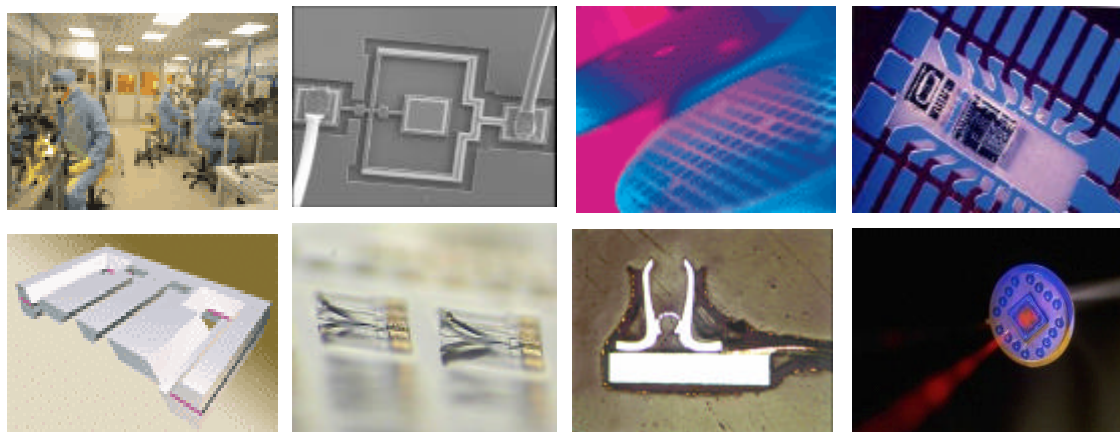


Nordic MEMS Support
Pre-project, Nordic Industrial Fund, autumn 2003

Nordic MEMS – Status and possibilities



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October 2003

Preface

This report describes briefly the status of Microsystems and related activities in the Nordic countries by the end of 2003. Possibilities with microsystem applications for Nordic companies and the influence this technology will have on the society in the future are also discussed.

The work has been carried out by the four research institutes and discussed with a reference group with representatives from other companies and institutions within the field.

This report forms a basis for the main project application delivered to Nordic Industrial Fund 15 September 2003.

Oslo, October 20, 2003

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Project Manager

Contents

1	Summary	4
2	Conclusions	5
3	Introduction	6
3.1	What are MEMS? - A short description of MEMS technology	6
3.2	Some MEMS applications	6
3.3	One chip, many applications	8
3.4	Current Challenges	10
4	Nordic MEMS activities – an overview	12
4.1	Sweden	12
4.1.1	Summarizing the activities in Sweden	12
4.1.2	Actors in Sweden	12
4.2	Denmark	14
4.2.1	Summarizing the activities in Denmark	14
4.2.2	Actors in Denmark	15
4.3	Norway	17
4.3.1	Summary of Norwegian MST activities	17
4.3.2	Actors in Norway	18
4.4	Finland	20
4.4.1	Overview of the status in Finland	20
4.4.2	Actors in Finland	20
4.4.3	Conclusion	22
	Appendix 1 - MEMS actors in Sweden	23
	Appendix 2 – MEMS actors in Denmark	26
	Appendix 3 – MEMS actors in Norway	28
	Appendix 4 – MEMS actors in Finland	30

1 **Summary**

Microsystems, or small, functional components, will be the key components in systems realizing “the instrumentation society” we are entering during the next 5-10 years.

There are numerous possible applications for microsystems. As a breakthrough technology, allowing unparalleled synergy between previously unrelated fields such as biology and microelectronics, many new microsystems applications will emerge, expanding beyond that which is currently identified or known.

Microsystems will have a value added effect for other industries, and have influence on many industry processes and services.

There is a large potential for synergy and strong industrial acceleration when establishing easy access between research centres, technology suppliers and companies across the borders of the Nordic countries.

In all Nordic countries large investments in laboratories for microsystem technologies have been done during the last 5 years. It's a common Nordic challenge to take advantage of these investments in other industry sectors than the electronics industry.

2 Conclusions

General about microsystems:

- 1 Microsystems, or small, functional components, will be the key components in systems realizing “the instrumentation society” we are entering during the next 5-10 years.
- 2 Microsystems will have a value added effect for other industries, and have influence on many industry processes and services.
- 3 There are numerous possible applications for microsystems. As a breakthrough technology, allowing unparalleled synergy between previously unrelated fields such as biology and microelectronics, many new microsystems applications will emerge, expanding beyond that which is currently identified or known.
- 4 The technology has a generic character. A microsystem developed for one application may be used for other applications as well with only small adjustments.

The Nordic perspective:

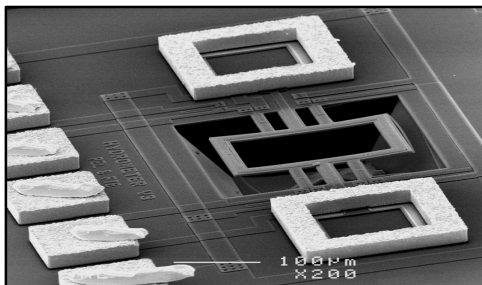
- 1 There is a large potential for synergy and strong industrial acceleration when establishing easy access between research centres, technology suppliers and companies across the borders of the Nordic countries.
- 2 A common Nordic competence platform of microsystem technologies will give Nordic companies access to design and production competence at a leading international level. A Nordic collaboration will strengthen the microsystems field to be competitive with larger economies like Germany, Britain, or France.
- 3 Microsystems (MEMS, MOEMS and microsensors) activities is beyond 1000 Mddk yearly in the Nordic countries
- 4 The research and industrial structure in the individual countries differ strongly in its organization and its topics and application areas
- 5 MEMS and MOEMS are firmly established on few specialized application. At least 10 companies have MEMS/MOEMS based products which are competitive on the world market. Over 20 universities are active in the field and together they cover a broad research platform
- 6 Mainly companies involved in component productions have invested in using the technology.
- 7 The Nordic technology base is firm and broad enough for wider use in many other industries.
- 8 There exist no other initiatives to establish synergy between the activities in the individual countries.

3 Introduction

3.1 What are MEMS? - A short description of MEMS technology¹

Micro-Electro-Mechanical Systems (MEMS) are devices containing extremely small mechanical elements, which are usually integrated together with electronic processing circuitry. MEMS is the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through microfabrication technology. MEMS are manufactured with techniques similar to those used for the manufacture of the microchips. While the electronics are fabricated using integrated circuit (IC) process sequences, the micromechanical components are fabricated using compatible "micromachining" processes that selectively etch away parts of the silicon wafer or add new structural layers to form the mechanical and electromechanical devices.

MEMS promises to revolutionize nearly every product category by bringing together silicon-based microelectronics with micromachining technology, making possible the realization of complete systems-on-a-chip. MEMS is an enabling technology allowing the development of smart products, augmenting the computational ability of microelectronics with the perception and control capabilities of microsensors and microactuators and expanding the space of possible designs and applications.



A MEMS viscosimeter

Microelectronic integrated circuits can be thought of as the "brains" of a system and MEMS augments this decision-making capability with "eyes" and "arms", to allow microsystems to sense and control the environment. Sensors gather information from the environment through measuring mechanical, thermal, biological, chemical, optical, and magnetic phenomena. The electronics then process the information derived

from the sensors and through some decision making capability direct the actuators to respond by moving, positioning, regulating, pumping, and filtering, thereby controlling the environment for some desired outcome or purpose. Because MEMS devices are manufactured using batch fabrication techniques similar to those used for integrated circuits, unprecedented levels of functionality, reliability, and sophistication can be placed on a small silicon chip at a relatively low cost.

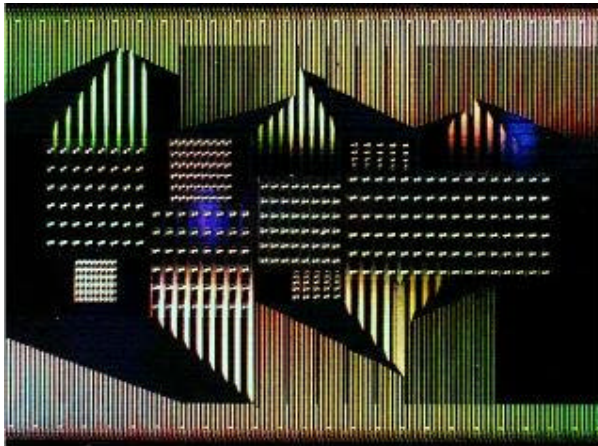
3.2 Some MEMS applications

There are numerous possible applications for MEMS. As a breakthrough technology, allowing unparalleled synergy between previously unrelated fields such as biology and

¹ Sources: NEXUS task force report, feb. 2002, MEMS-exchange website, MSTNEWS newsletter

microelectronics, many new MEMS applications will emerge, expanding beyond that which is currently identified or known. Here are a few applications of current interest:

Biotechnology



A MEMS- biocrater

MEMS technology is enabling new discoveries in science and engineering such as the Polymerase Chain Reaction (PCR) microsystems for DNA amplification and identification, micromachined Scanning Tunneling Microscopes (STMs), biochips for detection of hazardous chemical and biological agents, and microsystems for high-throughput drug screening and selection.

Communications

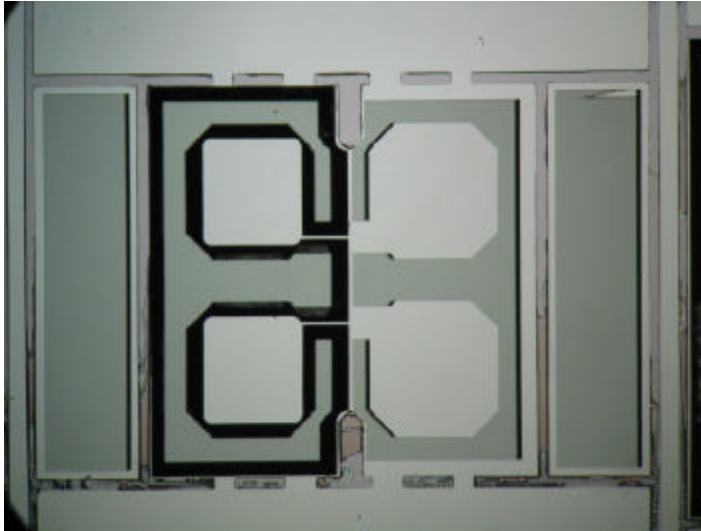
High frequency circuits will benefit considerably from the advent of the RF-MEMS technology. Electrical components such as inductors and tuneable capacitors can be improved significantly compared to their integrated counterparts if they are made using MEMS technology. With the integration of such components, the performance of communication circuits will improve, while the total circuit area, power consumption and cost will be reduced. In addition, the mechanical switch, as developed by several research groups, is a key component with huge potential in various microwave circuits. The demonstrated samples of mechanical switches have quality factors much higher than anything previously available.

Reliability and packaging of RF-MEMS components seem to be the two critical issues that need to be solved before they receive wider acceptance by the market.

Accelerometers

MEMS accelerometers are quickly replacing conventional accelerometers for crash air-bag deployment systems in automobiles. The conventional approach uses several bulky accelerometers made of discrete components mounted in the front of the car

with separate electronics near the air-bag; this approach costs over \$50 per automobile. MEMS technology has made it possible to integrate the accelerometer and electronics onto a single silicon chip at a cost between \$5 to \$10. These MEMS



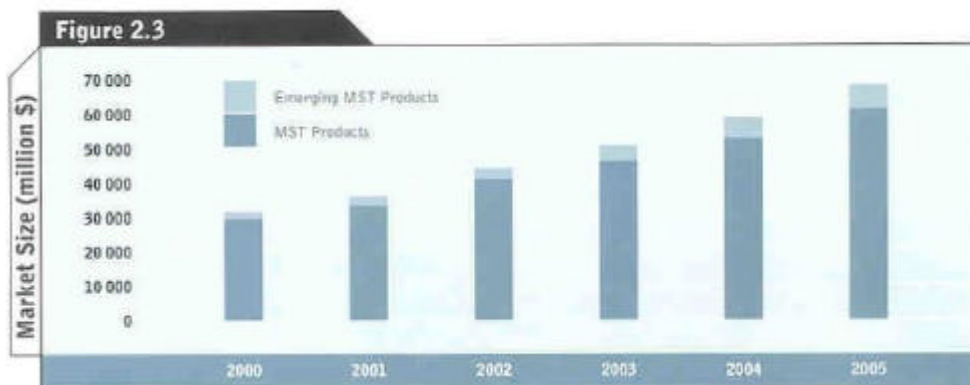
A MEMS gyro for Air Bag applications

accelerometers are much smaller, more functional, lighter, more reliable, and are produced for a fraction of the cost of the conventional macroscale accelerometer elements.

MEMS devices are extremely small -- for example, MEMS has made possible electrically-driven motors smaller than the diameter of a human hair (right) -- but MEMS technology is not primarily about size.

3.3 Markets for MEMS-products

The outstanding feature of the microsystem market is its universal manufacturing technology with applications in a large variety of industrial segments. This unique feature explains why the microsystem market is predicted to grow steadily by 20% p. a. from \$ 30 billion in the year 2000 to an estimated \$ 68 billion by the year 2005.



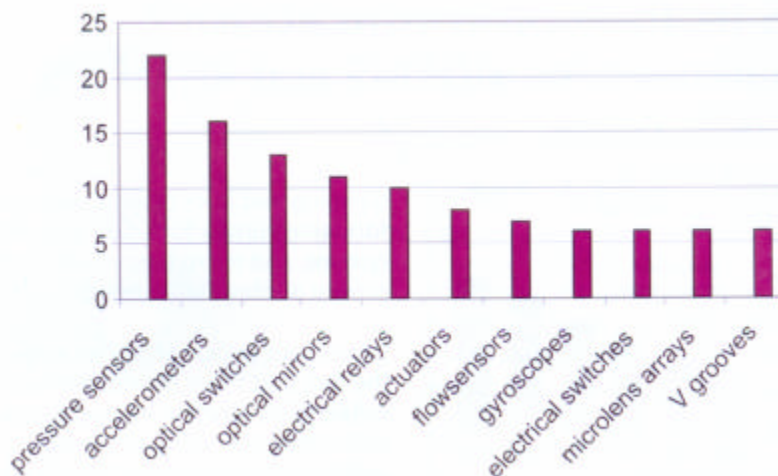
Estimated development of the total world market for microsystem-products 2000 – 2005 (NEXUS task force report, feb. 2002)

The microsystem market does not experience cycles similar to those of the semiconductor industry. In addition, the microsystem market is not as sensitive to the down turns experienced by, for example, the telecommunications segment in the year

2001. Many products and process technologies have proven maturity and there is, currently, a real market pull which has replaced the technology rush of the early nineties. The most important market segment in the period until 2005 is in IT peripherals encompassing producers with the largest volumes: inkjet heads, read/write heads and the newly introduced optical mouse. Furthermore, new emerging producers such as micro displays and electronic paper will further enlarge this application field in the following years. Biomedical applications offer the largest potential for emerging microsystem producers over the ten year span; examples of such products include bio-chips, intelligent drug delivery systems, implantable artificial organs, minimal invasive surgery and non invasive diagnostics. The automotive field was the driving force for microsystem process developments in the early nineties and is still a major segment with producer diversification into other fields such as avionics or military applications. A number of household applications are, in the meanwhile, introduced to the market whereas a breakthrough for telecommunication is likely to materialise within a few years.

MST products and technology have a number of distinguishing attributes that make them attractive for the advanced manufacturing industries of the coming century. These include:

- ? suitability for low cost, high volume,
- ? production
- ? reduced size, weight, and energy
- ? consumption
- ? high functionality
- ? improved reliability and robustness
- ? bio-compatibility



Main products of MEMS foundries (enabling MNT Foundry Review, 9/03)

Despite its relatively young history, microtechnology has already developed into a key multidisciplinary field. This is largely due to the fact that engineers in many technical areas are intensively searching for innovative solutions

achievable only with the help of microtechnical components. MEMS technology merges the functions of compute, communicate and power together with sense, actuate

and control to change completely the way people and machines interact with the physical world. Using an ever-expanding set of fabrication processes and materials, MEMS will provide the advantages of small size, low-power, low-mass, low-cost and high-functionality to integrated electromechanical systems both on the micro as well as on the macro scales.

To date, microsystems technology still is most widely spread in the automobile industry. Miniaturization makes possible a growing number of innovative applications without significantly increasing the need for space and the weight.

3.4 One chip, many applications

MEMS components may be used as a key-component in microsystems for a wide range of applications. To illustrate this, let's study a pressure sensor element like the one showed underneath. This MEMS-based pressure sensor could be integrated into several different microsystem applications, from tyre (?) pressure measurements in automotives to medical equipment and pump velvets (?).

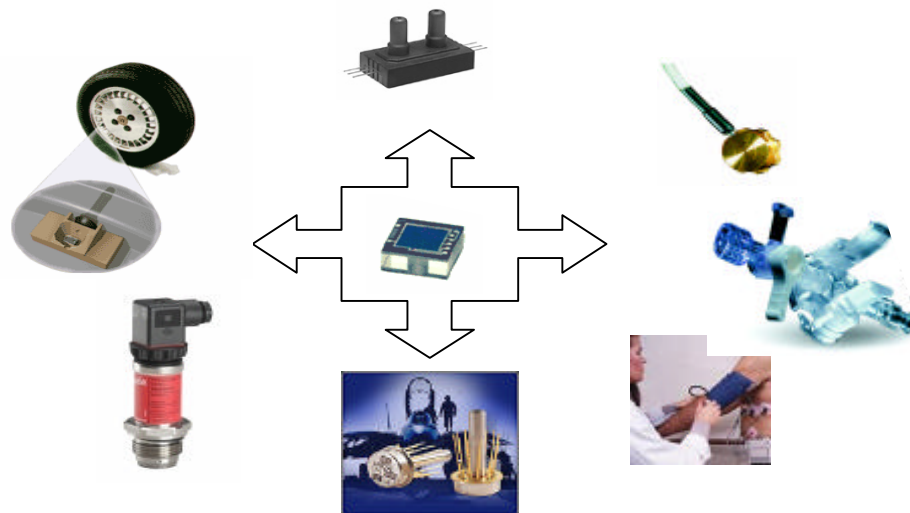


Illustration of the generic (?) character of the technology. A MEMS-based pressure sensor element could be intergrated into a wide range of different microsystem applications.

3.5 Current Challenges

MEMS technology is currently used in low- or medium-volume applications.

Some of the obstacles preventing its wider adoption are:

Limited Options

Most companies who wish to explore the potential of MEMS technology have very limited options for prototyping or manufacturing devices, and have no capability or expertise in microfabrication technology. Few companies will build their own

fabrication facilities because of the high cost. A mechanism giving smaller organizations responsive and affordable access to MEMS fabrication is essential.

Packaging

The packaging of MEMS devices and systems needs to improve considerably from its current primitive state. MEMS packaging is more challenging than IC packaging due to the diversity of MEMS devices and the requirement that many of these devices be in contact with their environment. Currently almost all MEMS development efforts must develop a new and specialized package for each new device. Most companies find that packaging is the single most expensive and time consuming task in their overall MEMS product development program. As for the components themselves, numerical modeling and simulation tools for MEMS packaging are virtually non-existent. Approaches which allow designers to select from a catalog of existing standardized packages for a new MEMS device without compromising performance would be beneficial.

Fabrication Knowledge Required

Currently the designer of a MEMS device requires a high level of fabrication knowledge in order to create a successful design. Often the development of even the most mundane MEMS device requires a dedicated research effort to find a suitable process sequence for fabricating it. MEMS device design needs to be separated from the complexities of the process sequence.

4 Nordic MEMS activities – an overview

All Nordic countries have invested in competence and facilities stimulating (?) the development of microsystems. The microsystem technology programmes in each country got different focus and size and are targeted towards different goals and directions. Realizing a common Nordic knowledge base on microsystem technologies will open unique opportunities for Nordic companies looking into area for future product applications. In the following text, an overview of the competence and main actors and activities in each country are described. Appendix 1-4 present a list of actors at universities, institutes and industry in each country as a supplement to this chapter.

4.1 Sweden

4.1.1 Summarizing the activities in Sweden

Microsystem technology is in Sweden ranked as an area of strategic industrial importance. Sweden has large range of companies seen as future users of Microsystems, companies highly suitable for MEMS-applications. These companies are representing a number of different activities such as IT, Automotive, Medicine, and Biotechnology. The concept of microsystems fits very well into the classical Swedish industrial focus on niche applications.

The growth of industrial companies in Sweden using microsystems has unfortunately not met the expectations. The Swedish position is today characterised by a strong investments on research and development of the fundamental micromechanical processes. Less has unfortunately been invested on factors important to the commercialisation and industrialisation of microsystems, these are factors such as reproducibility, reliability, cost optimization and industrial infra structure. Another growth constraining factor is the low knowledge and awareness of the concepts and possibilities of MEMS within the Swedish industrial community. The result of this is a lack of national “success stories” within the Swedish application industry. There must be strong initiatives made, oriented towards industrialisation and commercialisation of microsystems if Sweden is to be able to benefit from the investments made in universities and institutes. The estimated value of the R&D-work carried out at universities and institutes is in the order of 100 man-years per year, the Swedish industry is estimated to be engaging app 200 man-years per year, thus resulting in a total of app. 300 man-years per year.

4.1.2 Actors in Sweden

Universities and Universities of Technology

Uppsala University (UU), Division of Materials Science and the Division of Solid State Electronics at the Ångström Laboratory, is the leading university today for

research and development in the MEMS-area in Sweden. The activities are focused in three centres

- ? SUMMIT (The Center for Surface and Microstructure Technology), Microfluidics, Radio Frequency Applications (μ RF), Micro-optics (μ O) and Generic MST (μ G)
- ? AME (The Strategic Centre for Advanced MicroEngineering) recently transformed into AMNE (Advanced Micro and Nano Technology), Medical/biomedical/ biological applications, microoptical materials and modules for telecommunication
- ? ÅSTC (The Ångström Space Technology Centre) projects related to nano satellites, micropropulsion, thermal Switches and micro Pyros are carried out.

Chalmers University of Technology (CTH), the research related to microsystems is performed within the Microtechnology Centre at Chalmers, MC2, which also houses the most advanced clean room facilities in Sweden, and the Department of Microelectronics ED, Solid State Electronics Laboratory. On going project within: Beam steering, Fuel cell, Coriolis mass flow sensor, Viscosimeter, Micro-optics and RF-MEMS switches.

Royal Institute of Technology (KTH), Department of Signals, Sensors and Systems, Microsystem Technology (MST) and the Electrum Laboratory in Kista outside Stockholm are working in a number of different activities in the medical field (MedMEMS), the biotechnology field (BioMEMS), optical components (optoMEMS) and radio frequency signal components (RFMEMS).

Linköpings universitet (LiU), The Department of Physics and Measurement Technology, Biology and Chemistry, at the competence centre of S-SENCE (Swedish Sensor Centre). A number of projects are performed within the field of bio- and chemical sensor science and technology, comprising a direct co-operation between the Division of Applied Physics at Linköping University and industrial partners

At Lund institute of Technolgy (LTH), the Department of Electrical Measurements mainly focus on medical applications for MEMS. A number of spin-offs have been generated utilizing the MEMS research in medical applications.

Mälardalen University (MDH), The Department of Electronics are working on research projects concerning micro CO₂ sensors and Dielectrophoresis for cell separation.

Institutes

Acreeo, working mainly in the field of BioMEMS(chip for protein analysis, immunoassays, neuroprobes), OptoMEMS (design for optical broadband communication), Acreeo is also involved in various industrial projects for sensor development.

FOI (The Swedish Defence Research Agency), is mainly financing different research projects within the MEMS-area, these projects are carried out in cooperation with Universities, institutes and industry.

Imego (Institute of Microelectronics in Gothenburg), specializes in MEMS-technology in the field of Biosensing, Micromechanical systems, as well as sensor systems based on optical- and magnetic sensor elements. A motion tracking system has been developed based on some of Imegos patented inertial sensor components.

IVF (Industrial Research and Development Cooperation), working in projects concerning , Microsystem integration and Micromechanical packaging and assembly

Industry

Some of the large companies in Sweden are at present involved in development and manufacturing of Microsystems. These companies, such as ABB, Autoliv, Bofors, Ericsson and Saab, plays a major role in this development. Daughters of foreign companies are also involved in the development of Microsystems; these are for instance branches of Amersham, Agilent and Datex-Ohmeda. There are also a few small companies involved in development and manufacturing of MEMS, these are companies like Silex and Åmic. But the vast numbers of companies engaged in the microsystem area are very small companies, often spin-offs from universities and institutes.

Laboratories

During the last couple of years there have been some heavy investments made in large clean room and laboratory facilities in Sweden, such as the MC2 in Gothenburg, the Ångström Laboratory in Uppsala and the Electrum in Kista. The main parts of the investments are closely linked to universities and research institutes. Sweden has a very good base for development of Microsystems, unfortunately these laboratories are today struggling with their financing; this mainly due to a lack of response from the government and the industry.

4.2 Denmark

4.2.1 Summarizing the activities in Denmark

The Danish MEMS, MOEMS and microsensor activity have a relatively short history. Before 1990 only one company, Danfoss, had a MEMS-based product and the university research had a very low level of 5 man-years per year. At 1990 MIC at DTU was established and later in the 90'es the MOEMS activities was spun out into COM at DTU. COM and MIC has since that time been the centre of the Danish activities.

The research is still concentrated around MIC and COM and the total activity is more than 120 man-years per year. To support the commercialization, 5 service providing institutes has established activities of 35 man-years per year. DELTA is the strongest and started its activities more than 10 years ago². The Industrial activities in Denmark have risen from nearly nothing in 1990 to an activity of 250 man-years per year. The industrial activity is characterized by having a handful of companies who now have their own production facilities, two - three handful of start-up and some two handful of established companies, mainly with the medical field who now are entering into R/D. Nearly all industrial activities are related or spin-off of the research done at MIC and COM. Therefore the MEMS and the MOEMS community in Denmark is closely linked and very good collaboration and only very little competition.

In research and product development the Danish activities are strongest within Lab-on-a-chip (MIC and Danfoss), pressure sensors for industrial use (Grundfos and Danfoss), silicon microphones (Sonion) and Integrated optics for telecom (COM and NKT-integration and Hymite). The strong industrial focus on the Danish activities has resulted in focus on packaging and test, and establishing an R/D lab (PackLab) which is common for 4 industrial companies together with DELTA.

In terms of annual economic activities the governments spends approximately 100 MDKK and the companies spends approximately 300MDKK on R/D and production of MEMS/MOEMS based products.

4.2.2 Actors in Denmark

Universities

MIC, Mikroelektronikcenteret and COM³ at DTU have the highest activities in MEMS and MOEMS research in Denmark. The activities include MEMS design and MEMS prototype processing that is possible because of the 1000m² processing clean-room (class 100). Furthermore the activities involve a bio- and a nanogroup.

At the two departments 7 professors are involved with research of MEMS and MOEMS. Besides education of Post Docs and Ph.D. students in the field, MIC and COM also offers master courses of different kinds in MEMS and MOEMS.

IPL is another institute at DTU working mainly with electroplating and surface plating of MEMS for various purposes.

Ålborg University, SMI has sensor activities for medical purposes. The activities are based on mostly designing and use of MEMS.

² ref. fact sheet on MEMS and MOEMS in DK

³ COM – the Department of Communication at DTU, Danish Technology University

Institutes

DELTA has a business area, Microsystems, where the activities are concentrated on MEMS-wafer testing, MEMS-prototyping, MEMS-packaging and MEMS-failure analysis. DELTA has clean-room facilities for interconnection prototyping and a packaging clean-room in collaboration with 4 companies next to MIC. Another division at DELTA is optical sensor systems, where some of the work has been concentrated on miniaturized optical sensors.

RISØ has activities in the MOEMS area, and in collaboration with COM and MIC education of Post Docs. , Ph.D. students and Master students.

Technological Institutes departments Microtechnology / Surface analysis and Polymers offers injection moulding and laser cutting of microstructures in polymers. Microtechnology / Surface analysis also have surface and failure analysis of microelectronics.

STC, Sensor technology center, is a network organization owned by 5 GTS⁴ institutes, including DELTA and Technological Institutes. STC is offering knowledge in the sensor area and contact to the owners. The conclusion of an evaluation of STC is that the center is joining and focusing the work in the MEMS, MOEMS and micro sensors for all of the 5 owners⁵.

Industry

Several companies have started production of MEMS and MOEMS in their own cleanroom production facilities. As well as using the MEMS-components for own products, they also offer MEMS-fab services. The companies are Grundfos, SonionMEMS and NKT-research.

Danfoss and Dicon do not have MEMS-processing facilities but have production of finished packed MEMS components.

Grundfos has succeeded in developing a MEMS pressure sensor for the core product, pumps. Other companies are interested to implement MEMS sensors in their products and have parts of their research departments to look actively into this area. This group mostly counts hearing aids companies and medical companies.

Some of the larger companies have researchers placed at MIC for processing in the laboratory and some of these companies also join the Packlab partnership with DELTA

A lot of start-ups and spin-offs companies have started within the MIC. These companies use the process laboratory at MIC. Since this collaboration between MIC and the smaller companies the process facilities is expanded with Danchip.

⁴ GTS – Godkjente Teknologiske Serviceinstitutt (DK)

⁵ ref: International Evaluation of Sensor Technology Center and the Danish Sensor Initiative

The smaller companies are divided in two groups, one that produce or develop own products and one group that have services in MEMS. The latter group includes MEMS-fabs as NanoNord, SMB, Hymite. The first group is smaller companies where a few products. The counterpart of the small companies is still mostly research units and is funded by investments funds.

Strategic projects

Of the financed projects there is some different issues that has been covered such as MEMS design, Miniaturized Sensors, MEMS packaging, MEMS production.

- ? MEMS design: MiNAP, μ KAP, μ chem, Sesibon, Histack, Immunalyze, Freja, MicroTAS(Frameprogram)
- ? Miniaturized Sensors: MINOS, μ KAP,
- ? MEMS Packaging: SUM, MiNAP, μ KAP, Histack, Sesibon
- ? MEMS Production: SUM, MiNAP, NORMIC

The projects have a wide range of application area from bio, medical and chemical use (μ KAP, Immunalyze, μ Chem, MicroTAS (Frameprogram)) to pressure sensors (SUM). Optical sensors mostly for flow measurements have been developed in MINOS.

Networks, conferences and supplementary training

Different kinds of networks have been established at national and Nordic level. A SPM-erfagroup called “Microsystem and minisensors – production and quality” has been started by DELTA. A Nordic chapter of the IEEE-CPMT has lived successfully for several years.

During the last 5 years different kinds of conferences, workshops, theme days and exhibitions have been held in Denmark. Ex. EuroSensor, SUM-workshop, Workshop on MEMS Sensor Packaging, ECOC.

The TI is the only one to offer supplementary training in the area of MEMS technology with the course “Lab-on-a-chip”.

4.3 Norway

4.3.1 Summary of Norwegian MST activities

Microsystem technologies have a long history in Norway. Research activities carried out at SINTEF during the last 30 years, have been industrialised by companies like SensoNor, MemsCap, Presens and AME with great success. The airbag-sensor SA20

to SensoNor could be found in 35 million cars all over the world. But other parts of Norwegian industry have not looked into the possibilities offered by the technology, and at the moment there is a need for “industry push” for applications realised by microsystems. Nor the Norwegian Universities have traditions in this area, and the activities in the different groups nowadays have only been going on for some years. The Norwegian Microtechnology Centre (NMC) initiative was developed and pushed from SINTEF in 1997 and in 2003 a new laboratory with up-to-date facilities will be opened as a result of this initiative. A packaging lab and a realisation of a new institute for microsystem technologies at Vestfold College are also results of the initiative.

4.3.2 Actors in Norway

Universities and colleges

During the last 5 years the interest for MEMS and microsystem technologies at the universities has increased a lot. Both the University of Oslo and the Technical University of Trondheim have been running different programs and projects focusing aspects of microsystem technology.

At the University of Oslo, two departments are running MEMS related activities. The University will run one of the clean-rooms in the new Micro- and nanotechnology Research Laboratory (MRL) and start teaching classes in MEMS processing and optical MEMS as a supplement to the existing course in design and modelling.

At the University of Trondheim, department of Physical Electronics, ASIC for MEMS and micro optic components are two research areas.

Vestfold College, HVE, in Horten has the last years established a new department of microsystem technology. A bachelor education was started in 2002 as one of the first in Europe at this level. Master education is planned from 2005. Packaging and interconnection technologies is the main focus for the institute together MEMS design and modelling.

Institutes

SINTEF has a history of research activities within microelectronics and microsystems since 1960. The department of electronics and cybernetics has been the main national player in the development of microsystems, and is offering both design competence and production facilities to national and international customers.

Department of Electronics and Cybernetics offers research based innovation based on microsystem technologies. The institute covers all aspects of microsystem technology (sensor, microelectronics and actuator), from MEMS design and production to packaging and integration and ASIC-design. The new laboratory owned together with the University of Oslo, will drastically improve the capability on MEMS design and production.

Other departments at SINTEF have start looking into the micro- and nanotechnology.

Industry

SensoNor is one of the world's leading designers and volume producer of sensors and devices based on silicon micromechanical technology (MEMS). In addition to its own multi-disciplined MEMS design team, the company has its own waferfab and high volume backend production and test facilities. SensoNor also offers foundry production services to international customers within the MultiMEMS-project.

Some other companies, like PreSens, AME and Memscap, are also doing design and production of MEMS-based sensors. During the last years many start-up companies, like Idex, LifeCare and NorChip, have been established based on an idea of developing a MEMS-based sensor or product.

Other parts of Norwegian industry are in general not aware of the possibilities with MEMS technology. Some few have started looking into the possibilities.

Research activities

Both SINTEF and the Universities (UoO, NTNU and the last years HVE) have been running strategic research projects during the last 5 years.

SINTEF has been involved in 8 different EU-projects financed in the 5th framework program in EU.

In Horten, Microtech Innovation is developing an incubator concept focusing innovation through microsystems. This incubator is set up in close co-operation with HVE and SINTEF.

Laboratories

The new MRL laboratory in Oslo with state-of-the-art equipment will make it possible to exploit the potential of the MEMS technology. The facility will be an excellent national facility for micro- and nanotechnology. SINTEF will put efforts on the design and production of advanced microsystems, whereas the University of Oslo also will look into the nanotechnology area. The laboratories will be up and running during 2004.

At NTNU, the clean-room at the Department of Physical Electronics has equipment for e.g. thin film sputter deposition, optical analysis, Surface Acoustic Wave laser probing and semiconductor processing.

In Horten, Microtech Innovation has established a packaging and interconnection laboratory together with Vestfold collage, HVE. The research activity at HVE will be concentrated at this lab. HVE is also establishing a clean-room facility for the student activities at HVE.

4.4 Finland

4.4.1 Overview of the status in Finland

The MEMS activities are quite plentiful in Finland. There is one high-volume manufacturer of MEMS devices (VTI Technologies), medium-volume microsystems production for specific applications between Vaisala and VTT, silicon and SOI wafer manufacturing with focussed emphasis toward MEMS market, a silicon IC manufacturer, some other semiconductor, contract manufacturing, and packaging companies as well as enterprises interested in applying novel microtechnologies in their various electronic products.

4.4.2 Actors in Finland

Universities

The most intense academic MEMS activity in Finland is within Helsinki University of Technology (HUT). HUT has a high-quality clean room facility in the Micronova building with good equipment base to perform various fabrication studies. They also have long history in MEMS modelling, partly together with Centre for Scientific Computing (CSC). University of Jyväskylä strives for nanoelectronic expertise. Tampere University of Technology has strong background in (non-MEMS) III-V device development. Other supportive microelectronics activities are available for example in the University of Helsinki (Atomic Layer Deposition) and University of Joensuu (electron-beam writing).

Industry

VTI Technologies fabricates millions of micromechanical devices yearly, most of those for automotive applications. It is a world leader in the design and production of silicon capacitive inertial sensors. VTI offers solutions in acceleration, motion, shock, vibration, inclination and pressure measurements to a wide global customer range. Okmetic produces silicon wafers, striving for high quality products for semiconductor, sensor, and MEMS/MOEMS market. In addition to silicon wafers they also have silicon-on-insulator (SOI) products. Silicon-based analog-digital integrated active as well as passive circuits are produced in Micro Analog Systems or MAS. They participate in national and international MEMS projects. Companies already utilizing or developing microsystems in their production include Vaisala (CO₂ transmitters, radiosondes, and weather stations), Suunto (sports instruments) and Datex-Ohmeda / GE Medical Systems (patient care). Companies with back-end and packaging expertise include Filtronic LK and Elcoteq, and to name a smaller one, Rikola Ltd. Nokia is a potential major user of various MEMS devices in their mobile terminals. Polar manufactures modern fitness/sports -related goods. Honeywell has recently opened the Center of Excellence Finland, which acts as a developer of products, solutions and services for the pulp, paper, and printing industries. Part of PerkinElmer Life and Analytical Sciences, former Wallac is another potential user of advanced microsystems in their products. They, alike Thermo LabSystems might find use e.g. for microfluidic products. Companies that already have expressed their interest in

modern microelectromechanical products through participation in national projects can be listed as follows: Metso Automation, Fortum, Oras, Enermet, Coherent Tutcore, among others. Silecs produces low-k dielectric materials for microelectronic fabrication and ASM Microchemistry works on ALD processes. Planar Systems manufactures electroluminescent display devices (although not presently utilizing MEMS technologies), and Nanoway ramps up nanoelectronic production. Some detector companies – Metorex, Detection Technology, and Ajat - may also find interest in fabrication techniques originally developed for MEMS.

Institutes

VTT, the Technical Research Center of Finland, has been working on surface micromachining since the early 90's. The starting point was polysilicon-based thin film technology making use of oxide sacrificial layers. More recently (1997) SOI technology has been elaborated, and amorphous metal micromachining was initiated in 2000. VTT can also monolithically integrate CMOS and MEMS. Some discrete devices are commercially produced at VTT Micronova facilities, either using industrial or VTT personnel. Fabry-Perot interferometers and thermopiles, optimized for infrared wavelengths, are manufactured. Other commercially produced microdevices (non-MEMS) are ultra-sensitive magnetic field sensors (SQUIDS) and radiation detectors. Pressure sensors and capacitive micromachined ultrasonic transducers also have mature fabrication technology. Additionally, devices such as microresonators (silicon and ZnO), acoustical emission sensors, and microphones have successfully been made.

Centre of expertise of Adaptive Materials and Microsystems (part of Culminatum) promotes utilisation of microsystems in business, job creation and regional development.

Projects

Tekes, the National Technology Agency, is a major player in supporting R&D in Finland. They previously had a focussed program on MEMS and precision technology. Presently the dominant programme covering the MEMS field is called ELMO, striving for electronics miniaturization. ELMO is to be carried out between 2002-2005, and its budget is about 100 M€. Of course, only part of its titles is MEMS-related. The listing of the separate projects is most conveniently achieved through Tekes web pages⁶.

The Academy of Finland has a new programme on Future Electronics. Finnish universities, institutes, and companies strongly participate in the 6th framework projects of EU and its Networks of Excellence on microsystems and MEMS.

⁶ <http://akseli.tekes.fi/Resource.phx/tivi/elmo/en/description.htm>

Lab resources

For R&D, VTT has high-quality (class 10) clean room facilities of 1850 m² for BiCMOS and thin-film technology (down to 0.6 μm line widths), wherein also the MEMS devices are made. The Electronics institute in Oulu has additional facilities and technologies such as low-temperature co-fired ceramics (LTCC) that has been used for MEMS prototype packaging. Discrete process steps and manufacturing support can be obtained from various industrial and academic sources. The other R&D facilities but VTT have limited capabilities for producing volumes of devices. The personnell working closely on MEMS at VTT sums up to about 30. What seems to be missing in the Finnish scene is the commercialization path for MEMS devices within industries not familiar with handling silicon-based devices or chips.

4.4.3 Conclusion

The Finnish infrastructure in the field of MEMS is quite well developed and self-contained. There is an important manufacturer (VTI Technologies), although only a single one. There is also a well-equipped R&D institute for prototyping and low-to-medium volume production (VTT). Additionally, there is a spectrum of various companies generating application ideas and technology services. An important link is, however, missing between VTT as a MEMS wafer or chip producer and the multitude of companies not familiar with handling microelectromechanical devices on chip-level but still possessing potential interest of using those in their systems. The company base in a small country like Finland is limited, and the infrastructure could be strengthened through effective Nordic collaboration.

Appendix 1 - MEMS actors in Sweden

MEMS and micro-optic research and services and MEMS/micro-optic -based products in Sweden

Universities and Universities of Technology	Examples of on-going Projects	www
Chalmers University of Technology (CTH)	Beam steering Fuel cell Low temperature wafer-scale encapsulation and transfer technology Coriolis mass flow sensor Viscosimeter Micro-optics: SLM technology Fatigues and mechanical strength of microstructures RF-MEMS switches Nanoindenter Magnetic filed sensor Micromotor	www.ic.chalmers.se
Royal Institute of Technology (KTH)	Microbeads based processes On-chip liquid handling Mass spectroscopy spraying tips Transdermal liquid interfacing Transdermal biopotential electrodes Turbulent gas flow measurement Valve-less fluid micro-pump Micropneumatic gas control devices Thermal infrared-detector array Micromirror arrays MEMS for Antenna Systems Packaging and sealing Adhesive wafer and transfer bonding	www.s3.kth.se/instrlab
Linköpings universitet (LiU)	High temperature sensors based on SiC Time stable gas sensors	www.ifm.liu.se
Lund institute of Technology (LTH)	SI-integrated enzyme reactors Implantable nervus contact for control of artificial limbs	www.elmat.lth.se
Uppsala University (UU)	Micro dispensing MST for Microfluidics (μ F) MST for Radio Frequency Applications (μ RF) MST in Micro-optics (μ O) Generic MST (μ G) Nanosatellite programme Micro Propulsion Cold Gas Thrusters Micro Pyros Variable Emittance Panels Thermal Switches 3D-Multi Chip Modules 3D-Sun Acquisition Sensor	www.mst.material.uu.se
Mälardalen University (MDH)	RF-MEMS CO2 sensor DEEP - Dielectrophoresis for cell separation	www.mdh.se/iel/

Institutes	Examples of on going Projects	www
Acreo	BioMEMS Protein chip Immunoassays Neuroprobes Design of a optical system for broadband communication Generic MEMS	www.acreo.se
FOI	Is mainly a financier of different research projects within the MEMS-area	www.foi.se
Imego	Micro switch for telecom applications Beam steering, using MEMS-technology for guidance of light beams Bonding of SI-chip to a multilayer LTCC Motion Tracking by Inertial Sensors Development of a 3-axis accelerometer-system Development of a new gyro-system for "flying objects" MOEMS-systems using LTCC-technology Development of a Micro analysis viscosimeter MEMS platform for Bio reaction analysis MIP applied on MEMS-structures Micro fluidics	www.imego.com
IVF	Micro system integration Mirco mechanical packaging and assembly	www.ivf.se
Companies active in the development of MEMS	Products	www
ABB Robotics	Industrial robots	www.abb.com/robots
Adamantis AB	Diamond optics Design, manufacturer and supplier of electronic and optical instruments, systems and solutions for testing and measuring	www.adamantis.com
Agilent	Humidity Time Indicators (HTI)	www.agilent.com
Alfa Sensors		www.alfasensor.com
Amersham Biosciences AB	Biosensors Chemical sensor components and sensor modules for Air Quality Control for Comfort and Safety	www1.amershambiosciences.com
Applied Sensor AB		www.appliedsensor.com
Autoliv	Automotive safety	www.autoliv.com
Biacore AB	Biosensors	www.biacore.com
Biosensor Applications AB Sweden	Trace detection sensors for drug detection	www.biosensor.se
Bofors Defence AB	Military Defence Sensor applications Advanced chip-based technologies, primarily, for the discovery of new drugs	www.boforsdefence.com/sv/home.asp
Cellectric AB	Novel technology for fast in-plane switching of liquid crystals	www.cellectric.com
Ecsibeo AB		www.ecsibeo.se
Ericsson Microwave Systems	Radar sensors and military information networks	www.ericsson.com/microwave
Ericsson Radio Systems AB		www.ericsson.com/se/
Instrumentarium AB / Datex-Ohmeda	Sensors for medical use	www.datex-engstrom.com/
Gyros AB	Gyros miniaturizes and integrates laboratory applications Sensor for pulse oximetry and concentration of carbon dioxide	www.gyros.se
Hök Instruments AB		www.hokinstrument.se
Medirox AB	Sensors for haemostatic diagnostic	www.medirox.se
Micronic AB	Manufacturer of high-end laser pattern generators for the production of photomasks	www.micronic.se

Optronic AB	Development and manufacture of a number of optronics products	www.optronic.se
PiezoMotor Uppsala AB	Linear piezo motor	www.piezomotor.com
Pyrosequencing AB	Sensors for DNA analysis	www.pyrosequencing.com/
RADI Medical Systems AB	Sensors for medical use OEM provider of modular continuous tunable laser sources for fiber optic telecom and sensing and spectroscopy applications	www.radi.se
Radians Innova AB	Sensors for military use	www.radians.se
SAAB Bofors Dynamics AB	Sensors for defence, aviation and space	www.saab.se/dynamics/
Saab Aerospace and Defence AB	Sensors for pressure measurement	www.saab.se
Samba Sensors AB	Sensors for Indoor Climate Control	www.samba.se
SenseAir AB	Designing MEMS applications for the telecommunications and life science industries	www.senseair.se
Silex AB	Manufactures and develops thin film products and holographic gratings	www.silexmicrosystems.com
Spectrogon AB	Development and manufacturing of biochip platforms	www.spectrogon.com
Åmic AB	Invent and manufacture digital inkjet technology	www.amic.se
XaarJet AB		www.xaar.se

Appendix 2 – MEMS actors in Denmark

MEMS research and services and MEMS-based products in Denmark

Universities		www
MIC,		www.mic.dtu.dk
COM		www.com.dtu.dk
IPL		www.ipl.dtu.dk
Ålborg University, SMI		www.smi.auc.dk
Institutes		
DELTA		www.delta.dk
Risø		www.risoe.dk
Technological Institute (TI)		www.teknologisk.dk
STC		www.stc.dk
Companies	Products	www
Atonomics	Bio-chip, allergy	www.atonomics.dk
Briel & Kjær	Accelerometres, microphones	www.bk.dk
Cantion	Chemical analysis systems	www.cantion.com
Capres	Micro-4-point probes	www.capres.com
Chempaq	Medical sensors	www.chempaq.com
Dancotech	Assembly	www.dancotech.dk
Danfoss	Pressure sensors, chemical analysis systems	www.danfoss.com
Dantec	Flow-measurement (optical)	www.dantec.dk
Dicon	MOEMS	
DME	AFM/STM/SNOM-microscopes	http://www.dme-spm.dk/
Exiqon	DNA-chips	www.exiqon.dk
Flextronic	Assembly	www.flextronic.com
Foss	Food-sensors	http://www.fossdanmark.dk/
GN Resound	Hearing aids	www.gnresound.dk
Grundfos	Pressure sensors	http://www.grundfos.dk/
Hymite	Optical component	http://www.hymite.com/
Ibsen Photonics	MOEMS	www.ibsen.dk
NanoNord	Clean-room, foundry	www.nanonord.dk
NKT Integration A/S	MOEMS	www.nktintegration.com
NKT Research Center A/S	MOEMS	www.nkt-rc.dk
Novo Nordisk	Biomedical analysis	http://www.novonordisk.dk/
Oticon	Resonators	www.oticon.dk
Radiometer	Medical sensors	http://www.radiometer.dk/ http://www.radiometer.com
Scandinavian Micro Biodevices A/S (SMB)	DNA-chips, Microflow components	www.smb.dk
SonionMEMS A/S	Microphones, resonators etc.	http://www.sonionmems.com
Sophion	Medical components	http://www.sophion.dk/
Thomsen Bioscience	Bio-chip	www.thomsen-bioscience.com
Topsil	Silicon wafers for special applications	http://www.topsil.com/
Widex	Assembly of hearing aids	www.widex.dk
Vir A/S	Polymer systems for 'surface plasmon resonance'-measurement	http://www.vir-tech.dk/
Xenogenix	Systems for GMO-detection in food	http://www.xenogenix.com/
Giga, Intel		http://www.giga.dk

Projects (national & european)	Danish participants
SUM (DK)	DELTA, Danfoss, Grundfos, Capres, MIC, SonionMEMS
MiNAP (DK)	DELTA, Capres, MIC, NKT-research, Flextronic, Århus Universitet
Mikrokap (DK)	TI, DELTA, Danfoss, Vir, Radiometer, STC, MIC, IPL, Atonomics
Microchem (EU)	MIC, Danfoss
Sesibon (EU)	MIC, Danfoss
MINOS(DK)	DELTA, Risø, IPL, TI, Dantec, Kamstrup, Radiometer
Rammeprogram(DK), MicroTAS	MIC
Freja(DK)	MIC
Histack(EU)	MIC
Immunalyze(DK)	MIC, Exiqon
Normic(EU)	MIC, DELTA

Appendix 3 – MEMS actors in Norway

MEMS activities and services and MEMS-based products in Norway

Companies	Products	www
SensoNor ASA	Tyre pressure sensors, accelerometers, etc, wafer-fab, packaging, foundry services	http://www.sensonor.com
MEMSCAP AS	Pressure sensors, medical sensors	http://www.memscap.com
IDEAS ASA	Detection modules for gamma, beta and x-ray cameras	http://www.ideas.no
PreSens AS	Pressure sensors	http://www.presens.com
AME as	Photodetectors and optohybrids, manufacturing & assembly	http://www.ame.no
AME Space AS	SAW-filter etc. for space applications	http://www.alcatel-space.no
Scan-Sense AS	Pressure, temperature, load and force sensors	http://www.scansense.no
MicroComponent AS	Thick film substrates & hybrids assembly	http://www.microcomponent.no
Kitron Microelectronics AS	Design, manufacturing and assembly of MCM's and thick film hybrids	http://www.amitech.no
Photonyx Ltd.	MOEMS component	http://www.photonyx.com
NorChip AS	Biomedical diagnostic	http://www.norchip.com
LifeCare AS	Body-implantable wireless glucose-meter	http://www.lifecare.no/
Alertis Medical AS	Medical CO2-sensor for ischemia measurements	http://www.alertismedical.no/
OptoMed AS	Medical sensors based on fiberoptics	
Fifty-four point seven AS	Photo-acoustic gas sensing	http://www.fifty-four.no
IDEX AS	Finger-print recognition technology	http://www.idex.no
Interon AS	X-ray imaging	http://www.interon.no
Sonitor AS	Positioning system based on ultrasound	
Tomra Systems ASA	Optical sensors	http://www.tomra.no
ABB Research	MEMS for instrumentation	
Simrad Optronics AS	Infrared radiation source	
OptoSense AS	CO2 detectors	
University / Institute / others	Field of work	www
SINTEF	Research based development of microsystems	http://www.sintef.no
Dep. of Electronics and Cybernetics	Design and modeling of microsystems MEMS processing and characterization Radiation detectors Microsystems for demanding environments Packaging and interconnect ASIC for microsystems High-temperature ASIC	
University of Oslo, UoO		http://www.uio.no
Dep. of Physics	Physical Electronics, defect generation in semiconductors, radiation defects in silicon, silicon carbide, point defects and diffusion in semiconductors. MST Micro System Technology FIN Films, Interfaces and Nanomaterials	
Dep. of Informatics	Device modelling and circuit simulations MOEMS and MEMS, Micro-opto-electromechanical and Micro-electromechanical Systems	
University of Trondheim, NTNU		http://www.ntnu.no
Dep. of Physical Electronics	Synthesis, analysis, characterisation, and fabrication of fibre Bragg gratings for sensors and communications, quantum optics Design of ASICs for microsystems	

	Fiber- and Micro-optic Components and their Applications in Medical Sensors	
Vestfold College, HVE		http://www.hive.no/
Dep. of Microsystem technology	Design and modeling	
	Microsystem packaging	
	Bachelor education in Microsystem Technology (since 2002)	
	Master education planned from 2005	
MicroTech Innovation AS	Incubator, packaging lab facilities	http://www.microtech-innovation.no

Laboratories	Equipment	www
MRL - Micro- & Nanotechnology Research Laboratory	The facility will be an excellent national facility for micro- and nanotechnology research with a broad range of equipment for processing and characterisation	
SINTEF & UoO, Oslo		
MTI - Microsystem Packaging Laboratory	Characterisation of MEMS-components	http://www.microtech-innovation.no
HVE & MTI, Horten	Packaging of bare dies	
	Wire-bonding	
	Chip-on-board / thick film ceramics	
	Biocompatible encapsulation	
Clean-room, Dep. of Physical electronics	Thin film sputter deposition	
NTNU, Trondheim	Optical analysis	
	Surface Acoustic Wave laser probing and semiconductor processing.	

Research projects	Project focus	Participants (N)
MicroSystemTechnology (MST) - strategic institute project		SINTEF
FIN Films, Interfaces and Nanomaterials		UoO
Fiber- and Micro-optic Components and their Applications in Medical Sensors		NTNU
MOEMS and MEMS, Micro-opto-electromechanical and Micro-electromechanical Systems		UoO
Design of ASICs for Microsystems		NTNU
MST Micro System Technology		UoO
TESS (EU)	Photo acoustic gas sensing	SINTEF
PAMPAS (EU)	Photo acoustic gas sensing	SINTEF, 54,7 AS
IPHITEMPS (EU)	High temperature sensor packaging	SINTEF
NCMEye (EU)	Oil well down-hole instrumentation	SINTEF
PharusIT (EU)	Oil well down-hole instrumentation	SINTEF
HISICON (EU)	Solar cells	SINTEF
MASCOT (EU)	Acoustic CO2 sensing	SINTEF, SensoNor ASA
NETGAS (EU)	Photo acoustic gas sensing	SINTEF, SensoNor ASA
NORMIC (EU)	Manufacturing Cluster around SensoNor	SINTEF, SensoNor
MEMSOI I & II (EU)	Manufacturing Cluster around Tronic's	SINTEF
CCMICRO I & II (EU)	Competence Centre for microactuators and MST processes	SINTEF
CCMeSys I & II (EU)	Competence Centre for Physical Measurement Systems	SINTEF
MOEMSC I & II (EU)	Competence Centre for MOEMS	SINTEF
MultiMEMS (EU)	Manufacturing Cluster around SensoNor	SINTEF, SensoNor, MicroComponent, HVE

Appendix 4 – MEMS actors in Finland

MEMS and micro-optics activities and services and MEMS- and micro-optic based products in Finland

Universities		www
Helsinki University of Technology	MEMS	www.hut.fi
University of Jyväskylä	nanotechnology	http://www.jyu.fi/
Tampere University of Technology	modelling, III-V optics	http://www.uta.fi/english/ http://www.joensuu.fi/englishindex.html
University of Joensuu	optics, nanotechnology	http://www.joensuu.fi/englishindex.html
University of Oulu	micropackaging	http://www.oulu.fi/english/
Institutes		
VTT	MEMS	www.vtt.fi
CSC	MEMS modelling	http://www.csc.fi/index.phtml.en
InFotonics Center	optics	http://www.ifc.joensuu.fi/
Company	Products	www
VTI Technologies	inertial MEMS sensors	www.vti.fi
Vaisala	environm. measurements	www.vaisala.com
Datex-Ohmeda (GE)	patient care	http://www.datex-ohmeda.com/
Suunto	sports / fitness	http://www.suunto.com/
Polar	sports / fitness	http://www.polar.fi/
Heptagon	micro optics	http://www.heptagon.fi/
Coherent Tutcore	lasers	http://www.tutcore.fi/
Modulight	lasers	http://www.modulight.com/
Liekki	specialty fiber	http://www.liekki.com/
Corelase	specialty fiber	-
Asperation	telecom, electronics	http://www.asperation.com/
Nanocomp	nanotechnology	http://www.nanocomp.fi/
Nanoway	nanotechnology	http://www.nanoway.fi/
Photonium	manufacturing technology	http://www.photonium.fi/
Noptel	optoelectronics	http://www.noptel.fi/nop_eng/
Teleste	data communication	http://www.teleste.com/
Rikola	micro-optic modules	http://www.rikola.fi/
Filtronic LK	RF for handsets	http://www.filtroniclk.com/
Selmic	micro modules	http://www.selmic.com/
Honeywell	optical sensors	http://www.honeywell.fi/
ASM Microchemistry	atomic layer deposition	http://www.asm.com/
Planar Systems	electronic displays	www.planar.com
Micro Analog Systems	IC, integrated passives	http://www.mas-oy.com/
Okmetic	sensor / MEMS wafers	www.okmetic.com
Nokia	handsets, MEMS, optics	www.nokia.com
PerkinElmer	life and analytical science	http://las.perkinelmer.com/
Thermo Electron Corporation	liquid handling and micro-plate instrumentation	http://www.thermo.com/eThermo/CD/A/BU_Home/BU_Homepage/0,1285,116,00.html
Ajat	detectors	http://www.ajat.fi/
Detection Technology	detectors	http://www.deetee.com/
Metorex	detectors	http://www.metorex.fi/
Rados	detectors	http://www.rados.fi/

Projects	Participants	
AMORFIS (amorphous metal micromachining)	VTT, Finnish companies, Tekes	
EMMA (MEMS precision applications)	VTT, Finnish and European companies, EU, Tekes	http://www.vtt.fi/tte/research/tte7/research/emma/index.html
MEMRO (MEMS oscillator)	VTT, Finnish and European companies, Tekes	
MICROCOMPASS	VTT, Finnish companies, Tekes	
UMMETUS (CMOS-MEMS integration)	VTT, Finnish companies, Tekes	
WASP (wafer scale packaging)	VTT, Finnish and European companies, Tekes	