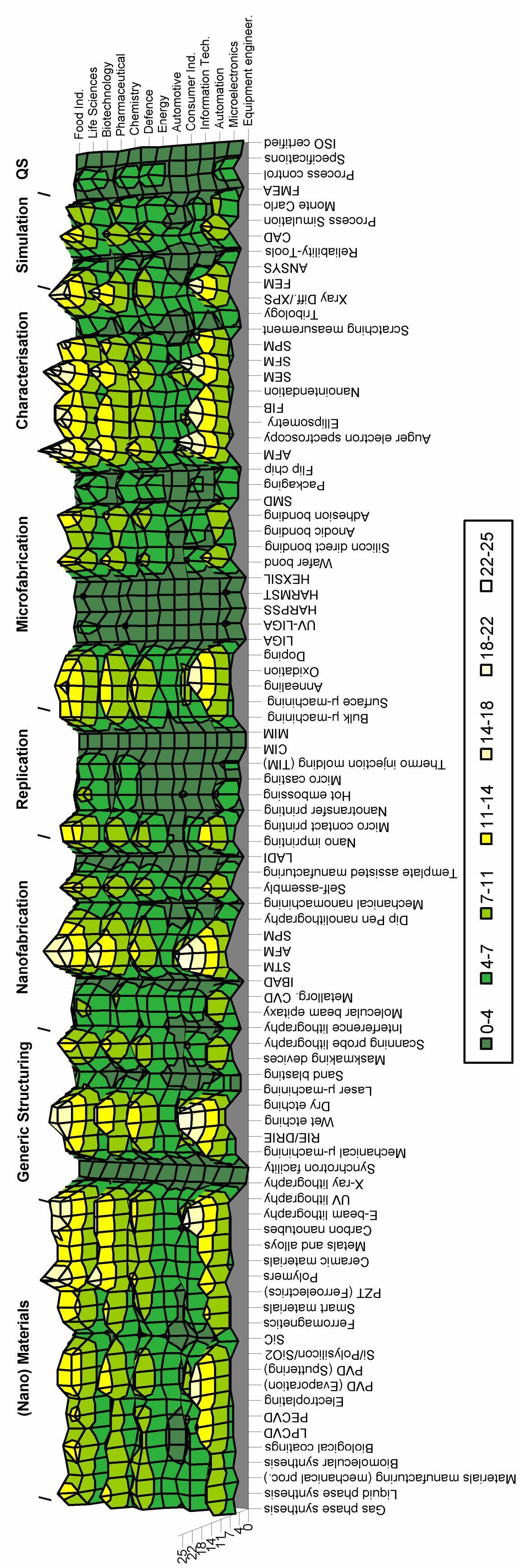

Figure 8.4-4 Technology vs. industries-map of all nano-oriented centers that have responded to EVA_1 questionnaire, indicating a general view on technologies from the focus of industrial sectors

Even if we do not intend to rank these industries according to any absolute scale we could identify “Energy” with probably the lowest relative expression profile among these five industries as a rather emerging industrial sector, whereas “Microelectronics” and “Chemistry” confirm their long-lasting affinity to MNT. “Life Sciences” and “Biotechnology” appear to be rather younger and particularly highly promising industries for the exploitation of MNT.

9 Conclusion

As was stated in section 0 we wanted to make out relevant technologies as well as industrial trends in micro and Nanotechnology (MNT). Furthermore, we focussed on identifying certain strategies for facilitating access to MNT by establishing competence centers with regard to possible differences in different global regions. The following list highlights key findings of EVA_1 without prioritising them as it is left to the readers to decide which part of the study appears to be of most value to them:

- Generally we have found that establishing a nano-oriented center appears to be a rather fashionable business of our times. However, the trend is not new as is indicated by a significant number of competence centers that have been founded prior to 2000. Typically nano-oriented centers have less than or a maximum number of 20 employees. Only a few centers are bigger than 100 employees. The rather low numbers might be related to the fact that a significant number of nano-oriented centers have been established recently. So they are still building up capacities. With approx. 50 % probability nano-oriented centers are R&D-oriented; another 21 % would count for knowledge-orientation and also 18 % for providing access to technologies and infrastructure. There is only a 4 % probability to find industry-orientation. Even if the mission of nano-oriented centers is highly likely to consist of spreading knowledge, pursuing cutting edge science and integrating disciplines it was interesting that precisely these centers mainly target industrial users with scientists only coming second.
- By adapting the Boston Consulting Group Portfolio Analysis Matrix to EVA_1 we were able to compare different centers in order to display the relative market or application attractiveness versus technological strengths. As such we could identify different strategic approaches such as focussed centers operating a dedicated set of technologies on the one hand and highly diversified centers which mainly operate a comprehensive set of technologies on the other.
- In centers with a different thematic orientation we could identify significant differences regarding the occurrence of individual micro and nanotechnologies and the tendency towards targeting different application areas and industrial sectors. This was derived from comparing micro and nano integration centers with nano-biological centers as two relevant examples. However it was a universal finding that independent of a specific orientation more or less the same technological patterns were observed for different application areas, i. e. resembling a specific set of highly relevant technologies, which lead us to the assumption of something like "mainstream MNT".
- <u>Micro and nano (integration) centers:</u> Based on a data set of 12 centers in 8 different countries we could identify two main groups. Seven centers tend to be rather small, operate a dedicated set of technologies and are focussed on an individually limited number of applications. In contrast five of the micro and nano-oriented centers operate and maintain a rather comprehensive set of technologies and are open to diverse applications. As such they tend to be much larger than the focussed centers with dedicated set of technologies. In a first approach we found a linear dependency between technology plurality (as

measure for technological strength) and application plurality (as measure for market attractiveness), typically with an increasing size of the centers if technology plurality increases. In order to gain specific information on the commonness of specific technologies we have ranked 89 micro and nanotechnologies out of 8 categories in a way as to identify the most common technologies in micro and nano oriented centers. These were: AFM, FEM, SEM, wet etching, bulk µ-machining, annealing, dry etching, metals and alloys, polymers, PVD, RIE/DRIE, UV Lithography to name only those with a relative occurrence larger than 70 %. Furthermore, we have identified the following industrial sectors as mainly targeted by micro and nano oriented centers: Life Science, Biotechnology, Chemistry, Energy, Microelectronics.

- Nano bio centers: Only 5 centers that responded to EVA_1 are dealing almost exclusively with nano and bio issues, 3 of which from U.S.A. and 2 from Europe so that conclusions would have to be drawn with caution. It is interesting to note that the centers from Europe are networks with a rather high number of members but with no R&D work pursued within the frame of the center's funding. In contrast, the 3 U.S. American centers are R&D-oriented centers pursuing cutting edge science whereas the European centers rather stimulate R&D work or foster knowledge dissemination. We could not identify an Asian nano-bio-oriented center even though there are world class institutes located e. g. in Singapore or Korea among others. Regarding technological capabilities nano-bio centers are significantly different from micro and nano centers. The most common technologies comprise AFM, E-beam lithography, polymers, SEM, STM, X-ray diffractometry, biological coatings, carbon nanotubes, ceramic materials, FIB, Monte Carlo methods and SPM to name only those with a relative occurrence larger than 70 %. It is obvious that nano-bio centers mainly target the following industries: Life Science, Biotechnology, and Chemistry.
- Comparing the strategies of Asia/Pacific, Europe and U.S.A. shows that in particular Europe might be dominated by few large scale infrastructure facilities which are complemented by a significant number of networks and mainly knowledge-oriented centers. The U.S.A. seems to exploit an alternative strategy towards funding a palette of smaller but focussed centers rather than a low number of diversified centers. Diversification is assured by the high variety of such small centers, which are mostly focussed towards different application areas.
- Concerning technological patterns we have listed qualitative differences as were derived by an evaluation of technology maps. In general U.S. American centers exploit the most comprehensive set of technologies, with clear focus on characterisation, classical Silicon technologies and a strong commitment towards (new) nanomaterials and a reasonable scope of methods for generic structuring. Even individual technologies have been identified that are of different relevance to centers from different global regions. Among others Monte Carlo methods seems to have a significant relevance to U.S. American centers wheras they seem to be of less or even no relevance to European or Asian centers. The strengths of the Asia/Pacific centers are found in simulation, nanofabrication using AFM and SPM, generic structuring and technologies for the production of nanomaterials. European strengths are characterisation methods, nanofabrication using AFM, SPM and STM and

generic structuring. High aspect ratio technologies (HARPSS, HARMST and LIGA) appear to be European specialities.

- Regardless of the thematic orientation we could identify differences concerning the relevance of different industrial sectors that are related to the geographical regions Asia/Pacific, Europe, U.S.A.. However, three industrial sectors are targeted by nano-oriented centers in these geographical regions irrespective to the center's location: "Biotechnology", "Chemistry" and "Life Sciences". "Defence" and "Energy" – two industrial sectors representing two of the most recent basic social requirements "safety" and "wealth" – seem to be comparably relevant only to U.S. American centers.
- From a universal point of view - i. e. regardless of thematic orientation or regional location - analysing the occurrence of different micro and nanotechnologies in a way lead to the 'definition' of "mainstream MNT", i. e. a set of MNT that is provided, operated and maintained by a majority of nano-oriented centers worldwide. AFM and SEM techniques are leading technologies which are offered by almost 90 % of the centers worldwide.
- So-called 'universal killer applications' with a significantly high relevance to nano-oriented centers irrespective to type, mission, thematic orientation and geographical location proved to be "Materials", "Science in general", "Medical devices" and "Healthcare" as well as "Sensorics", "Analytics", "Security" and "Environment".

9.1 Any Recommendations?

EVA_1's approach is more or less to give a state of the art picture in micro and nanotechnologies as well as in strategies for facilitating access to them. So giving advice would be definitely out of our scope. However, to us there are some points that seem to be worth considering:

- Nanotechnology and its relatives still seem to be a business for scientists rather than for industrial people. Even if we take into account that market expectations are beyond 1 billion USD/a it might be too early to expect widespread transfer of new technologies into industrial application when neither scientific basics are understood nor the huge potential of new materials, novel effects as well as of potential threats of nanotechnology have been sufficiently explored. We are convinced that a sustainable approach to research and development in nanotechnology and its relatives requires additional means to simply establishing nano-oriented centers. Among others these are transdisciplinary research cooperation, e.g. technology forecast and assessment, socio-economic and toxicological work. A rather balanced long-term strategy is required with reasonable financial support and a willingness to stick to it beyond the shortness of breath in R&D funding of our time.
- Centers provide access to know how and infrastructure. If a particular center is a network then it more or less provides access to infrastructure as it is available at the sites of its members by the time of its inauguration. If there are no additional sources for updating the infrastructure this strategy clearly bears the danger of falling behind the state of the art. By evaluating the typical budget for establishing and for maintaining a center there doesn't seem to

exist a strategy or more precisely a source of funding for updating nano-oriented centers and networks once they are established.

- Linking a highly diversified community of nano-oriented centers seems to be realized only in the U.S.A.. While we won't discuss the plausibility of networking nano-oriented centers in Asia/Pacific, to us it appears to be reasonable that a better coordination of resources could be established at least in Europe. This would make sense in a way as it might be linked with additional (national or international) sources and a European strategy for nano-infrastructure.

9.2 Outlook

Before publishing the EVA_1 study we have had the opportunity to present parts of it as well as preliminary results at different states of completion to different audiences ranging from bilateral discussion, talks at seminars in governmental administrations to even scientific conferences. While we mostly felt encouragement for our work we are well aware that this might only be a first step and the EVA_1 initiative could become a subject of constant improvement. Without any doubt, there are numerous aspects we are interested in future such as tracking the relevance of individual technologies and industrial sectors for MNT or to further improve the portfolio method as well as to combine performance indicators with strategic claims to name a few.

In order to further improve the EVA_1 initiative we appreciate any comment, general feed back or specific request e. g. regarding additional questions to a possible future questionnaire or the like from our readers.

Please feel invited to use the following form (fax it to +49 (0) 7247 82 55 79) or to send an email to info@nanomikro.fzk.de referring to EVA_1 with your contribution.

Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft

Feed back form

Evaluating nano-oriented competence centers

Please use this form to comment on EVA_1 and return by fax +49 – 7247 82 55 79

Sender:

Name:
Function:
Company/Institution:
Address:
Country:
Phone:
Email:

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www.fzk.de/nanomikro/eva_1

Appendix A: EVA_1 questionnaire

Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft

Mapping global micro-nano centers

EVA_1

Questionnaire

Please take 15 minutes of your precious time to complete the questionnaire and send it back via FAX: +49-7247 82 55 79 by April 20th 2005

Instantly you will be rewarded with

i) a copy of the EVA_1 study
(in English; available in August 2005)

and ii) a mug of Forschungszentrum Karlsruhe.

1. Name of Centre:______________________________

2. Abbreviation:______________________________

3. Year of foundation:______________________________

4. First year of full operation:______________________________

5. Number of employees *in 2005:*__________________*in full operation:*______________

6. Please classify what fits to define the type of your center (you can select more than one)

- **R&D Project** (Center fulfils a specific/specified R&D task) ?
- **Science Center** (You focus on generating basic science) ?
- **Infrastructure Center** (You provide services and access to standardised technologies) ?
- **Network** (You provide access to other key players in the field and act like a communication platform) ?
- **Industrial Center** (You try to make profit with your capabilities) ?
- **Association or Initiative** (You cover someone other's interests) ?
- **Other** (please specify): ______________________________

7. What of the following could be part of your mission statement? (You can select more than one)

- **Pursuing original cutting edge science** ?
- **Facilitating exploitation of scientific developments** ?
- **Providing access to standardized technologies and sophisticated capabilities** ?
- **Integrating disciplines** ?
- **Spreading knowledge** ?
- **Industrial manufacturing and production** ?
- **Interlinking and networking** ?
- **Consultancy** ?
- **Education** ?
- **Other** (please specify): ______________________________

Forschungszentrum Karlsruhe (http://www.fzk.de) is one of Europe's leading National Research Centres, among other topics highly dedicated to developments in the fields of nano and microsystems. 1/4

EVA_1 is an institutionalised funded project for global surveillance of micro-nano centers. Presumably it will be published in 08/05.

Matthias Kautt is deputy director of Forschungszentrum's *Nano and Microsystems Program* and editor of the *EVA_1* study.

Please send this sheet to FAX: +49 – 7247 82 55 79

8. Your center is focused on meeting the needs of which of the following groups. (You can select more than one)

Scientists	?
Large Industry	?
Small and medium sized enterprises (SME)	?
Associations	?
Government employees	?
Other (please specify): ______________________________	

9. What micro nano technology is available in your center? (Please select as much as appropriate)

(Nano) Materials	Generic Structuring	Nanofabrication	Replication	Micro-fabrication	Characterisation
? Gas phase synthesis	? E-beam lithography	? Scanning probe lithography	? Nano imprinting	? Bulk µ-machining	? AFM
? Liquid phase synthesis	? UV lithography	? Interference lithography	? Micro contact printing	? Surface µ-machining	? Auger electron spectroscopy
? Materials manufacturing (mechanical proc.)	? X-ray lithography	? Molecular beam epitaxy	? Nanotransfer printing	? Annealing	? Ellipsometry
? Biomolecular synthesis	? Synchrotron facility	? Metallorg. CVD	? Hot embossing	? Oxidation	? FIB
? Biological coatings	? Mechanical µ-machining	? IBAD	? Micro casting	? Doping	? Nanointendation
? LPCVD	? RIE/DRIE	? STM	? Thermo inject-tion molding (TIM)	? LIGA	? SEM
? PECVD	? Wet etching	? AFM		? UV-LIGA	? SFM
? Electroplating	? Dry etching	? SPM	? CIM	? HARPSS	? SPM
? PVD (Evaporation)	? Laser µ-machining	? Dip-pen nano-lithography	? MIM	? HARMST	? Scratching measurement
? PVD (Sputtering)	? Sand blasting	? Mechanical nanomachining		? HEXSIL	? Tribology
? Si/Polysilicon/SiO_2	? Maskmaking devices	? Self-assembly		? Wafer bond	? XRay Diff./XPS
? SiC		? Template assisted manufacturing		? Silicon direct bonding	
? Ferromagnetics		? LADI		? Anodic bonding	
? Smart materials				? Adhesion bonding	
? PZT (Ferroelectrics)				? SMD	
? Polymers				? Packaging	
? Ceramic materials				? Flip chip	
? Metals and alloys					
? Carbon nanotubes					

Simulation	Quality System	If other, please specify:
? FEM	? FMEA	? ------------------------------
? ANSYS	? Process control	? ------------------------------
? Reliability-Tools	? Specifications	? ------------------------------
? CAD	? ISO certified	
? Process Simulation		
? Monte Carlo		

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Please send this sheet to FAX: +49 – 7247 82 55 79

10. Please indicate all manners that your center sustains itself (You can select more than one)

You provide paying customers access to technology	?
You obtain (additional) public project funding through a peer reviewed process	?
You have a dedicated centre with fixed budget (either from public or industrial/private sources)	?
You are an industrial entity generating sales and profits	?
You provide knowledge dissemination	?

Other (please specify): ____________________

11. If you link different partners or institutes… (You can select more than one)

… you share a common web site	?
… you act as a single unit in public relations and commercialisation	?
… your main business is demonstration of technical, scientific, or strategic synergies	?
… you exploit or develop elaborated communication technologies	?
… a main task of you is knowledge management and dissemination of knowledge	?
… your partnership consists of a leader and subordinate partners and of a highly developed (hierarchical) business structure	?
… you mainly deal with tasks of rather low complexity	?
… you mainly deal with tasks of high complexity	?
… you represent more than the sum of your individual partners	?
… you share complex dependencies between equal partners and share well defined structures regarding business processes	?

12. What application area or industrial sector do you strive for? (You can select more than one)

?	Biotechnology	?	Chemistry	?	Sensorics	?	Healthcare	?	Automation	?	Environment
?	Pharmaceutical	?	Diagnostics	?	Life Sciences	?	Materials	?	Wellness	?	Security
?	Consumer Prod.	?	Therapy	?	Microelectronics	?	Automotive	?	Energy	?	Defence
?	Medical devices	?	Implants	?	Equipment engineer.	?	Metrology	?	Analytics	?	Manufacturing
?	Science in general	?	Food Ind.	?	Information Tech.	?	----------------	?	--------------	?	-------------------

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13. Please estimate your annual budget:______________________**in which currency?**_________

If you don't know exactly, please try to indicate the range [**in million USD per year**]*:*

? < 0.5 million ? 0.51 … 1.99 ? 2.0 … 4.9 ? 5 … 7 ? > 7

14. Please estimate your investment costs in order to set up the center:______________
in which currency? ____________

If you don't know exactly, please try to indicate the range [**in million USD**]*:*

? < 1 million ? 1.1 … 2.9 ? 3.0 … 9.9 ? 10 … 20 ? > 20

15. Average Turnover/Revenues [per year]:____________________**in which currency?**_________

If you don't know exactly, please try to indicate the range [**in million USD per year**]*:*

? < 0.1 million ? 0.11 … 0.49 ? 0.5 … 1 ? 1.1 … 3 ? > 3

16. Please approximate the average number of peer-reviewed scientific publications your center generates per year:____

17. Please approximate the average number of doctorate students your center employs yearly:____

18. Please use this space to tell us anything else about micro-nano technology or fabrication centers you would like us to consider.

? **Yes, I completed the questionnaire and want to receive a free copy of the EVA_1 study**

Please send it to:

Full Name/Title: ________________________________

Institution: ________________________________

Department: ________________________________

Postal Address ________________________________

____

____

____

E-Mail: ________________________________

Phone: ________________________________

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Appendix B: Data sheets of the centers that responded to EVA_1

We do not offer a complete list of centers contacted. However, the following pages extracts relevant information of single nano centers as was derived from the returned questionnaires.

Table B-1 List of Centers which replied to the EVA_1 questionnaire

Multi-Material Micro Manufacture	EU
Center for Nano-Scale Systems Ben-Gurion University	Israel
Center for Affordable Nanoengineering of Polymer Biomedical Devices, Ohio	USA
Center for Biological and Environmental Nanotechnology	USA
CC-Nanobiotech-Kompetenzzentrum Nanobiotechnology	Germany
Kompetenzzentrum NanOp	Germany
Kompetenzzentrum Ultrapräzise Oberflächen Bearbeitung	Germany
Center for Innovation in Micro and Nanotechnology	France
Center for High-Rate Nanomanufacturing	USA
The DOE Center for Integrated Nanotechnologies	USA
Center for Micro and Nano Processing	USA
Center for Micro and Nano Systems	China
The Center for Microtechnology and Nanotechnology	USA
Center for Nanoscale Materials	USA
Center for Nanoscience and Technology	Taiwan
EPFL Center of Micro Nano Technology	Switzerland
Micro and Nanotechnology Network Euregio Bodensee	Europe
Institute for Atomic and Molecular Physics, Nanofabrication	The Netherlands
Fraunhofer Center Nanoelectronic Technologies	Germany
Frontiers Network of Excellence	EU
Forschungszentrum Jülich, Institute Thin Film and Interfaces	Germany
Forschungszentrum Karlsruhe, Programme Nano and Microsystems	Germany
John A. Swanson Micro and Nanotechnology Lab.	USA
Korea Nanotechnology Research Society	Korea
KTH/KI Nano and Microtechnology Center	Sweden
Maryland Center for Integrated Nano Science and Engineering	USA
Manufacturing Engineering Center Cardiff University	UK
MESA+ Institute for Nanotechnology	The Netherlands
The University of Birmingham Microengineering and Nanotechnology Research Center at Birmingham University	UK
Competence Network for Nanomaterials	Germany
Nano/Bio Interface Center	USA
National Center of Competence in Research (NCCR) Nanoscale science	Switzerland
National Center for Nanoscience and Nanotechnology	China
Nano-Electrical-Mechanical-System Research Center	Taiwan
National NanoFab Center	South Korea
Northwestern University Nanoscale Science and Engineering Center for Integrated Nanopatterning and Detection Technologies	USA
Nanotechnology Research Association of Korea	South Korea
Oregon Nanoscience and Microtechnologies Institute	USA
RWTH-NANOCLUB	Germany
TASC (Advanced technology and Nanoscience) INFM	Italy
Veneto Nanotech S.C.P.A.	Italy
Sara and Moshe Zisapel Nanoelectronics Research Center	Israel

Name: Multi-Material Micro Manufacture		Europe
Coordinator: Professor Stefan Dimov		
Acronym: 4M	**Internet address:** http://www.4m-net.org/	
Founded: 2004	**Size:** 30 partner organisations	

Description: 4M is a NoE Funded under the FP6 of the European Union. By Integrating the complementary research projects in the partner organisations the aim is to develop micro and nano technology for the batch manufacture of micro components and devices. The thirty partner organisations, scattered across Europe, integrate the research of more than 100 researchers. The research is funded by the partner organisations, the networking by the EU. Education and the spreading of knowledge are essential characteristics of 4M, as are networking and the availability of specialised equipment and expertise to the partner organisations. Not only research scientists but SME's industry and government employees will benefit from 4M.

Technology portfolio

(Nano)materials: gas phase synthesis, liquid phase synthesis, materials manufacturing (mechanical proc.), biomolecular synthesis, biological coatings, LPCVD, PECVD, Electroplating, PVD (evaporation), PVD (sputtering), Si/polysilicon/SiO_2, SiC, ferromagnetics, smart materials, PZT (ferroelectrics), polymers, ceramic materials, metals and alloys, carbon nanotubes.

Generic Structuring: E-beam lithography, UV lithography, X-ray lithography, Synchrotron facility, mechanical µ-machining, RIE/DRIE, wet etching, dry etching, laser µ-machining, sand blasting, mask-making devices.

Nanofabrication: scanning probe lithography, interface lithography, molecular beam epitaxy, metal-org CVD, IBAD, STM, AFM, SPM, dip-pen lithography, mechanical nanomachining, self-assembly, template assisted manufacturing, LADI.

Replication: nano-imprinting, micro contact printing, nanotransfer printing, hot embossing, micro-casting, thermo injection molding (TIM), CIM, MIM.

Micro-fabrication: Bulk µ-machining, surface µ-machining, annealing, oxidation, doping, LIGA, UV-LIGA, HARPSS, HARMST, HEXSIL, wafer bond, silicon direct bonding, anodic bonding, adhesion bonding, SMD, packaging, flip chip.

Characterisation: AFM, Auger electron spectroscopy, ellipsometry, FIB, nanointendation, SEM, SFM, SPM, scratching measurement, tribology, X-ray diff./XPS.

Simulation: FEM, ANSYS, reliability tools, CAD, process simulation, Monte Carlo.

Quality System: FMEA, process control, specifications, ISO certified

Main fields of application sensorics, microfluidics, microphase

Name: Center for Nano-Scale Systems Ben-Gurion University		Israel
Director:		
Acronym: CNSS	**Internet address:** http://www.bgu.ac.il/physics/	
Founded: 2005	**no. of employees:** 25	

Description: CNSS is a fabrication center: one of the service and R&D units of the Ilse Katz Center for Meso and Nano-Scale Science and Technology at Ben-Gurion University. The aim is to develop smart interfaces to incorporate mechanical and information links between nanostructures and the other components of a device. The center is financially supported by public and private funds in both peer reviewed projects and collaboration. It aims to be a profit making infrastructure center; pursuing cutting edge science, facilitating the exploitation of scientific developments by providing access to standardised technologies and sophisticated capabilities. The center is interdisciplinary and involved in education, knowledge dissemination and consultancy.

Technology portfolio

(nano)materials: PECVD, Electroplating, PVD (sputtering), Si/Polysilicon/SiO_2, SiC, smart materials, metals and alloys, carbon nanotubes.

Generic Structuring: E-beam lithography, UV lithography, mechanical µ-machining, RIE/DRIE, wet etching, dry etching.

Nanofabrication: STM, AFM.

Micro-fabrication: annealing

Characterisation: AFM, Auger electron spectroscopy, ellipsometry, FIB, SEM, SPM, X-ray diff./XPS.

Simulation: CAD, process simulation, Monte Carlo.

Main fields of application biotechnology, science in general, sensorics, microelectronics, materials, metrology.

Name: Center for Affordable Nanoengineering of Polymer Biomedical Devices Ohio USA	USA
Director: Professor L. James Lee	
Acronym: CANPBD	**Internet address:** http://www.eng.ohio-state.edu/research/labs/canpbd.php
Founded 2004	**no. of employees:** 87

Description: CANPBD is a National Science Foundation funded Nanoscale Science and Engineering Center. It expects to make major breakthroughs in developing affordable manufacturing methods to form, reinforce, bond and assemble polymer structures at the nanoscale for biomedical and other applications. Additional funding is obtained via peer reviewed funding projects and its role as an infrastructure center which provides paying customers access to technology. Scientists, large industry, SME's and government employees are served by the center.

Technology portfolio

(nano)materials: liquid phase synthesis, materials manufacturing (mechanical proc.), biological coatings, LPCVD, PECVD, Electroplating, PVD (evaporation), PVD (sputtering), Si/Polysilicon/SiO_2, SiC, smart materials, polymers, ceramic materials, metals and alloys, carbon nanotubes.

Generic Structuring: E-beam lithography, UV lithography, mechanical µ-machining, RIE/DRIE, wet etching, dry etching, laser µ-machining.

Nanofabrication: scanning probe lithography, interference lithography, STM, AFM, SPM, dip-pen nanolithography, mechanical nanomachining, self-assembly, template assisted manufacturing.

Replication: nano-imprinting, micro-contact printing, nanotransfer printing, hot embossing, micro-casting, thermo injection molding (TIM), CIM, MIM.

Micro-fabrication: bulk µ-machining, surface µ-machining, annealing, oxidation, doping, LIGA, UV-LIGA, wafer bond, adhesion bonding, packaging.

Characterisation: AFM, Auger electron spectroscopy, ellipsometry, FIB, nanointendation, SEM, SFM, SPM, X-ray diff./XPS.

Simulation: FEM, CAD, process simulation, Monte Carlo.

Main fields of application biotechnology, pharmaceutical, medical devices, science in general, chemistry, diagnostics, therapy, implants, sensorics, life sciences, health care, materials, analytics, environment, manufacturing

Name: Center for Biological and Environmental Nanotechnology		USA
Director: Professor Vicki Colvin		
Acronym: CBEN	**Internet address:** http://cben.rice.edu/	
Founded: 2001	**no. of employees:** 11	

Description: CBEN is a National Science Foundation funded Nanoscale Science and Engineering Center. Its focus is research at the interface between "dry" nanomaterials and aqueous media such as biological and environmental systems. CBEN provides access to other key players in the field and acts as a communication platform. There is an industrial affiliates programme and small and start up companies are also partnered in an entrepreneurial education programme with the on site school of management. Integration of disciplines spreading of knowledge and education are priorities of CBEN, its educational service extending to providing teaching material and links with local schools.

Technology portfolio

(nano)materials: gas phase synthesis, liquid phase synthesis, biomolecular synthesis, biological coatings, Si/Polysilicon/SiO_2, ferromagnetics, polymers, ceramic materials, metals and alloys, carbon nanotubes.

Generic Structuring: E-beam lithography

Nanofabrication: STM, AFM, SPM, self-assembly.

Characterisation: AFM, SEM, SFM, SPM, X-ray diff./XPS.

Simulation: Monte Carlo.

Main fields of application biotechnology, medical devices, science in general, chemistry, diagnostics, therapy, implants, life sciences, health care, materials, metrology, analytics, environment.

Name: CC-Nanobiotech-Kompetenzentrum Nanobiotechnology		Germany
Coordinator: Dr Kerstin Krauß		
Acronym: CC-nanobiotech	**Internet address:** http://www.cc-nanobiotech.de/	
Founded: 2003	**Size:** 3 employees, 5 partner organisations	

Description: CC-Nanobiotech is a BMBF Competence Network based in Kaiserslautern, Germany. The aim is the sustainable development of an internationally competitive nanobiotechnology region for SME's, research institutions and industry. Education, public relations work and technology development are major features of the network.

Technology portfolio

(nano)materials: liquid phase synthesis, biological coatings, ferromagnetics, smart materials, PZT (ferroelectrics), polymers, ceramic materials.

Generic Structuring: E-beam lithography, UV lithography, mechanical µ-machining, wet etching, dry etching.

Nanofabrication: molecular beam epitaxy, STM, AFM, SPM.

Replication: micro-contact printing, nanotransfer printing, hot embossing.

Micro-fabrication: bulk µ-machining, surface µ-machining, annealing, oxidation, doping, wafer bond, silicon direct bonding, anodic bonding, adhesion bonding.

Characterisation: AFM, Auger electron spectroscopy, ellipsometry, FIB, SEM, SFM, SPM, X-ray diff./XPS.

Main fields of application biotechnology, consumer prod., medical devices, chemistry, implants, food ind., sensorics, life sciences, microelectronics, materials.

Name: Kompetenzzentrum NanOp	Germany
Coordinator: Dipl—Phys. Matthias Kuntz	
Acronym: CC NanOp	**Internet address:** http://www.nanop.de/
Founded: 1999	**Size:** 3 employees 40 partner organisations

Description: BMBF competence center funded by the state and research foundations. It is the national network for the application of lateral nanostructures, nanoanalytical techniques and optoelectronics. Partner organisations are form SME's larger firms, research organisations and universities. Its goal is to accelerate R&D in NanOp's. Cooperation and know-how transfer between the partners are key to its success. Support and advice is available for potential start ups.

Technology portfolio

(Nano)materials: gas phase synthesis, materials manufacturing (mechanical proc.), PECVD, Electroplating, PVD (evaporation), PVD (sputtering), Si/polysilicon/SiO_2.

Generic Structuring: RIE/DRIE, wet etching, dry etching.

Nanofabrication: molecular beam epitaxy, metal-org CVD, STM, AFM, self-assembly.

Micro-fabrication: annealing, oxidation, doping.

Characterisation: AFM, ellipsometry, SEM, X-ray diff./XPS.

Simulation: FEM, CAD, Monte Carlo.

Main fields of application consumer prod., sensorics, microelectronics, information tech., materials, automotive, metrology, environment

Name: Kompetenzzentrum Ultrapräzise Oberflächen Bearbeitung	Germany

Coordinator: Dr Uwe Brand

Acronym: CC UPOB e.V.	**Internet address:** http://www.upob.de/
Founded: 1998	**Size:** 1.5 employees, 34 partner organisations

Description: BMBF Competence center is an association for users, developers, and researchers in the area of ultra precise surfaces from industry, research institutions and universities. The network facilitates the finding of research partners, organises workshops and presentations at exhibitions. It is active in standardisation and offers assistance with feasibility studies.

Technology portfolio

(nano)materials: materials manufacturing (mechanical proc.), Si/polysilicon/SiO_2, ceramic materials, metals and alloys.

Generic Structuring: X-ray lithography, mechanical µ-machining, laser µ-machining.

Nanofabrication: STM, AFM, SPM, mechanical nanomachining.

Micro-fabrication: Bulk µ-machining, surface µ-machining, doping

Characterisation: AFM, nanointendation, SEM, SFM, SPM, tribology.

Simulation: process simulation.

Main fields of application consumer prod., metrology, manufacturing

Name: Center for Innovation in Micro and Nanotechnology		**France**
Director: Jean-Francois Veyrat		
Acronym: MINATEC	**Internet address:** http://www.minatec.com/minatec_uk/	
Founded: 2001	**Size:** 2000 employees planned to rise to 3500	

Description: CEA-Leti and INP Grenoble form a center for innovation in micro and nano technology (Minatec). Minatec has an integrated approach to innovation from the exploration of technological breakthroughs to immediate applications i.e. basic to applied research. The interdisciplinary collaboration has a broad scope but is focussed on several key topics. The site is located at Grenoble with over 250 firms, including SME's and start up's, and research establishments in the near vicinity. Funding is through public grants and peer reviewed sources and payments to access the facility. There are also well developed education and further education facilities available both on and off the Minatec site.

Technology portfolio

(nano)materials: gas phase synthesis, liquid phase synthesis, materials manufacturing (mechanical proc.), biomolecular synthesis, biological coatings, LPCVD, PECVD, Electroplating, PVD (evaporation), PVD (sputtering), Si/Polysilicon/SiO_2, SiC, ferromagnetics, smart materials, PZT (ferroelectrics), polymers, ceramic materials, metals and alloys, carbon nanotubes.

Generic Structuring: E-beam lithography, UV lithography, mechanical µ-machining, RIE/DRIE, wet etching, dry etching, laser µ-machining, sand blasting, mask-making devices, synchrotron access.

Nanofabrication: scanning probe lithography, interference lithography, molecular beam epitaxy, metal-org CVD, IBAD, STM, AFM, SPM, mechanical nanomachining, self-assembly, template assisted manufacturing, LADI.

Replication: nano-imprinting, micro-contact printing, hot embossing, micro-casting.

Micro-fabrication: bulk µ-machining, surface µ-machining, annealing, oxidation, doping, LIGA, UV-LIGA, HARPSS, HARMST, HEXSIL, wafer bond, silicon direct bonding, anodic bonding, adhesion bonding, SMD, packaging, flip chip.

Characterisation: AFM, Auger electron spectroscopy, ellipsometry, FIB, nanointendation, SEM, SFM, SPM, scratching measurement, tribology, X-ray diff./XPS.

Simulation: FEM, ANSYS, reliability tools, CAD, process simulation, Monte Carlo.

Quality system: FMEA, process control, specifications, ISO certified.

Main fields of application consumer prod., medical devices, science in general, chemistry, diagnostics, therapy, implants, food ind., sensorics, life sciences, microelectronics, equipment engineer, information tech., health care, materials, automotive, metrology, wellness, energy, analytics, environment, security, defence

Name: Center for High-Rate Nanomanufacturing	USA
Director: Professor Ahmed Busnaina	
Acronym: CHN	**Internet address:** http://www.nano.neu.edu/
Founded: 2004	**Size:** team 68 including 9 in organisation

Description: CHN is a National Science Foundation funded Nanoscale Science and Engineering Center. The aim is to bridge the gap between scientific research and the creation of commercial products. The center employs novel science to enable high-rate/high-volume nanomanufacturing of nanotemplates for guided self-assembly of nanoelements in 2 and 3 dimensions. There are 4 partner universities and a museum of science. Partnerships with industry have been developed. Education and outreach programmes for schools and with the public and the holding of courses and workshops for research and industry are essential features of CHN. Related societal research is also conducted.

Technology portfolio

(Nano)materials: materials manufacturing (mechanical proc.), Electroplating, PVD (evaporation), PVD (sputtering), Si/polysilicon/SiO_2, polymers, carbon nanotubes.

Generic Structuring: E-beam lithography, UV lithography, mechanical μ-machining, wet etching, dry etching.

Nanofabrication: scanning probe lithography, STM, AFM, SPM, template assisted manufacturing.

Replication: nano-imprinting, micro contact printing, nanotransfer printing.

Micro-fabrication: annealing, oxidation, wafer bond.

Characterisation: AFM, SEM, SFM, SPM, tribology, X-ray diff./XPS.

Simulation: ANSYS, CAD, process simulation, Monte Carlo.

Main fields of application science in general, microelectronics, materials, manufacturing

Name: The DOE Center for Integrated Nanotechnologies	USA
Director: Dr Julia Phillips	
Acronym: CINT	**Internet address:** http://cint.lanl.gov/
Founded: 2002	**Size:** 50

Description: The Center for Integrated Nanotechnologies (CINT) is a Department of Energy/Office of Science Nanoscale Science Research Center (NSRC) operating as a national user facility devoted to establishing the scientific principles that govern the design, performance, and integration of nanoscale materials. It pursues original cutting edge science, facilitates exploitation of scientific developments, provides access to standardised technologies and sophisticated capabilities, and integrates disciplines. The spreading of knowledge, interlinking and networking, and consultancy are also features of the center. The primary users of CINT are research scientists.

Technology portfolio

(Nano)materials: biomolecular synthesis, PECVD, PVD (evaporation), polymers, ceramic materials, metals and alloys.

Generic Structuring: E-beam lithography, RIE/DRIE, dry etching.

Nanofabrication: molecular beam epitaxy, STM, AFM, SPM, dip-pen lithography, mechanical nanomachining, self-assembly.

Replication: nano-imprinting, micro contact printing

Micro-fabrication: surface µ-machining, annealing, oxidation, packaging.

Characterisation: AFM, ellipsometry, nanointendation, SEM, SFM, SPM.

Main fields of application biotechnology, science in general, sensorics, microelectronics, information tech., materials, energy, environment, security, defence

Name: Center for Micro and Nano Processing		USA
Director: Dr Chung-Chiun Liu		
Acronym: CMNP	**Internet address:** http://www.engineering.case.edu/cmnp/index.html	
Founded: 2004	**no. of employees:** 8	

Description: CMNP is a transformation of the Microfabrication Laboratory and the Electronics Design Center at CASE Western University with the addition of a new research capability in nanofabrication. Resident faculty is at hand at the center to assist in reducing technical barriers to entry into the field for potential users and to create further R&D opportunities particularly for SME's. Funds are obtained from the user facility with different rates for internal and external users. Additional funding is obtained from peer reviewed research projects, also foundry work carried out at the center. A further benefit of CMNP is education.

Technology portfolio

(nano)materials: LPCVD, PECVD, PVD (sputtering), Si/Polysilicon/SiO_2, SiC

Generic Structuring: RIE/DRIE, wet etching, mask-making devices.

Micro-fabrication: bulk µ-machining, surface µ-machining, annealing, oxidation, doping, wafer bond.

Other Thick film printing, ink jet printing

Main fields of application medical devices, sensorics, health care, energy, environment,

Name: Center for Micro and Nano Systems		China
Director: Professor Wen J. Li		
Acronym: CMNS	**Internet address:** http://www2.acae.cuhk.edu.hk/~cmns/	
Founded: 2001	**no. of employees:** 20	

Description: CMNS develops processes and instrumentation technologies for R&D of micro and nano systems. The facility is based at the Faculty of Engineering at the Chinese University of Hong Kong. It is accessible free of charge for members of the faculty and on a fee basis for other University members and users in Hong Kong. Several collaborations with local industry have been agreed. Education, public relations and a consultancy service are additional features of CMNS.

Technology portfolio

(nano)materials: PECVD, Electroplating, PVD (evaporation), Si/polysilicon/SiO_2, polymers, metals and alloys.

Generic Structuring: E-beam lithography, UV lithography, mechanical µ-machining, RIE/DRIE, wet etching, dry etching, laser µ-machining.

Nanofabrication: SPM.

Replication: nano-imprinting, micro contact printing, hot embossing.

Micro-fabrication: Bulk µ-machining, surface µ-machining, annealing, oxidation, doping, UV-LIGA, wafer bond, adhesion bonding, packaging, flip chip.

Characterisation: AFM, ellipsometry, nanointendation, SEM, SPM, tribology, X-ray diff./XPS.

Simulation: FEM, ANSYS, CAD.

Main fields of application biotechnology, medical devices, science in general, sensorics, automation, environment

Name: The Center for Microtechnology and Nanotechnology		USA
Director: Dr Raymond P. Mariella Jr		
Acronym: CMNT	**Internet address:** http://www-eng.llnl.gov/mic_nano/mic_nano.html	
Founded: 1987	**no. of employees:** 55	

Description: RCMNT is a R&D science infrastructure center which encourages academic collaborations and sabbatical visits by researchers. The aims are to pursue original cutting edge science, facilitate the exploitation of scientific developments, by providings access to standardised technologies and sophisticated capabilities, integrating disciplines, spreading knowledge, interlinking and networking and education. The main users are scientists and occasional industry and SME's. Additional financial support is obtained by public project funding through a peer reviewed process and knowledge dissemination.

Technology portfolio

(nano)materials: gas phase synthesis, liquid phase synthesis, materials manufacturing (mechanical proc.), biomolecular synthesis, biological coatings, PECVD, Electroplating, PVD (evaporation), smart materials, PZT (ferroelectrics), polymers, ceramic materials, metals and alloys, carbon nanotubes.

Generic Structuring: UV lithography, mechanical µ-machining, RIE/DRIE, wet etching, dry etching, laser µ-machining, mask-making devices.

Nanofabrication: scanning probe lithography, interference lithography, AFM, SPM, dip-pen nanolithography, mechanical nanomachining, self-assembly.

Replication: nano-imprinting, micro-contact printing, micro-casting, thermo injection molding (TIM).

Micro-fabrication: bulk µ-machining, surface µ-machining, annealing, oxidation, wafer bond, silicon direct bonding, anodic bonding, adhesion bonding, packaging.

Characterisation: AFM, Auger electron spectroscopy, ellipsometry, FIB, nanointendation, SEM, SFM, SPM, tribology, X-ray diff./XPS.

Simulation: FEM, ANSYS, CAD, Monte Carlo.

Main fields of application biotechnology, medical devices, science in general, chemistry, diagnostics, sensorics, life sciences, health care, materials, metrology, energy, analytics, environment, security, defence, manufacturing

Name: Center for Nanoscale Materials		USA
Director: Dr Eric Isaacs		
Acronym: CNM	**Internet address:** http://nano.anl.gov/	
Founded: 2003	**Size:** at full operation will have >100 employees	

Description: CNM provides an infrastructure and tools for nanoscience and nanotechnology research. Its mission is to support basic research and the development of advanced instrumentation. Outside users are welcome both as collaborators and independent investigators. Researchers from university, large industry and government employees are served by the center which is interdisciplinary and active in spreading knowledge. Consultancy is available. Funding is from peer reviewed projects and the user facility.

Technology portfolio

(Nano)materials: materials manufacturing (mechanical proc.), biological coatings, carbon nanotubes.

Generic Structuring: E-beam lithography, X-ray lithography

Nanofabrication: scanning probe lithography

Replication: nano-imprinting

Micro-fabrication: surface µ-machining

Characterisation: Auger electron spectroscopy.

Simulation: process simulation

Main fields of application biotechnology, medical devices, science in general, chemistry, implants, sensorics, microelectronics, information tech., materials, automation, energy, analytics security, defence

Name: Center for Nanoscience and Technology		Taiwan
Director: Dr Shie-Ming Peng		
Acronym: CNST	**Internet address:** http://nanost.ntu.edu.tw/englishweb/aboutus.asp	
Founded: 2001	**no. of employees:** 6 administration	

Description: CNST is located at the National University of Taiwan. It is supported by the ministry of education and its primary purpose is to integrate the research at the university. Teaching and fair use of core facility are hallmarks of CNST. It houses laboratories for common use, has an interdisciplinary teaching programme and runs several integrated research projects. The center is also a user facility serving scientists, SME's, large industry and associations. Additional funding is from peer reviewed projects and customers of the facility.

Technology portfolio

(nano)materials: gas phase synthesis, liquid phase synthesis, materials manufacturing (mechanical proc.), biomolecular synthesis, LPCVD, PECVD, PVD (evaporation), PVD (sputtering), Si/Polysilicon/SiO_2, PZT (ferroelectrics), polymers, carbon nanotubes.

Generic Structuring: E-beam lithography, UV lithography, mechanical µ-machining, RIE/DRIE, wet etching, dry etching.

Nanofabrication: scanning probe lithography, AFM, SPM.

Replication: micro-contact printing, hot embossing.

Micro-fabrication: bulk µ-machining, surface µ-machining, wafer bond, anodic bonding, adhesion bonding, packaging.

Characterisation: AFM, ellipsometry, nanointendation, SEM, SPM, scratching measurement, X-ray diff./XPS.

Simulation: FEM, ANSYS, CAD.

Main fields of application biotechnology, medical devices, science in general, chemistry, diagnostics, sensorics, life sciences, microelectronics, information tech., health care, materials, metrology, energy,

Name: EPFL Center of Micro Nano Technology		Switzerland
Director: Professor Philippe Renaud		
Acronym: CMI	**Internet address:** http://cmi.epfl.ch/	
Founded: 1999	**Size:** 12	

Description: CMI is a complex of clean rooms and processing equipment for the training and scientific experimentation for users of microtechnologies. Key features are education, scientific research and access to microfabrication processes. Consultancy is offered The main users are scientists. Income is from a public source fix budget.

Technology portfolio

(Nano)materials: LPCVD, PECVD, Electroplating, PVD (evaporation), PVD (sputtering), Si/polysilicon/SiO_2, smart materials, PZT (ferroelectrics), metals and alloys.

Generic Structuring: E-beam lithography, UV lithography, RIE/DRIE, wet etching, dry etching, sand blasting, mask-making devices.

Nanofabrication: AFM.

Replication: nano-imprinting.

Micro-fabrication: Bulk μ-machining, surface μ-machining, annealing, oxidation, UV-LIGA, HARMST, wafer bond, anodic bonding.

Characterisation: AFM, FIB, SEM.

Simulation: FEM.

Main fields of application science in general, implants, sensorics, life sciences, microelectronics, information tech., materials, metrology, analytics

Name: Micro and Nanotechnology Network Euregio Bodensee	Europe
Director: Stefan Fahr	
Acronym: MNT Euregio Bodensee	**Internet address: -**
Founded: 2002	**no. of employees:** 6

Description: Network initiative for the geographical area around Lake Constance; the corner where Switzerland, Germany and Austria meet. The cross border cooperation aims to form a technology region where scientists, large industry, SME's, associations and government employees are interlinked and networked. The network provides access to standardised technologies and sophisticated capabilities; it integrates disciplines, actively spreads knowledge, offering consultancy, and education from which it achieves financial support. The networked institutions offer a joint further education programme.

Technology portfolio

(nano)materials: LPCVD, PECVD, Electroplating, PVD (evaporation), PVD (sputtering), Si/Polysilicon/SiO_2, SiC, ferromagnetics, smart materials, PZT (ferroelectrics), polymers, ceramic materials, metals and alloys.

Generic Structuring: UV lithography, wet etching, dry etching.

Nanofabrication: STM, AFM.

Replication: hot embossing, micro-casting, thermo injection molding (TIM).

Micro-fabrication: bulk µ-machining, surface µ-machining, oxidation, doping, UV-LIGA, HARMST, wafer bond, silicon direct bonding, anodic bonding, adhesion bonding, SMD, packaging, flip chip.

Characterisation: AFM, ellipsometry, nanointendation, SEM, SFM, X-ray diff./XPS.

Simulation: FEM, ANSYS, CAD.

Quality system: process control.

Main fields of application biotechnology, medical devices, chemistry, diagnostics, life sciences, microelectronics, equipment engineer, materials.

Name: Institute for Atomic and Molecular Physics, Nanofabrication		The Netherlands
Director: Dr Jan Verhoeven		
Acronym: FOM AMOLF	**Internet address:** http://www.amolf.nl/	
Founded: 2000	**Size:** 6	
Description: The Nanofabrication center is located at AMOLF a research institute of the Dutch Foundation for Fundamental Research on Matter from which it is funded. The main focus of the research is growth from sub-layers to several tens of monolayers and the formation of nanostructures. It is a science center pursuing original cutting edge science, active in consultancy and education. Its service group is scientists.		
Technology portfolio **(Nano)materials** PVD (evaporation), PVD (sputtering), SiC, ferromagnetics, metals and alloys. **Nanofabrication:** IBAD, STM, AFM. **Characterisation:** AFM, Auger electron spectroscopy, ellipsometry, SEM, X-ray diff./XPS.		
Main fields of application science in general, chemistry, microelectronics, materials		

Name: Fraunhofer Center Nanoelectronic Technologies		Germany
Director: Dr Peter Kücher		
Acronym: CNT	**Internet address:** http://www.fraunhofer.de/fhg/profile/fhi/CNT/index.jsp	
Founded: 2005	**no. of employees:** 3	

Description: CNT Dresden is an institute of the Fraunhofer Society recently established as a public-private partnership with industry. Interdisciplinary teams from the industrial partners and the Fraunhofer Society combine forces to develop solutions to processing problems in nanoelectronics. Individual projects may involve the participation of up to 100 researchers. Integrating and networking also education are key aims of the center. Funding is gained through a fixed budget, additional funding is by payment to access the technologies offered and public project funding.

Technology portfolio

(nano)materials: liquid phase synthesis, materials manufacturing (mechanical proc.), LPCVD, PECVD, Electroplating, ceramic materials, metals and alloys.

Generic Structuring: E-beam lithography, RIE/DRIE, wet etching, dry etching.

Nanofabrication: metal-org CVD, STM, AFM, SPM.

Micro-fabrication: annealing, oxidation, doping,

Characterisation: AFM, ellipsometry, FIB, nanointendation, SEM, SFM, X-ray diff./XPS.

Main fields of application consumer prod., microelectronics, materials, metrology, analytics, manufacturing

Name: Frontiers Network of Excellence		Europe
Coordinator: Prof. David Reinhoudt University Twente, Netherlands		
Acronym: Frontiers	**Internet address:** http://www.frontiers-eu.org/	
Founded: 2004	**Size:** 12 partners from 12 research groups: ca 200 researchers	

Description: Frontiers is a NoE Funded under the FP6 of the European Union. The funding is for a period of 4 years and contributes towards integrating the research activities of the partner organisations with the aim of facilitating the exploitation of scientific developments. Frontiers integrates centers of excellence in life sciences related nanotechnology at a European level and forms a virtual European Nanosciences laboratory. The research focus is on single molecules and nanoclusters, nano-bio interfacing, and nanoapplications. Funding allows the sharing of research facilities between the partners. The focus of the technology is instrumentation for life sciences related nanotechnology. Education activities have the goal of the development of a European educational programme on nanotechnology related life sciences. The twelve partner institutions are from 8 European countries and scientists large industry and SME's. Ethics and social dimensions of nanotechnology are an integral part of the project.

Technology portfolio

(Nano)materials biological coatings, polymers, carbon nanotubes.

Generic Structuring: E-beam lithography, X-ray lithography

Nanofabrication: scanning probe lithography, STM, AFM, SPM, dip pen lithography, self-assembly.

Replication: nano-imprinting, micro contact printing, nanotransfer printing.

Characterisation: AFM, ellipsometry, FIB, SEM, SFM, SPM, X-ray diff./XPS.

Simulation: Monte Carlo.

Other optical tweezers, magnetic tweezers

Main fields of application pharmaceutical, medical devices, diagnostics, life sciences, health care, materials, analytics

Name: Forschungszentrum Jülich, Institute Thin Film and Interfaces	Germany
Director: Professor Andreas Offenhäusser	
Acronym: ISG (FZJ)	**Internet address:** http://www.fz-juelich.de/isg/#
Founded: 1988	**no. of employees:** -

Description: The research institute for thin films and interfaces is at the Forschungzentrum Jülich, a member of the Helmholtz Society. The cutting edge interdisciplinary research focuses on nanostructured thin layer systems and semi-conductor electronics, the contacting of micro and nanoelectronic components , chemical-biological systems and the structure and dynamics of inorganic interfaces and biological layers. Scientists, large industry, SME's and government employees benefit from the institute. Additional finance is gain by access to the technology, peer reviewed projects and knowledge dissemination.

Technology portfolio

(nano)materials: biomolecular synthesis, biological coatings, LPCVD, PECVD, Electroplating, PVD (evaporation), PVD (sputtering), Si/polysilicon/SiO_2.

Generic Structuring: E-beam lithography, UV lithography, RIE/DRIE, wet etching, dry etching, mask-making devices.

Nanofabrication: molecular beam epitaxy, STM, AFM, SPM, self-assembly.

Replication: nano-imprinting, micro contact printing, hot embossing.

Micro-fabrication: annealing, oxidation, doping.

Characterisation: AFM, Auger electron spectroscopy, ellipsometry, SEM, SFM, SPM, X-ray diff./XPS.

Simulation: FEM, CAD, process simulation, Monte Carlo.

Main fields of application biotechnology, sensorics, microelectronics,

Name: Forschungszentrum Karlsruhe, Programme Nano and Microsystems	Germany
Director: Dr N. Fabricius	
Acronym: Nanomikro	**Internet address:** www.fzk.de/nanomikro
Founded: 2005	**no. of employees:** 440

Description: Programme Nano and Microsystems integrates the former Nanotechnology programme and Microsystems Programme at the Karlsruhe Research Center which is a member of the Helmholtz Association of research Centers. R&D work at the center encompasses the Karlsruhe Nano Micro Faciliy (KNMF), electronic properties, nanoscale materials, photonics. Nanomikro is a science and infrastructure center pursuing cutting edge science, facilitates the exploitation of scientific developments, through KNMF it provides access to standardised technologies and sophisticated capabilities. The programme Integrates scientific disciplines and is active in spreading knowledge and networking also education. Cooperations exist with scientists, large industries and SME's. Funding is primarily obtained from public sources, industry cooperation and peer reviewed projects.

Technology portfolio

(nano)materials: gas phase synthesis, liquid phase synthesis, materials manufacturing, biological coatings, LPCVD, PECVD, Electroplating, PVD (Evaporation), PVD (Sputtering).

Generic Structuring: E-beam lithography, UV lithography, x-ray lithography, synchrotron facility, mechanical μ-machining, RIE/DRIE, Laser μ-machining, maskmaking devices.

Nanofabrication: Interference lithography, IBAD, AFM, Dip-pen nanolithography, LADI.

Replication: Nano-imprinting, hot embossing, micro casting, thermo injection molding(TIM), CIM, MIM.

Micro-fabrication: LIGA, UV-LIGA, HARMST, Wafer bond, SMD, packaging, flip chip.

Characterisation: AFM, Auger electron Spectroscopy, ellipsometry, FIB, Nanoindentation, SEM, Scratching measurement, tribology, X-ray diff/XPS.

Simulation: FEM, ANSYS, CAD, Process simulation,

Quality system: FMEA, process control, specifications, ISO certified.

Other: Laser assisted deposition, screen printing, UV curing, materials property design (fluorescent nanoparticles).

Main fields of application: biotechnology, consumer prod. Science in general, chemistry, life sciences, Information technology, materials, metrology, automation, energy, analytics, environment, manufacturing.

Name: John A. Swanson Micro and Nanotechnology Lab.		USA
Director: Dr William W. Clark		
Acronym: JASMIN	**Internet address:** http://www.engr.pitt.edu/site/scmns/mems/	
Founded: 2003	**no. of employees:** 3.0	

Description: The research Laboratory is located in the School of Engineering at the University of Pittsburgh. It is devoted to the fabrication and testing of micro and Nanoscale systems. The facility was developed to serve researchers from the institutes of the University as well as local industry. It is a science and infrastructure center, pursuing cutting edge science, spreading knowledge and education. Financial support is from users of the facility, public funding and knowledge dissemination.

Technology portfolio

(nano)materials: PVD (sputtering), PZT (ferroelectrics), polymers, carbon nanotubes.

Generic Structuring: UV lithography, RIE/DRIE, wet etching, sand blasting.

Replication: micro-contact printing

Micro-fabrication: bulk µ-machining, annealing, adhesion bonding,

Characterisation: AFM, SEM.

Simulation: FEM, ANSYS.

3D Optical profiler, wire bonder, micro probe station (Karl Suss)

Main fields of application biotechnology, science in general, life sciences, materials, metrology, energy, analytics, manufacturing

Name: Korea Nanotechnology Research Society		Korea
Director: Professor Han Jo Lim		
Acronym: KoNTRS	**Internet address:** http://main.kontrs.or.kr/	
Founded: 2003	**Size:** 500 members	
Description: KoNTRS network will have 2000 employees by full operation. Scientists, associations and government employees are served by KoNTRS whose main aims are to facilitate the exploitation of scientific developments, spread knowledge, interlinking and networking, consultancy and education. It also has a role evaluating Korean Nanotechnology. KoNTRS is a dedicated center with a fixed budget from the government, finance is also gain by users of the available technology and profits from production at the facility as well as knowledge dissemination.		
Technology portfolio KoNTRS is a network of specialists working on various fields		
Main fields of application science in general		

Name: KTH/KI Nano and Microtechnology Center	Sweden
Director: Professor Börje Johannsson; Prof. Lars Mattsson	
Acronym: KTH/KI NMTC	**Internet address:** http://www.micronano.kth.se
Founded: 2002	**no. of employees:** 60

Description: The center is an umbrella organisation which provides seed money for joint proposals, joint PhD Courses and seminars. Scientists from ca 10 departments contribute to the working of the center but are not employed by it. The science center focuses on both basic and applied science and also acts as a network. NMTC promotes interdisciplinary research and networking across traditional educational disciplines, faculty and institutional boundaries in the area of nanoscale and microsystem engineering. Knowledge dissemination and education are also important features. Scientists, large industry and SME's use the facilities. Additional funding is obtained from paying customers as well as public project funding.

Technology portfolio

(nano)materials: materials manufacturing (mechanical proc.), biomolecular synthesis, biological coatings, PVD (evaporation), PVD (sputtering), Si/Polysilicon/SiO_2, ferromagnetics, polymers, metals and alloys.

Generic Structuring: E-beam lithography, X-ray lithography, RIE/DRIE, wet etching, dry etching, laser µ-machining, sand blasting, mask-making devices.

Nanofabrication: IBAD, STM, AFM, self-assembly.

printing, hot embossing, micro-casting, thermo injection molding (TIM), CIM, MIM.

Micro-fabrication: LIGA

Characterisation: AFM, ellipsometry, SEM, SPM, tribology, Other: light scattering, mechanical pro.

Simulation: FEM, CAD, process simulation, Monte Carlo.

Quality system: process control.

Main fields of application biotechnology, medical devices, diagnostics, sensorics, materials, metrology, automation, energy, manufacturing

Name: Maryland Center for Integrated Nano Science and Engineering	USA
Director: Professor Gary W. Rubloff	
Acronym: M-CINSE	**Internet address:** http://www.nanocenter.umd.edu/
Founded: 2004	**Size:** 5

Description M-CINSE was established and is financially supported by three colleges of the University of Maryland, It promotes nano research and education initiatives and acts as a center point for contacts seeking expertise and partnerships. Scientists, large industry, SME's, government employees are served by the center. Additional funding is obtained by public funded research projects, and paying customers accessing the facilities. M-CINSE is an R&D infrastructure center which is also a profit making organisation. Its aims are to pursue original cutting edge science, facilitate the exploitation of scientific developments, provide access to standardised technologies and sophisticated capabilities, integrate disciplines and spread knowledge. Interlinking and networking, consultancy and education belong to the roles of the center.

Technology portfolio

(Nano)materials: gas phase synthesis, liquid phase synthesis, biomolecular synthesis, biological coatings, LPCVD, PECVD, Electroplating, PVD (evaporation), PVD (sputtering), Si/polysilicon/SiO_2, SiC, ferromagnetics, smart materials, PZT (ferroelectrics), polymers, ceramic materials, metals and alloys, carbon nanotubes.

Generic Structuring: E-beam lithography, UV lithography, RIE/DRIE, wet etching, dry etching.

Nanofabrication: scanning probe lithography, molecular beam epitaxy, metal-org CVD, IBAD, STM, AFM, SPM, dip-pen lithography, self-assembly, template assisted manufacturing, LADI.

Replication: nano-imprinting, micro contact printing, nanotransfer printing.

Micro-fabrication: Bulk µ-machining, surface µ-machining, annealing, oxidation, doping, wafer bond, anodic bonding, adhesion bonding, packaging.

Characterisation: AFM, Auger electron spectroscopy, ellipsometry, FIB, nanointendation, SEM, SFM, SPM, scratching measurement, tribology, X-ray diff./XPS.

Simulation: FEM, CAD, process simulation, Monte Carlo.

Quality System: process control

Main fields of application biotechnology, medical devices, science in general, chemistry, diagnostics, therapy, sensorics, life sciences, microelectronics, equipment engineer, information tech., health care, materials, metrology, energy, analytics, environment, security, defence, manufacturing

Name: Manufacturing Engineering Center Cardiff University,	Wales UK
Director: Dr Stefan Dimov	
Acronym: MEC	**Internet address:** http://www.mec.cf.ac.uk/
Founded: 1995	**Size:** 80 employees

Description: sponsored by the Welsh Assembly Government, Welsh Development agency and the European Regional Development Agency MEC offers specialist services in Time Compression Technologies especially to SME's. The center is at the University of Cardiff and is one of Europe's best equipped product development manufacture and control centers also focussing on generating basic science. Additional funding is obtained through peer review projects.

Technology portfolio

(Nano)materials: polymers, ceramic materials, metals and alloys.

Generic Structuring: UV lithography, mechanical µ-machining, RIE/DRIE, laser µ-machining.

Nanofabrication: mechanical nanomachining.

Replication: hot embossing, micro-casting, thermo injection molding (TIM).

Micro-fabrication: Bulk µ-machining, surface µ-machining.

Characterisation: FIB, nanointendation, SEM.

Simulation: CAD.

Quality System: ISO certified

Main fields of application biotechnology, consumer prod., medical devices, diagnostics, implants, health care, automation, defence, manufacturing

Name: MESA+ Institute for Nanotechnology		Netherlands
Director: Dr C.J.M. Eijkel		
Acronym: MESA+	**Internet address:** http://www.mesaplus.utwente.nl/	
Founded: 1999	**Size:** 450	

Description: The institute is a growing National Nanotechnology Laboratory and commercialisation center. It links top-down microfabrication and bottom-up chemical and materials science approaches. There is increasing cooperation developing between the participating research groups of the University of Twente. Facilities are also available for use by external research groups and companies. In addition to research the center trains graduate and post graduate students in Nanotechnology. Commercialisation of the results is aimed for. Finance is obtained from peer reviewed projects as well as by user revenue, knowledge dissemination and a fixed budget.

Technology portfolio

(Nano)materials: biological coatings, LPCVD, PECVD, Electroplating, PVD (evaporation), PVD (sputtering), Si/polysilicon/SiO_2, SiC, ferromagnetics, smart materials, PZT (ferroelectrics), polymers, ceramic materials, metals and alloys.

Generic Structuring: E-beam lithography, UV lithography, mechanical µ-machining, RIE/DRIE, wet etching, dry etching, sand blasting, mask-making devices.

Nanofabrication: scanning probe lithography, interface lithography, molecular beam epitaxy, metal-org CVD, STM, AFM, SPM, dip-pen lithography, self-assembly, template assisted manufacturing.

Replication: nano-imprinting, micro contact printing.

Micro-fabrication: Bulk µ-machining, surface µ-machining, annealing, oxidation, doping, UV-LIGA, HARMST, wafer bond, silicon direct bonding, anodic bonding, adhesion bonding

Characterisation: AFM, ellipsometry, FIB, SEM, SFM, SPM, X-ray diff./XPS.

Simulation: FEM, ANSYS, reliability tools, CAD, process simulation

Quality System: process control

Main fields of application biotechnology, pharmaceutical, medical devices, science in general, chemistry, diagnostics, implants, food industry, sensorics, life sciences, microelectronics, equipment engineer, health care, materials, energy, analytics

Name: The University of Birmingham Microengineering and Nanotechnology Research Center at Birmingham University		UK
Director: Professor Philip D. Prewett		
Acronym: MNRC	**Internet address:** http://www.micro-nano.bham.ac.uk/	
Founded: 1998	**no. of employees:** 4 academic staff and 10 students	
Description: Forms one of the three nanotechnology pillars at Birmingham University, which together form a nanotechnology network within the university. The others being nanoscience and micro and nanoparticles. MNRC is a science center which has cooperations with industry. Funding is gained through national and European peer reviewed projects. Finance is also received by paid access to the facilities.		
Technology portfolio **Micro-fabrication:** bulk µ-machining, anodic bonding. **Characterisation:** AFM, FIB, SEM, SFM. **Simulation:** FEM		
Main fields of application biotechnology, pharmaceutical, science in general		

Name: Competence Network for Nanomaterials		Germany
Coordinator: Dr Regine Hedderich		
Acronym: NanoMat	**Internet address:** www.nanomat.de	
Founded: 1999	**Size:** 2 employees, 24 partners	

Description: NanoMat is a network of universities, research centers, small and large companies based mainly in Germany and belongs to the BMBF Competence Networks. The theme of the network is "Synthesis and investigation of nanostructured metals and ceramics, and investigation of the materials and applications which result from their nanoscale nature." NanoMat has offices at the Forschungszentrum Karlsruhe which provides the staff. NanoMat is also active in the area of the sustainable development of nanotechnology and gains additional funding through peer reviewed projects. It also holds regular workshops and seminars, and participates at fairs and exhibitions.

Technology portfolio

(nano)materials: gas phase synthesis, liquid phase synthesis, materials manufacturing (mechanical proc.), polymers, ceramic materials, metals and alloys, carbon nanotubes.

Main fields of application science in general, chemistry, life sciences, health care, materials,

Name: Nano/Bio Interface Center		USA
Director: Professor Dawn Bonnell		
Acronym: NBIC	**Internet address:** www.nanotech.upenn.edu	
Founded: 2004	**no. of employees:** 22	

Description: NBIC addresses the fundamental principles of molecular functions at interfaces and consequences to society. The study of the ethics of nano-bio technology is integral to the programme. Investigators from ten departments of three schools of the university are united in the center. The center is an R&D science center, pursuing interdisciplinary cutting edge science. Education within the university and also outside with material for high school teachers and students is a priority. Funding is from a central source and peer reviewed projects.

Technology portfolio

(nano)materials: biomolecular synthesis, PVD (evaporation), PVD (sputtering), SiC, ferromagnetics, polymers, ceramic materials, metals and alloys, carbon nanotubes.

Generic Structuring: E-beam lithography, UV lithography,

Nanofabrication: scanning probe lithography, STM, AFM, dip-pen nanolithography,

Micro-fabrication: annealing, doping,

Characterisation: AFM, FIB, SEM, X-ray diff./XPS.

Simulation: CAD, process simulation, Monte Carlo.

Main fields of application chemistry, sensorics, life sciences, materials, analytics,

Name: National Center of Competence in Research (NCCR) Nanoscale science | Switzerland

Director: Professor Hans Joachim Güntherodt

Acronym: NCCR Nanoscience

Internet address: http://www.nccr-nano.org/nccr/

Founded: 2001

no. of employees: ca 200

Description: Swiss national center of competence and research in nanoscale science. NCCR Nanoscience is a national network of universities, research institutions and industrial partners. Basic research has a strategic importance in aiming for technological advances. Research is interdisciplinary with the aim of facilitating the transfer of research results from one institution to another and identifying and applying pioneering new principles. Spreading of knowledge and consultancy are therefore key roles of the network. Funding is from a central source, knowledge dissemination and peer reviewed projects.

Technology portfolio

(nano)materials: biomolecular synthesis, biological coatings, ferromagnetics, polymers, carbon nanotubes.

Generic Structuring: E-beam lithography, wet etching, dry etching, , mask-making devices.

Nanofabrication: scanning probe lithography, molecular beam epitaxy, metal-org CVD, STM, AFM, SPM, dip-pen nanolithography, mechanical nanomachining, self-assembly.

Replication: nano-imprinting, micro-contact printing, hot embossing, micro-casting, thermo injection molding (TIM).

Micro-fabrication: HEXSIL

Characterisation: AFM, Auger electron spectroscopy, ellipsometry, nanointendation, SEM, SFM, SPM, scratching measurement, tribology, X-ray diff./XPS.

Main fields of application biotechnology, pharmaceutical, medical devices, science in general, chemistry, diagnostics, therapy, life sciences, microelectronics, equipment engineer, information tech., health care, materials

Name: National Center for Nanoscience and Nanotechnology		China
Director: Professor Bai Chun Li		
Acronym: NCNST	**Internet address:** http://www.nanoctr.cn/e_index.jsp	
Founded: 2002	**no. of employees:** 155	

Description: NCNST is a science center founded jointly by the Chinese Academy of Sciences and the Ministry of Education with Peking and Tsinghua Universities. It is a non profit making organisation which obtains funding from a dedicated budget, participation in peer reviewed projects, a user facility and knowledge dissemination. Scientists, SME's and associations benefit from NCNST. The main branches of focus are nanoprocessing and nanodevice laboratories, nanomaterials and nanostructure laboratories, nanomedicine and nanobiotech laboratories, nanostructure characterisation and test labs and a coordination laboratory. Recently a cooperation agreement has been agreed with the South Korean National Nanofabrication Center NNFC.

Technology portfolio

(nano)materials: gas phase synthesis, liquid phase synthesis, materials manufacturing (mechanical proc.), biomolecular synthesis, biological coatings, LPCVD, PECVD, Electroplating, PVD (evaporation), PVD (sputtering), Si/polysilicon/SiO_2, SiC, ferromagnetics, smart materials, PZT (ferroelectrics), polymers, ceramic materials, metals and alloys, carbon nanotubes.

Generic Structuring: E-beam lithography, UV lithography, mechanical µ-machining, RIE/DRIE, wet etching, dry etching, laser µ-machining, mask-making devices.

Nanofabrication: scanning probe lithography, metal-org CVD, STM, AFM, SPM, dip pen lithography, self-assembly, template assisted manufacturing.

Micro-fabrication: annealing, oxidation, doping, wafer bond, silicon direct bonding, anodic bonding, adhesion bonding, SMD, packaging, flip chip.

Characterisation: AFM, Auger electron spectroscopy, ellipsometry, FIB, SEM, SPM, tribology, X-ray diff./XPS.

Simulation: FEM, ANSYS, reliability tools, CAD, process simulation, Monte Carlo.

Quality System: FMEA, process control, specifications, ISO certified

Main fields of application biotechnology, pharmaceutical, medical devices, science in general, chemistry, diagnostics, therapy, implants, sensorics, life sciences, microelectronics, equipment engineer, information tech., health care, materials, automotive, metrology, automation, energy, analytics, environment, security, defence, manufacturing

Name: Nano-Electrical-Mechanical-System Research Center		Taiwan
Principal Investigator: Professor H.P. Huang, Prof. C.K. LEE		
Acronym: NEMS Center	**Internet address:** http://nanost.ntu.edu.tw/englishweb/nems_pi.asp	
Founded: 2000	**no. of employees:** 6	

Description: NEMS is an integrated research project at the Center for Nanoscience and Nanotechnology Taiwan (CNST). The aim is to push NEMS technology from the laboratory to manufacture. The project also offers an infrastructure and network functions, consultancy and education. Scientists, SME's and associations are benefit from the NEMS center. Funding is from a fixed budget, peer reviewed projects, paying customers and knowledge dissemination.

Technology portfolio

(nano)materials: gas phase synthesis, liquid phase synthesis, materials manufacturing (mechanical proc.), biomolecular synthesis, biological coatings, LPCVD, PECVD, Electroplating, PVD (evaporation), PVD (sputtering), Si/Polysilicon/SiO_2, SiC, smart materials, PZT (ferroelectrics), polymers, ceramic materials, metals and alloys, carbon nanotubes.

Generic Structuring: UV lithography, RIE/DRIE, wet etching, dry etching

Nanofabrication: scanning probe lithography, AFM, SPM.

Micro-fabrication: bulk µ-machining, surface µ-machining, annealing, oxidation, wafer bond, anodic bonding, adhesion bonding.

Characterisation: AFM, nanointendation, SPM.

Simulation: FEM, ANSYS, CAD.

Main fields of application biotechnology, science in general, chemistry, diagnostics, sensorics, life sciences, microelectronics, equipment engineer, information tech., health care, materials, automotive, metrology, automation, energy, environment, security, defence

Name: National NanoFab Center	South Korea

Director: Professor Lee Hee-Chul

Acronym: NNFC	**Internet address:** http://www.nnfc.com/eng/main/index.jsp
Founded: 2002	**Size:** 45 employees

Description: NNFC will have 65 employees by full operation. R&D, Infrastructure center and profit making organisation, serving scientists, SME's and governmental organisations. Funding is from a fixed budget and the user facility. The impulse of the center is towards the transfer of research to industry, and the development of new equipment for nanotechnology. Hands on training is offered to users of the facility.

Technology portfolio

(Nano)materials: LPCVD, PECVD, Electroplating, PVD (evaporation), PVD (sputtering), Si/polysilicon/SiO_2, metals and alloys, carbon nanotubes.

Generic Structuring: E-beam lithography, UV lithography, mechanical µ-machining, RIE/DRIE, wet etching, dry etching.

Nanofabrication: molecular beam epitaxy, metal-org CVD, STM, AFM, SPM, mechanical nanomachining, template assisted manufacturing.

Replication: nano-imprinting, micro contact printing, hot embossing.

Micro-fabrication: annealing, oxidation, doping, LIGA, adhesion bonding.

Characterisation: AFM, ellipsometry, FIB, nanointendation, SEM, SFM, SPM.

Main fields of application microelectronics, metrology

Name: Northwestern University Nanoscale Science and Engineering Center for Integrated Nanopatterning and Detection Technologies	USA
Director: Professor Chad Mirkin	
Acronym: NSEC	**Internet address:** http://www.nsec.northwestern.edu/
Founded: 2001	**no. of employees:** 6

Description: NSEC is funded by the NSF. The research center is a collaboration of several US universities and research laboratories; The goal is to create an accelerated pathway from conception to commercialisation and involves interdisciplinary research, the provision of access to standardised technologies and sophisticated capabilities and networking. There is also a comprehensive educational outreach program. Public project funding is obtained through a peer review process. The needs of scientists, large industry and SME's are met by the center.

Technology portfolio

(nano)materials: liquid phase synthesis, materials manufacturing (mechanical proc.), Si/Polysilicon/SiO_2, ferromagnetics, smart materials, PZT (ferroelectrics), polymers, ceramic materials, metals and alloys, carbon nanotubes.

Generic Structuring: E-beam lithography, UV lithography, X-ray lithography, mechanical μ-machining, wet etching, dry etching, mask-making devices.

Nanofabrication: scanning probe lithography, interference lithography, molecular beam epitaxy, metal-org CVD, STM, AFM, SPM, dip-pen nanolithography, self-assembly, template assisted manufacturing.

Replication: nano-imprinting, micro-contact printing, nanotransfer printing.

Micro-fabrication: bulk μ-machining, surface μ-machining, annealing, oxidation, doping, silicon direct bonding, adhesion bonding.

Characterisation: AFM, Auger electron spectroscopy, ellipsometry, FIB, SEM, SFM, SPM, X-ray diff./XPS.

Simulation: CAD, Monte Carlo.

Quality system: process control, specifications.

Main fields of application biotechnology, pharmaceutical, consumer prod., medical devices, science in general, chemistry, diagnostics, therapy, sensorics, life sciences, microelectronics, equipment engineer, health care, materials, automotive, metrology, automation, wellness, energy, analytics, environment, security, defence, manufacturing

Name: Nanotechnology Research Association of Korea		South Korea
Chairman: Dr Lee Hee-Gook		
Acronym: NTRA	**Internet address:** http://nanokorea.net/eng/	
Founded: 2001	**Size:** 9 employees**,** member companies: 46, universities:19, Institutes:6	
Description: NTRA facilitates the active participation of industry and networks the nanotechnology capacity of universities and research institutes. Its funding is from a dedicated fixed budget. Large industry, associations and government employees are served by NTRA.		
Technology portfolio **(Nano)materials:** gas phase synthesis, liquid phase synthesis, materials manufacturing (mechanical proc.), LPCVD, PECVD, carbon nanotubes. **Generic Structuring:** E-beam lithography, UV lithography, wet etching, dry etching, mask-making devices. **Nanofabrication:** STM, AFM, SPM, dip-pen lithography, self-assembly. **Micro-fabrication:** packaging. **Characterisation:** AFM, Auger electron spectroscopy, FIB, SEM, SFM, SPM, X-ray diff./XPS.		
Main fields of application microelectronics, materials, energy,		

Name: Oregon Nanoscience and Microtechnologies Institute | USA

Director: Dr Robert D. Rung

Acronym: ONAMI | **Internet address:** www.onami.us

Founded: 2004 | **no. of employees:** 90

Description: ONAMI involves local universities and researchers also local industry which includes INTEL and Hewlett Packard. It serves the Oregon and Pacific Northwest area. It is a region rich in advanced R&D and manufacture, referred to as the Silicon Forest. The Institute fulfils the role of R&D science and infrastructure center and a network facility, active in education which encourages entrepreneurship. Scientists, large industry, SME's and government employees are all served. Financial support is by users of the center, funded from peer reviewed projects, the centers own budget and knowledge dissemination.

Technology portfolio some but not all available to outside users

(nano)materials: gas phase synthesis, liquid phase synthesis, materials manufacturing (mechanical proc.), biomolecular synthesis, Electroplating, PVD (evaporation), PVD (sputtering), polymers, ceramic materials, metals and alloys, carbon nanotubes.

Generic Structuring: E-beam lithography, UV lithography, mechanical µ-machining, wet etching, dry etching, laser µ-machining, sand blasting, mask-making devices.

Nanofabrication: metal-org CVD, STM, AFM, self-assembly.

Replication: nano-imprinting, hot embossing, thermo injection molding (TIM), CIM, MIM.

Micro-fabrication: annealing, adhesion bonding, SMD.

Characterisation: AFM, Auger electron spectroscopy, ellipsometry, FIB, nanointendation, SEM, X-ray diff./XPS.

Simulation: FEM, CAD.

microlamination, ALD, transparent/low temperature electronics

Main fields of application biotechnology, consumer prod., medical devices, chemistry, diagnostics, life sciences, microelectronics, equipment engineer, health care, materials, automotive, metrology, automation, energy, analytics, environment, security, defence, manufacturing

Name: RWTH-NANOCLUB		Germany
Manager: Dr Marion E. Franke		
Acronym: RWTH NANOCLUB	**Internet address:** http://www.nanoclub.rwth-aachen.de/	
Founded: 2002	**Size:** 40 member groups	

Description: The nanoclub networks interdisciplinary activities in nanoscience and nanotechnology at the University RWTH Aachen, and several local research centers. Scientists, SME's and government employees are served by the nanoclub. The center has a dedicated budget and gains additional funding by peer reviewed projects and has several cooperations with industry.

Technology portfolio

(nano)materials: liquid phase synthesis, materials manufacturing (mechanical proc.), biological coatings, PVD (evaporation), PVD (sputtering), ferromagnetics, smart materials, PZT (ferroelectrics), polymers, ceramic materials, metals and alloys.

Generic Structuring: E-beam lithography, UV lithography, RIE/DRIE, wet etching, dry etching, laser µ-machining, mask-making devices.

Nanofabrication: scanning probe lithography, interference lithography, molecular beam epitaxy, STM, AFM, dip-pen nanolithography, mechanical nanomachining, self-assembly.

Replication: nano-imprinting, micro-contact printing.

Micro-fabrication: surface µ-machining, annealing, oxidation, doping, wafer bond, silicon direct bonding.

Characterisation: AFM, Auger electron spectroscopy, ellipsometry, FIB, nanointendation, SEM, SFM, tribology, X-ray diff./XPS.

Simulation: Monte Carlo

Main fields of application biotechnology, pharmaceutical, medical devices, chemistry, therapy, sensorics, life sciences, microelectronics, information tech., materials, automotive, energy, analytics.

Name: TASC (Advanced technology and Nanoscience) INFM		Italy
Director: Professor Giorgio Rossi		
Acronym: TASC-INFM	**Internet address:** http://www.infm.it/Uk/Research/Labs/tasc.html	
Founded: 1994	**no. of employees:** 52	

Description: TASC Science and Infrastructure center. A national resource for the solid state physics, materials science and synchrotron radiation communities. The center pursues original cutting edge science, facilitates the exploitation of scientific developments, provides access to standardised technologies and sophisticated capabilities, integrates disciplines, and is active in education. Scientists, large industry, SME's, associations, government employees benefit from the center.

Financially support is gained by grants from the European Union and the Italian government, research funds and collaborations.

Technology portfolio

(nano)materials: PECVD, Electroplating, PVD (evaporation), ferromagnetics, metals and alloys, carbon nanotubes.

Generic Structuring: E-beam lithography, UV lithography, X-ray lithography, Synchrotron facility, RIE/DRIE, wet etching, mask-making devices.

Nanofabrication: scanning probe lithography, molecular beam epitaxy, STM, AFM, SPM, mechanical nanomachining, self-assembly.

Replication: nano-imprinting.

Micro-fabrication: annealing, oxidation, doping, LIGA, UV-LIGA.

Characterisation: AFM, Auger electron spectroscopy, ellipsometry, FIB, SEM, SPM, X-ray diff./XPS.

Other TEM high resolution z-contest, cross sectional STM, six beam lines at ELETTRA synchrotron

Main fields of application science in general,

Name: Veneto Nanotech S.C.P.A.	Italy
Director: Marco Signorelli	
Acronym: Veneto Nanotech	**Internet address:** www.venetonanotech.it
Founded: 2003	**no. of employees:** 8

Description: Veneto Nanotech is a network and infrastructure center which facilitates the exploitation of scientific developments by providing access to standardised technologies. Networking consultancy, education and knowledge dissemination are key aims. Scientists and SME's are the main users of the center. Funding is gained from a central source also by additional project funding, user fees and industrial production. The site houses a nanofabrication facility, managed by a non-profit making organisation and created by a sizeable regional investment. Universities and companies can contract research to the center or use the facilities themselves. There is a business plan competition, open to teams from all over the world to promote high-tech start ups in the nanotechnology sector. Nanotech advises the Italian government on the thematic areas of research for its funding programme.

Technology portfolio

(nano)materials: LPCVD, PECVD, Electroplating, PVD (evaporation), PVD (sputtering), Si/Polysilicon/SiO_2, smart materials, polymers, ceramic materials, metals and alloys, carbon nanotubes.

Generic Structuring: UV lithography, X-ray lithography, wet etching, dry etching, laser µ-machining.

Nanofabrication: scanning probe lithography, interference lithography, metal-org CVD, STM, AFM, SPM, mechanical nanomachining, self-assembly.

Replication: nano-imprinting, micro-contact printing, nanotransfer printing.

Characterisation: AFM, ellipsometry, nanointendation, SEM, SFM, SPM, tribology, X-ray diff./XPS.

Main fields of application health care, materials, metrology, environment.

Name: Sara and Moshe Zisapel Nanoelectronics Research Center	Israel
Director: Professor Eliezer Finkman	
Acronym: ZNRC	**Internet address:** http://www.ee.technion.ac.il/labs/nano/Info/AboutUs/Introduction.html
Founded: 2004	**no. of employees:** 13 faculty and ca 15 technicians

Description: ZNRC is a science center based at Technion, the Israel Institute of technology which provides an infrastructure serving scientists, SME's and associations. Named after its benefactors the center will help to establish the nanoelectronics field of research. Cutting edge interdisciplinary research aims at developing nanoscale electronic components. Financial support is gained by paying customers, funding is also gained from public sources and knowledge is disseminated.

Technology portfolio

(nano)materials: LPCVD, PVD (evaporation), PVD (sputtering), Si/Polysilicon/SiO_2, polymers, carbon nanotubes.

Generic Structuring: E-beam lithography, UV lithography, RIE/DRIE, wet etching, dry etching, sand blasting, mask-making devices.

Nanofabrication: metal-org CVD, STM, AFM, self-assembly.

Replication: micro-contact printing

Micro-fabrication: bulk µ-machining, surface µ-machining, annealing, oxidation, doping, flip chip.

Characterisation: AFM, Auger electron spectroscopy, ellipsometry, FIB, SEM, SPM, X-ray diff./XPS.

Main fields of application science in general, chemistry, microelectronics, materials,

Appendix C: List of Figures

Figure 8.4-3 The "most common" technologies offered (operated and maintained) by nano-oriented competence centers irrespective of geographic aspects or any specific thematic orientation. The diagram extracts those technologies from fig: 8.4-2, that have been nominated by more than 50 % of all centers.

Figure 8.4-4 Technology vs. industries-map of all nano-oriented centers that have responded to EVA_1 questionnaire, indicating a general view on technologies from the focus of industrial sectors

Appendix D: List of Tables

Appendix E: Abbreviations

AFM	Atomic Force Microscopy
ANSYS	A family of computer simulation programmes
BCG	Boston Consulting Group
BioMEMS	Micro-Electro-Mechanical Systems for the Biomedical sector
CAD	Computer Aided Design
CIM	Ceramic Injection Molding
CVD	Chemical Vapour Deposition
DOE	US American Department of Energy
DRIE	Deep Reactive Ion Etching
EU	European Union
EVA_1	Evaluation of Nano-oriented Competence Centers
FEM	Finite Element Method
FIB	Focussed Ion Beam
FMEA	Failure Mode and Effect Analysis
FZK	Forschungszentrum Karlsruhe
HARPSS	High Aspect Ratio Combined Poly and Single Crystal Silicon
HEXSIL	A process for the fabrication of polysilicon structures
HARMST	High Aspect Ratio Microstructure Technology
ISO	International Organisation for Standardisation
IBAD	Ion Beam Assisted Deposition
LADI	Laser Assisted Direct Imprint
LIGA	Lithography, Plating and Molding: Lithographie galvanoformung abformtechnik
UV-LIGA	Ultra-Violet LIGA
LPCVD	Low Pressure Chemical Vapour Deposition
MEMS	Micro-Electro-Mechanical Systems
MIM	Metal Injection Molding
MNT	Micro and Nano-technologies
NSEC	Nanoscale Science and Engineering Center
NSF	US American National Science Foundation
NSRC	Nanoscale Science Research Center
PECVD	Plasma Enhanced Chemical Vapour Deposition
PVD	Physical Vapour Deposition
PZT	Lead Zirconate Titanate

R&D	Research and Development
RIE/DRIE	Reactive Ion Etching/Deep Reactive Ion Etching
SBU	Strategic Business Unit
SEM	Scanning Electron Microscopy
SFM	Scanning Force Microscopy
SMD	Surface Mounted Device
SME	Small and Medium Sized Enterprises
SPM	Scanning Probe Microscopy
STM	Scanning Tunnelling Microscopy
TIM	Thermo injection molding
UK	United Kingdom
USA	United States of America
USD	United States Dollar
XPS	X-ray Photoelectron Spectroscopy

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