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# MST-Regionenbericht „Asien“

**erstellt im Rahmen der**
**Innovationsunterstützenden Maßnahmen**
**für die MST im**
**Förderprogramm „Mikrosysteme“**
**des BMBF**

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# MEMS/MST Development in Asia

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## 1. Introduction

MEMS (micro electro mechanical systems) technology is finding its way into a broader range of products, in addition to the conventional mainstream applications in computer peripherals, automobiles, and display devices. MEMS is considered to be one of the key enabling technologies that will have an impact on the way we work, live, communicate and play. However, it has become a shared notion among concerned people that there are considerable technical and management challenges to the successful exploitation of MEMS technology in the marketplace. This report summarizes how Asian countries (Japan, Korea, Taiwan, Singapore, and China/HK) are coping with such challenges in order to commercialize MEMS technology to strengthen industrial competitiveness and enhance the standards of living.

## 2. Global Overview on MEMS Development

The use of silicon as a mechanical structure has been proposed and tested for over 25 years, but it is during the 1990s when the government agencies in various countries seriously started providing strategic funding to advance R&D in MEMS, Micromachines and Microsystems. After many years of extensive funding, the research, prototyping, and engineering infrastructure in industrially advanced nations have improved to the extent that companies can take advantage of such publicly-supported facilities relatively inexpensively. In the private sector, technical sophistication continued in well-established MEMS product categories such as inkjet print heads, automotive pressure and acceleration sensors, and digital micro-mirror devices. These MEMS devices have been produced in large quantities. More recently, FBAR (thin film bulk acoustic resonator) and silicon microphones have come to be widely used in information & communication technology systems.

Today, the interest in micro/nanotechnology remains very strong. New products and applications are emerging. For example, mobile phones continue to improve in functionality: the future generations of mobile phones will require tiny acceleration sensors for positioning and user interface; Si microphones to lower production cost of handsets; multi-band RF (radio frequency) MEMS switches; better power sources to ensure a longer battery life. Digital cameras will require tiny gyroscope sensors for image stabilization. Hard disk drive-based mobile devices such as MP3 music players and digital video cameras will require tiny acceleration sensors to protect HDD from shock. Consumer electronics are expected to become the next-generation application platform for MEMS devices.

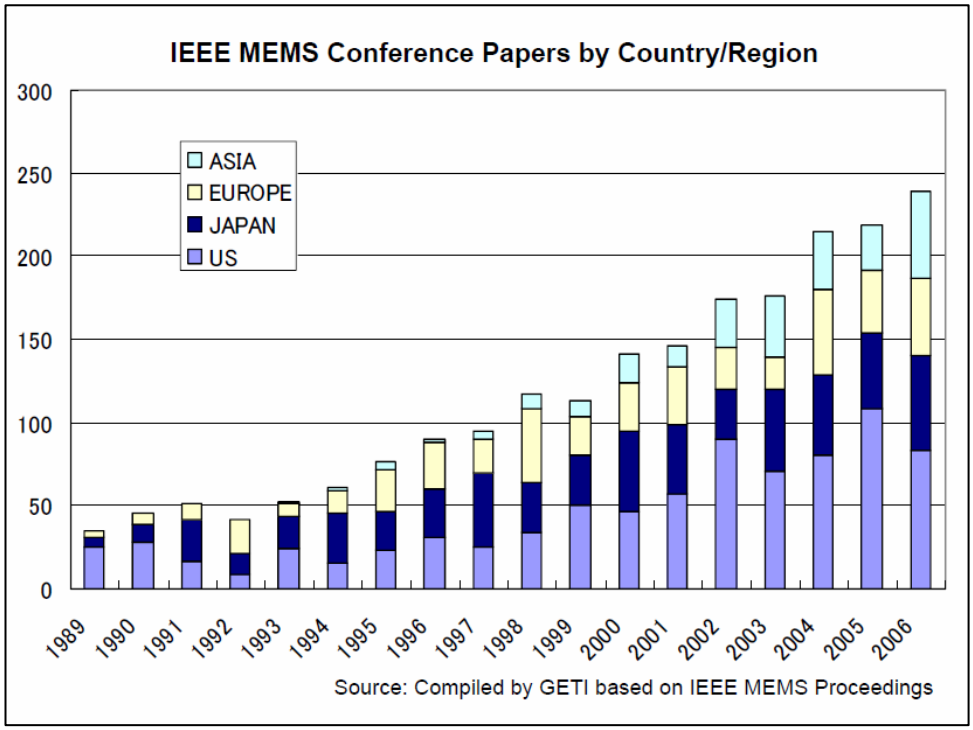
On the research front, the U.S. National Nanotechnology Initiative announced in 2000 has produced a significant impact on the public science and technology funding strategies in many countries in the world. It is estimated that the global public and private investments in nanotechnology R&D have expanded more than tenfold in the last 5 years. Researchers have quickly responded to this global trend by proposing new research projects to address fundamental issues in physics, chemistry, photonics, electrical, mechanical and bio engineering and multi-disciplinary fields. It was a logical next step for those who conducted MEMS and microsystems technology research to widen their research scope to include exploratory nano science and technology by further downsizing the micro structures and adding new materials such as carbon nanotubes to propose novel device concepts. MEMS and microsystems researchers have benefited greatly from the rapid increase in funding for nanotechnology.

## 3. Growing Presence of Asian Players in MEMS/MST R&D

GETI have analyzed the technical papers accepted and presented at the “IEEE International Conference on Micro Electro Mechanical System (IEEE MEMS)” over the years in order to make an international comparison and understand the R&D trend. IEEE MEMS is one of the most prestigious international conferences in the field of MEMS that started in 1987 and covers a comprehensive array of topics related to the design and fabrication of novel micro and nano systems and their applications. IEEE MEMS has been hosted in the US, Europe, and Japan/Asia in turns.

Figure 1 shows the number of papers accepted at IEEE MEMS conferences by country of the first authors. It is clear from the figure that the US has increased the number of papers compared to Japan and Europe. An analysis of the first authors’ affiliations has revealed that the number of US universities submitting papers has increased from roughly 10 in the mid-1990 to almost 35. We think that the steady increase in the number of papers from US groups at IEEE MEMS is a direct result from the long-term funding from DARPA (Defense Advanced Research Projects Agency). In comparison, the papers submitted by Japanese companies slightly decreased after the Micromachine Technology Project came to an end in 2001, though the papers from Japanese universities have been on the rise recently. This is in part because the Japanese government has selected nanotechnology as one of the priority areas in national science and technology policy and provided strategic funding in the last 5-6 years.

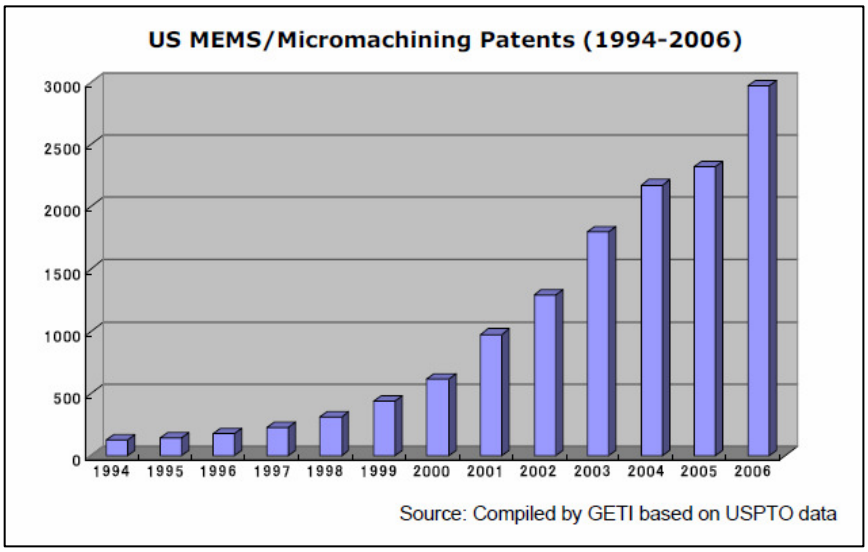
Figure 1: IEEE MEMS Conference Papers by Country/Region, 1989-2006




It is interesting to note that Asian countries (ex-Japan) have come to play a bigger role in this conference in recent years. Leading groups in MEMS in Asia are located mainly in Korea and Taiwan. On the other hand, MEMS/MST research groups are widely distributed in many countries in Europe – from Germany, Switzerland and Sweden to France, Belgium, the Netherlands, Finland, UK, and others. Nonetheless, Asia (ex-Japan) has recently outperformed Europe in terms of papers accepted at this prestigious conference. For example, Korea alone presents more papers than those from Germany. This is an intriguing point.

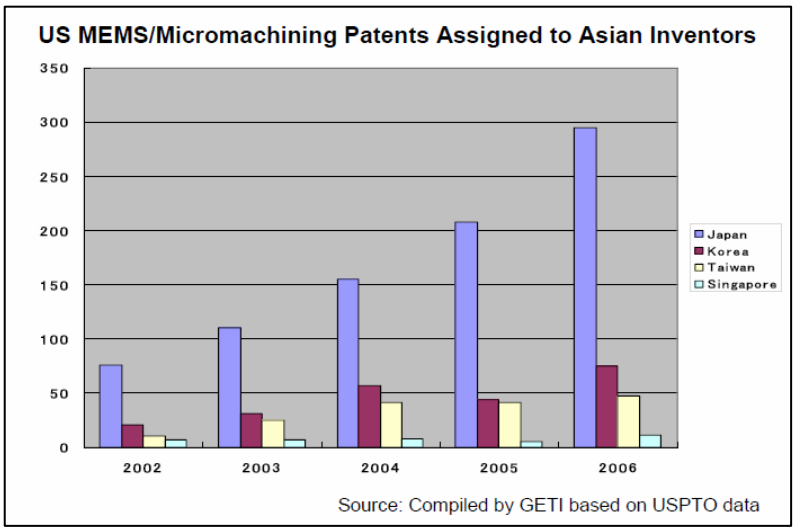
We also looked at the trends in MEMS/Micromachining-related patent applications. For the convenience sake, we only analyzed the US Patent and Trademark Office's database.
The number of relevant US patents has grown considerably especially since 2001, as shown in Figure 2.

Figure 2: Increase in US MEMS/Micromachining Patents from 1994 to 2006




The number of US MEMS/Micromachining-related patents assigned to Japanese inventors has increased rapidly in recent years (see Figure 3). According to our analysis, Japanese assignees currently account for 10% of the US patents related to MEMS/Micromachining. The number of relevant US patents assigned to Japanese inventors increased at a compound annual growth rate of over 40% from 2002 to 2006. In contrast, overall US patents related to MEMS/Micromachining increased by 23% annually over the same period of time. Compared to Japan, Korea's and Taiwan's growth in US MEMS/Micromachining-related patents is modest. Interestingly, 50-60% of relevant US patents assigned to Korean inventors are owned by Samsung group companies. Taiwan inventors are more varied, but many of them are public research institutes and universities. We can conclude from the analysis that 1) though Japanese firms publish less at technical conferences than before, they are more aggressive in developing technologies and products for commercialization, and that 2) Asian (ex-Japan) players are more active than before at the laboratory level but industrial effort seems still quite limited, with the exception of a few leading companies such as Samsung and LG.

Figure 3: US MEMS/Micromachining Patents Assigned to Asian Inventors




It is not clear how European players fit into this global picture, because European groups do not publish as aggressively as their US, Japanese and Asian counterparts, at least as far as the IEEE MEMS Conference is concerned. Public research institutes in Europe now function like corporate central research laboratories, and they are highly motivated to collaborate with industrial partners to find technical solutions together rather than just publishing the research results at conferences. Under the research contracts, the public researchers are discouraged to discuss research effort freely. In addition, many researchers from several research institutes and companies in different countries in Europe often collaborate on projects under EC's research funding. Perhaps, this is part of the reason why the number of papers from "European" groups as counted by the first author appears limited statistically.

On the other hand, US MEMS/Micromachining-related patents assigned to European inventors are not many in number. The number of relevant US patents assigned to German inventors, for example, over the period of 2002-2006 is less than that for Koreans. Yet there are companies in Europe which have been very successful in commercializing MEMS technology, such as Bosch. The linkage between science and innovation in European MEMS/MST field needs further analysis.

# 4. Country Briefs

## 4.1 Japan

### Public Funding for R&D

Japan has provided public support for micromachine R&D since the beginning of the 1990s. The Ministry of Economy, Trade and Industry (METI) sponsored the 10-year national Micromachine Technology R&D Project between 1991 and 2000, providing 20+ companies and research institutes[1] with subsidies to develop baseline technologies to enable micromachine-based systems. The participating companies remained almost fixed for 10 years.

METI also supported a MEMS project in 2003-2005, focusing on the establishment of MEMS sensor, optical MEMS and RF MEMS fabrication techniques. The 3-year project provided funding to Omron, Olympus and Matsushita Electric Works along with Kyushu, Tokyo and Ritsumeikan Universities. In addition, METI launched a 3-year project called “MemsONE” (Mems Open Network Engineering System of Design Tools) in 2004. The objective of MemsONE project is to develop a MEMS design and analysis support system to enable inexperienced engineers to design MEMS devices easily and evaluate the designs quickly. The project involves 8 companies[2] and 13 universities, and its annual budget is about 400 million yen ($3.5 mil). The first version of MemsONE design and analysis support system will be released in April 2007.

Furthermore, METI launched another 3-year MEMS project in 2006 in an attempt to develop baseline technologies for next-generation MEMS devices. The objective of the new project is to develop technologies for integrating heterogeneous functions (e.g. MEMS & nanotech, MEMS & electronics, and MEMS & MEMS) to enable even smaller and more reliable devices. The annual budget for this project was 1,100 million yen ($10 mil) in 2006.

In Japan, many companies already have MEMS R&D capabilities in-house and been busy in developing products for target applications. They do not very much depend on public funding from METI to develop next-generation MEMS technology; instead, they are busy developing products for target applications internally. Large companies interested in MEMS have the resources to collaborate with top-notch research universities and industrially-relevant public research institutes in Japan and abroad. The relatively limited public funding from METI should not be regarded as the lack of interest in MEMS in Japan. Rather, it shows the strength and

[1] The project member companies were: Aisin Cosmos, Denso, FANUC, Fuji Electric R&D, Fujikura, Hitachi Ltd., Kasawaki Heavy Industry, Matsushita Giken, Mitsubishi Cable, Mitsubishi Electric, Mitsubishi Heavy Industry, Mitsubishi Materials, Murata Mfg., Olympus, Omron, Sanyo Electric, Seiko Instruments, Sumitomo Electric Industrial, Terumo, Toshiba, Yaskawa Electric, Yokogawa Electric, and SRI International of the US.

[2] Omron, Olympus, Matsushita Electric Works, Mitsubishi Electric, Hitachi Ltd., Mizuho Information & Research, Mathematical Systems Inc., Nihon Unisys Excelutions.

willingness of industry to conduct cutting-edge research and development at its own cost and risk.

**Industry**

Recently, there was a report from SEMI that there are 77 MEMS fabs in Europe and that 24 of them are research institutes. This means about one-third of MEMS fabs in Europe are in the public domain. In comparison, we can easily name at least 50 listed companies, in Japan alone, that manufacture silicon-based MEMS devices. Many of them integrate such MEMS devices into their own module and system products, while a number of companies offer MEMS foundry services to external customers too. Dai Nippon Printing (DNP) is an exceptional, pure-play MEMS foundry service provider in Japan. DNP is the leading manufacture of semiconductor photomasks and various display materials. The company has recently invested 4,000 million yen ($35 mil) to expand its MEMS process capability to meet the growing demand from MEMS foundry customers. There are dozens of other companies that provide foundry services in one way or another. Such foundries in Japan include Sony, which manufactures silicon microphone chips for Knowles Electronics, a leading supplier of microphones.

One major characteristics about the MEMS industry in Japan is the involvement of many, vertically-integrated firms to differentiate their next-generation products by taking advantage of MEMS technology. For example, Tokyo Electron, the leading supplier of semiconductor equipment, acquired the MEMS division from Sumitomo Metals several years ago. Since the acquisition, Tokyo Electron has realigned MEMS R&D efforts at the division to help enhance the value of new semiconductor equipment. Another example is Canon Inc., the leading company for inkjet printers and digital cameras. The company is conducting MEMS R&D in an attempt to differentiate the future generations of products using MEMS technology. Canon announced, for instance, the development of a MEMS-based flow sensor for use with a micro fuel cell system at a technical workshop. The examples illustrate the potential of MEMS technology to assist Japanese industry in enhancing its competitive edge in the global market.

Today, the hot spot in the MEMS industry is no doubt the consumer electronics sector. Multi-axis accelerometers are finding home in many applications ranging from game consoles and MP3 music players to mobile phones, pedometers and others. The new regulation in Japan that calls for the mobile phone service providers to sell handsets equipped with a global positioning system function on the handset for emergency communication in 2007 will boost demand for 3-axis accelerometers in mobile phones to accurately position the users. Major suppliers of such sensors have recently increased production capabilities by 5-6 times to cope with the surging demand in Japan. European and US manufacturers have announced new products with reduced size and enhanced features. Asia is expected to grow into the world's leading market for MEMS for consumer applications in the years to come.

Most of the 3-axis accelerometer producers in Japan license key MEMS sensor patents from Wacoh, an R&D company which specializes in multi-axis inertial sensor technology development and has an extensive, global intellectual property portfolio. A new US start-up company, Virtus Advanced Sensors, has been established to commercialize advanced inertial sensor products based on Wacoh technology for the global markets. Headquartered in Pittsburgh, PA, Virtus also has product development and marketing operations in Japan and Hong Kong and plans to establish an operation in Europe in the near future. Virtus will initially target high-volume consumer electronics products and develop other niche, high-end markets later.

**Networks**

There are several networks to promote information exchange and collaboration among companies, university groups, and public research institutes. Professor Masayoshi Esashi of Tohoku University helped create the MEMS Park Consortium in collaboration with the City of Sendai and Miyagi Prefecture governments two years ago. Based in Sendai, the MEMS Consortium cooperates with a number of external groups and hosts seminars to disseminate information about research results and business trends. The annual membership fee for the Consortium is 50,000 yen ($450). Currently, there are over 100 member companies.

Prof. Esashi played a key role in the recent collaboration agreement between the City of Sendai and Fraunhofer-Gesellschaft. Under the agreement, the parties involved with the MEMS Park Consortium - namely Tohoku University researchers, Consortium member companies, and local governments – and Fraunhofer Institutes will share information to identify areas for potential cooperation. The underlying idea behind the agreement is to offer an integrated support network: Tohoku University will conduct basic and proof-of-concept research, Fraunhofer Institutes will conduct applied research based on contracts with Japanese companies, which may have become initially interested in such joint projects through interactions with Tohoku University groups, and MEMS Core, a local MEMS company, will provide engineering and prototyping services. This way, companies can reduce the technical risk of bringing new ideas from the lab to the marketplace. Prof. Esashi thinks that providing access to the vast network of Fraunhofer Institutes' applied research capabilities will make it easy for Japanese firms to develop products using MEMS technology.

The Micromachine Center (MMC) recently organized the MEMS Industry Forum linking its own members and other MEMS-related companies, academic institutions, regional public research centers, and even overseas organizations. The objective of the MEMS Industry Forum is multiple: MIF will make policy recommendations, promote collaboration between industry and academia, and support various events. MMC, a foundation established in 1992 to originally administer the Micromachine Technology Project (1991-2000), has hosted the Micromachine Exhibition since then and currently manages METI-sponsored MEMS projects. The annual

membership fees for the MEMS Industry Forum are 1 million yen ($8,500) for full members; 50,000-300,000 yen ($450-2,600) for associate members; and 10,000 yen ($90) for individual MEMS fellows. Supporting members of the Micromachine Center are automatically given the full membership of MIF.

GETI and several companies have launched another network to accelerate commercialization of microtechnology. Named the “Micro Nano Global Network” (MNGN), the bottom-up network will link companies large and small to enable them to exchange latest information about microfabrication processes, assembly, packaging, materials, characterization equipment, etc. which is not easy to obtain at ordinary commercial technical seminars. The network will host seminars to enable members to reach out to potential customers and partners. The idea about the network came from company executives who have been frustrated by the lack of direct and effective ways of communicating with potential customers and those who feel that information becomes obsolete very quickly in rapidly changing technology fields. The network experimentally hosted a one-day open forum in August 2006 and successfully attracted 200 people from 140 companies and institutions. MNGN founding members will shortly announce the details of the network. Mr. Susumu Kaminaga, president of Sumitomo Precision Products, will assume the post of chairman of the global network initially. As the name suggests, the network is open to non-Japanese members.

### 4.2 Korea

**Public Funding**

The Korean government has continuously provided public support for MEMS technology development. MOCIE (Ministry of Communication, Information and Energy) and MOST (Ministry of Science and Technology) have supported multi-year R&D programs relating to MEMS, Microsystem and Microdevice technology since the mid-1990s. The National MEMS Program (1995-2002) helped lay the technical foundation for MEMS devices and micromachining in Korea. This program was followed by other programs with more specific technical focus and application goals. The Intelligent Microsystem Program (1999-2010) has been sponsored by MOST and intended to develop microsystem technology for endoscopic microcapsule devices and micro-PDAs. The funding for this 10+ year program is $190 million. The Optical & Thermofluidic Microdevice Program (2001-2011) is supported by MOCIE and designed to advance development of optical and thermofluidic microdevice technology. The funding for this program will amount to $65 million for 10 years. Companies as well as universities and research institutes receive funding under these programs.

**Infrastructure**

Building the research infrastructure for micro/nanotechnology is a common challenge for both industrially advanced and developing nations. The Korean government enacted the Law for the Promotion of Nanotechnology Development in 2001 and has supported the establishment of public facilities for nanofabrication. The National NanoFab Center (NNFC), located on the KAIST (Korea Advanced Institute of Science and Technology) in Daejeon, is one of such public facilities that went operational in 2005.

The total budget for the National NanoFab Center project is $290 million over the course of 9 years until 2011. Plans call for investing $118 million for equipment and $33 million for the construction of facility building. The gap between the $290 million budge and the $151 million expenditures on equipment and building is the ongoing operational expenses the Center will have to collect from nanofabrication users to run the public facility. Recent statistics show that roughly 50% of projects come from the academia, 30% from industry and 20% from research institutes. In terms of revenues, industrial customers account for over 50%.

The NNFC has a clean room space of roughly 5,000 square meters on two floors with Class10-10,000 cleanness levels. Currently, about half of the space is being utilized. The Center has purchased the state-of-the-art equipment for CMOS, MEMS and biochip fabrication which can handle various substrates ranging in size from a discrete piece to an 8-inch wafer. A unique feature of the NNFC is the fact that the Center has employed a number of technicians who

have worked in large semiconductor companies in Korea. This means that users (researchers) can just outsource to the Center the test fabrication of nanoelectronics and MEMS devices and biochips without worrying about the staff's familiarity with advanced fabrication equipment.

The NNFC is motivated to collaborate with foreign partners as well. The Center has formed an alliance with China's National Center for Nanoscience and Technology and jointly established the "Korea-China Nanotechnology Research Center" inside NNFC in 2005. Hee Chul Lee, president of NNFC, became the deputy of Korea, while Chun Li Bai, professor at the Chinese Academy of Sciences, became the deputy of China at the joint research center. The objectives of the joint center are to exchange information and conduct joint research on nanotechnology in an effort to create new businesses. The Center holds regular meetings to promote exchange of human resources and technology. In addition, NNFC promotes international cooperation by hosting joint workshops with German and US counterparts at the Center.

NNFC is one of five national centers for nanotechnology. Other centers are: Korean Advanced Nanotechnology Center (KANC), East Suwon; National Center for Nanomaterials Technology (NVNT) at Postech University, Pohang; National Nano Integration Center (NNIC) in Jeonju (under construction); and Guandju Nanotechnology Integration Center (GNIC) in Gwandju (to be completed by the end of 2006).

**Industry**

Samsung and LG are among the most active companies in developing MEMS technology in Korea. Samsung Advanced Institute of Technology (SAIT) used to have a very large MEMS R&D staff: the group consisted of nearly 150 researchers working on almost every MEMS topic ranging from inkjet print head, accelerometer and gyroscope, optical MEMS, biochip, power MEMS, and so on. In 2005, some of the units of the MEMS R&D group at SAIT were transferred to the relevant business divisions in Samsung group companies such as Samsung Electro-mechanics Co. in an attempt to bring products to market quickly.

After the Asian financial crisis in 1997-98, the Korean government strongly encouraged the creation of small businesses in an effort to transform the Korean economic and industrial structure into a more horizontal one. As a result, many start-up companies were established to bring new MEMS ideas to market. Some of such companies were founded by former engineers and researchers who worked at Daewoo Electronics, which once had a very large MEMS team to realize a Korean equivalent of Texas Instruments' digital micro-mirror device. Daewoo's MEMS team demonstrated what they called the TMA (thin-film micromirror array) display at SID in the late 1990s, was about to start production when the company went bankrupt.

MEMS companies in Korea can be categorized in two groups: those that are spin-off or affiliated with conglomerates, and those that are independent. According to MEMS experts in Korea, the former group of companies tends to be more successful. This is not surprising at all, considering the fact that the Samsung group alone reportedly accounts for a quarter of Korea's GDP. Yet, how big such MEMS companies affiliated with large firms will grow in the near future remains to be seen. Vertically integrated companies may find it makes more sense to procure innovative components from suppliers outside the group instead of developing and manufacturing them from scratch internally. "To make or to buy" is always a critical question to large firms.

### 4.3 Taiwan

**Public Funding**

Taiwan started a MEMS industry promotion program in the mid-1990s. The Ministry of Economy invited MEMS experts from around the world to host the MEMS Industry Development Strategy Meeting in 1999, which set the basic strategy to leverage the competitive IC foundry infrastructure to position Taiwan as the "MEMS Fab of the world." Based on this strategy, the Industrial Technology Research Institute (ITRI) has played a pivotal role in learning and developing MEMS technology and transferring knowledge to industry.

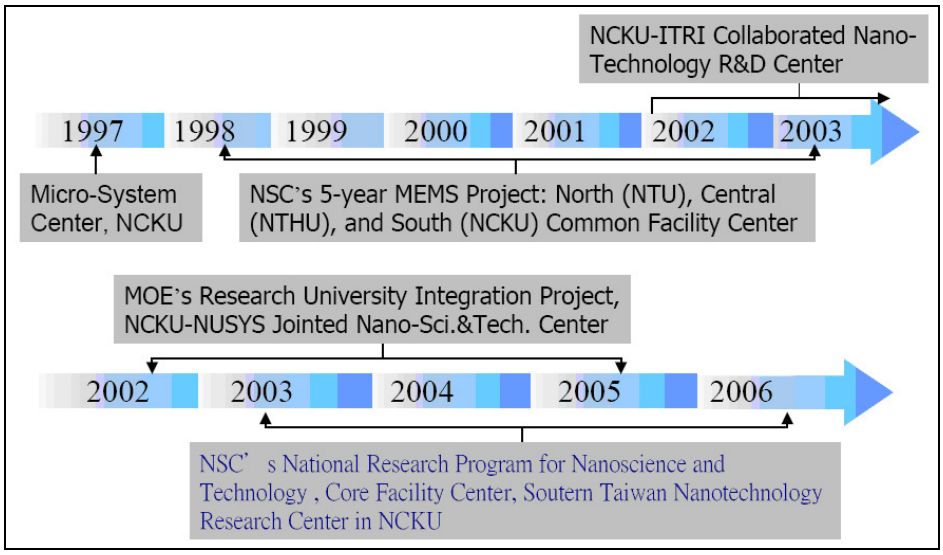
ITRI opened the so-called "MEMS Common Lab" facilities to enable researchers and engineers to develop technology cost-effectively. The lab offers 12 technical modules available for use, which include wet etching, dry etching and PECVD, PVD, photolithography, furnace, assembly and testing, bulk micromachining, packaging and testing, reliability testing, micro-electroforming, micro molding, and system integration. This is expected to enhance the capability to support Taiwan's microsystems industry and create R&D and product realization platform for new products and technology development to industry and academic research institutes.

Taiwan's National Science Council (NSC) provided support for the regional (north, central and south) MEMS facility centers at National Taiwan, Tsing-Hua, and Cheng-Kung Universities respectively. These centers served as the foundation to establish multidisciplinary research centers when nanotechnology became one of the top priority areas in science and technology policy.

The Institute of Microelectromechanical Systems (MEMS Institute) was established in 2002 at National Tsing-Hua University in the central Hsinchu region to bring together MEMS/NEMS-related education, research and related resources and pursue multidisciplinary themes. The Institute has 20 faculty members (4 full time and 16 adjunct professors) and admits 15 Masters students and 15 PhD candidates every year. Like other leading research universities in Taiwan, most of the faculty at the MEMS Institute obtained PhDs in the US and are well connected with overseas colleagues and fully aware of global research trends. The Institute actively interacts with local research centers including the Central Regional MEMS Center, Nano/MEMS Center, Biomedical Engineering Center, Photonics Research Center, Nano Devices Lab (NDL), National Center High-Performance Computing (NCHC), Precision Instrument Development Center (PIDC), Chip Implementation Center (CIC), and Synchrotron Radiation Research Center (SRRC) in order to conduct research effectively.

In the northern region, National Taiwan University opened the Center for Nano Science and Technology to conduct research on NEMS (nanoparticles, nanofilms, fullerenes and nanotubes) design, metrology, manipulation, and fabrication. One of the target applications for such nanomaterials is high-energy components such as lithium ion batteries and supercapacitors. In the southern region, National Cheng Kung University established the Center for Micro/Nano Science and Technology (CMNST) and aggressively investigate biomedical-related areas such as cell manipulation, fully integrated chip for pathogen detection, integrated micro flow cytometer as well as nanotechnology areas such as selective growth of nanowires and development of nanostructured materials for solid oxide fuel cells and dye-sensitized solar cell applications. ITRI also aims to develop a new industrial cluster in the southern Tainan region that specializes in MEMS design, packaging and testing. ITRI's plans call for clustering 10 MEMS design houses in Tainan and achieve combined annual revenues of over US$15 million at an early stage.

Figure 4: Evolution from Micro to Nanotech Research at National Cheng-Kung University, Tainan (Source: NCHU)



**Industry**

Taiwan's national strategy was to pursue ways to transform silicon foundry resources into a competitive MEMS foundry industry. To achieve this goal, a considerable amount of public and private investment has been made to build MEMS manufacturing infrastructure in Taiwan. Reportedly, private investment in more than 10 MEMS-related companies reached US$300 million by 2002. International United Technology has transferred technology from ITRI and developed its inkjet business. LighTuning, established in 2001, has commercialized a series of fingerprint sensor products. However, some companies have experienced difficulty and gone through restructuring recently. NeoStone Microfabrication, which planned to manufacture MEMS accelerometers, went out of business in 2006.

Asia Pacific Microsystems (APM), founded in 2001 by a former ITRI executive and a National Tsing-Hua University professor, is Taiwan's largest MEMS foundry. The company has raised $66 million of working capital and has produced microstructures for inkjet heads, pressure sensors, temperature sensors, wireless components and modules for Bluetooth, WLAN and cellular phones, among others. Although the company once employed 280 people, the business had not developed as the founders and investors initially anticipated. APM recently came under the umbrella of Unimicron, which also has affiliated MEMS foundry, ChipSense Corporation. Unimicron is the 6$^{th}$ largest printed circuit board manufacturer in the world and a group company of UMC, the world's second largest IC foundry. The recent acquisition has made the Unimicron group the largest MEMS foundry in Taiwan.

Virtus Advanced Sensors of the US has entered into a strategic collaboration partnership with the Unimicron group and ChipSense. The companies will collaborate on producing 3-axis accelerometers for a variety of consumer electronics oriented market applications. The partnership is expected to bring advanced technical knowledge to Taiwan for value-added manufacturing of MEMS devices for high volume market segments.

### 4.4 Singapore

**Public Funding**

Singapore has strived to shift the economy into a knowledge-based one by fostering scientific research and developing talent. The Agency for Science, Technology and Research (A*STAR) plays the central role in coordinating research activities in Singapore to achieve the goal. A*STAR consists of four arms: the Biomedical Research Council (BMRC), the Science & Engineering Research Council (SERC), a Corporate Planning and Administration Division, and the agency's commercialization arm Exploit Technologies Pte Ltd. There are 13 research institutes under the two research councils. Many of the institutes cater to nanotechnology, and the following institutes are active in MEMS and microsystem-related R&D: Institute of Microelectronics (IME), Singapore Institute of Manufacturing Technology (SIM Tech), Institute of Materials Research and Engineering (IMRE), Data Storage Institute (DSI), Institute and High Performance Computing (IHPC), and Institute of Bioengineering and Nanotechnology.

IME offers R&D foundry service in its silicon wafer fabrication facility. Occupying a floor space of 21,000 sq. feet, IME's class 10/100 clean room facility is equipped with industry compatible process, metrology and defect inspection equipment for advanced CMOS and MEMS device fabrication. The development work can be carried out together with IME or qualified customers can also have access to IME's facilities. Small volume pilot production can be done using IME's fabrication facility.

IME focuses its attention to microsystems packaging technology development of ultra-thin package designs; flip-chip technology, 3D packaging; wafer level packaging, optical, electrical, thermal, mechanical design and assembly, and others. In addition, IME is responding to the fast growing fields of life sciences by focusing on the packaging of BioMEMS and microfluidics devices. At the recent International uTAS Conference held in Tokyo in November 2006, IME presented 10 papers introducing novel technologies such as micro-coils for bioassays, sample delivery for nanowire biosensors, integrated patch clamping for cell-based drug discovery, high-performance micro nozzles for emultions, micro filters for separation of blood cells, etc. IME is also building competencies in the area of nano-structured materials and self-assembly processes for device packaging.

IME forms collaborative programs with local and overseas universities, research institutes and industry to meet the long-term goal of shifting to the economy based on value-added manufacturing. Most recently, IME has entered into research collaboration agreements with Panasonic Electronic Devices to explore IME's MEMS platform technology for Panasonic's new product lines and with the Swiss-held Physical Logic – Bio Research Pte Ltd. to develop a MEMS

accelerometer for biomedical applications. Not only MEMS technology development expertise but also complementary assets such as ASIC design capabilities and packaging excellence make IME a reliable research partner.

Singapore Institute of Manufacturing Technology (SIM Tech) is another A*STAR research institute that actively conduct MEMS-related R&D. SIM Tech conducts research on MEMS design, modeling, fabrication, packaging and system integration and has demonstrated MEMS devices and subsystems including optical switch, RF component and micro power generation system. Like IME, SIM Tech collaborates with external partners in academia and industry in an attempt to enhance Singapore industry's competitiveness.

National University of Singapore and Nanyang Technological University are the leading research universities in Singapore. Research groups at these universities carry out research on MEMS device development such as RF component, optical MEMS, bioMEMS and micro sensors as well as micro/nano fabrication techniques.

### 4.5 China/HK

**Public Funding**

MEMS research has been supported rather differently in mainland China and in Hong Kong. Hong Kong University of Science and Technology (HKUST) is a center for microsystem research focusing on micro/nano fabrication technology, devices and integrated systems, MEMS packages as well as basic physics. In particular, the Nanoelectronics Fabrication Facility (NFF) at HKUST is the first microfabrication laboratory established at a higher-education institution in Hong Kong. The mission of the NFF is to provide facilities for the faculty and students of the University to conduct teaching, research and industrial services. Currently, there are about 80 projects covering the many interdisciplinary research areas including: MEMS, flat panel displays, biochips, advanced Ultra-large Scale Integrated (ULSI) circuit devices and technologies, RF and power integrated circuits, advanced electronic packaging, nanoscience and technology, sensors and actuators.

At the Chinese University of Hong Kong (CUHK), the Center for Micro and Nano Systems (CMNS) was established by the Department of Electronic Engineering (EE) and Department of Automation and Computer-Aided Engineering (ACAE) under the Faculty of Engineering to explore the science and engineering knowledge related to MEMS and NEMS fabrication, and to develop MEMS and NEMS devices with local high-tech industries viable for commercialization. The mission of CMNS is to establish processes and instrumentation technologies for research and development related to micro and nano systems. The Center provides a physical infrastructure devoted to developing micro and nano structures, which complements the existing MEMS, microelectronics and material sciences facilities in the Faculty of Engineering and Faculty of Science. CMNS is the first entity in Hong Kong dedicated to the research and development of micro and nano sensors and actuators that can be used for diverse applications in information, bio, and nano systems.

China's national nanotechnology strategy was formulated quickly in response to the US's announcement of its National Nanotechnology Initiative (NNI). China had conducted some materials research under a series of government programs since the 1980s, and the national strategy has been designed to build upon the existing research base, launch new programs, and construct new research centers equipped with state-of-the-art facilities. Coincidentally, China implemented science and technology policy measures to change its "national innovation system" to make research effort more relevant to industrial and socio-economic needs. As a result of such transformation, research collaboration between academic institutions and industry is being encouraged, and university spin-off companies have been founded to commercialize research results. In the field of nanotechnology, two major national centers for nano science and technology have been established in Beijing and Shanghai. The Chinese government has

aggressively recruited Chinese scientists who had worked in leading research institutes abroad to lead new research departments in such national nanotech centers.

In mainland China, MEMS research gained support from government agencies under 5-year Plans during the 1990s. Funding agencies include the Ministry of Science and Technology, Ministry of Education, Chinese Academy of Sciences (CAS), National Natural Science Foundation of China (NNSFC), and the previous Commission of Science, Technology and Industry for National Defense (COSTIND). A decade of research funding for MEMS has resulted in the formation of several regions where MEMS fabrication facilities and research talents are clustered, which include the Beijing and Shanghai areas.

In Beijing, Peking University's Department of Microelectronics and Institute of Microelectronics have three institutes under their roof – ULSI Novel Device and IC Technology Institute, System On Chip (SOI) Institute and MEMS Institute. The National Key Laboratory of Nano/Micro Fabrication Technology in Peking University is a leading facility for MEMS. In addition, Tsinghua University's Institute of Microelectronics and Micro/Nanometer Technology Research Center are a major group in MEMS-related research with a standard 0.6-0.8 micron CMOS process line and novel micro/nano fabrication process modules. They carry out research on various topics ranging from pressure and acceleration sensors, optical switches, and RF MEMS devices to nano devices, bio chips, and micro fuel cells. In Shanghai, the Shanghai Institute of Microsystem and Information Technology (SIMIT) is one of the leading groups in MEMS research and conducts research on optical MEMS, communication system technology, and functional materials and devices, among others.

## 5. Conclusion

Long-term public support for MEMS research and development in Asia has resulted in solid research infrastructure equipped with state-of-the-art facilities and innovation clusters across the region. The main focus in strategic funding for MEMS has evolved from research and development of (and in some cases, absorbing knowledge on) baseline design and fabrication techniques to the test-manufacture of prototype devices and packaging technology for target applications that are relevant to the perceived market needs. A noticeable trend in recent years is the shift toward the use of microtechnology for biomedical applications, including high-throughput screening of drug candidates, blood analysis for diagnosis purposes, bio and chemical sensors for healthcare and environmental concerns, and prostheses such as an artificial vision.

Although Asian countries (ex Japan) were followers in MEMS and Microsystems development, the gap between the advanced nations and the developing nations in Asia has narrowed in science and technology. The latest information about science policies and technology development strategies travels very fast in the Internet age. Policy makers and scientists can quickly learn about priority areas abroad and implement similar programs in their home countries. Asian countries have been quick in responding to the global nanotechnology boom and constructed many research centers with latest equipment. Since many of such new research centers are led by scientists who recently returned from abroad, research topics are comparable to what are found in overseas research institutions. It is possible that well funded research groups in Asia can afford newer, more expensive equipment than their counterparts in Europe and the US. In other words, thanks to the recent national strategies on nanotechnology, a number of research institutions in Asia have become fully integrated into the world's leading-edge research community without much delay. This is a new trend.

In addition, like the rest of the industrial world, S&T policy makers have implemented measures to encourage university-industry collaboration in Asia. Even China has changed its "national innovation system" to make sure that research institutions cater to industrial needs. Government funded research institutions and universities in Asia seek to collaborate with companies at home and abroad. Singapore has been very active in this regard. Recently, an increasing number of foreign companies find it cost effective to sign work contracts with research groups in China. This trend has been accelerated by the move by foreign companies to set up their own research centers in China.

However, if we look at the current status of commercialization of MEMS technology in each country, the overall picture is not very bright. The growth of the MEMS market has been slow, despite many rosy projections published by market research firms. In Asia, Japan is the only country that has a sizable MEMS market at home, with many players in the automotive, IT, entertainment, and industrial sectors. Other countries are still striving to industrialize MEMS and nanotechnology. The good news is that Asia is the world's center for microelectronics packaging and home to mass production of many electronic systems. Therefore, it is highly likely that Asia will contribute to the growth of the MEMS industry at an accelerated rate thanks to the improved R&D infrastructure and diligent research workforce.

## Appendix

A list of selected universities and research institutes engaged in MEMS/NEMS research in Asia.

## Japan

| University/Institute | Research Topics |
|---|---|
| Tohoku University | - Microsensors and microstructures<br>- Ultra-high-density data storage<br>- Micro energy sources<br>- Biomedical devices<br>- Optical MEMS and Nano-scale optics |
| University of Tokyo | - Assembly technology<br>- Sensors and actuators<br>- Optical MEMS, Bio-MEMS, RF MEMS<br>- Nanotechnology |
| Tokyo Institute of Technology | - PZT thin film-based sensor<br>- Visual prosthesis<br>- Nanotechnology |
| Waseda University | - Microfluidics<br>- Nanotechnology |
| Toyohashi University of Technology | - Smart micro chips for health monitoring |
| Nagoya University | - Nano bio devices, Bio chip systems<br>- Anisotropic chemical etching of single crystal silicon<br>- 3D microstructures<br>- Sensors and actuators |
| Kyoto University | - Microengineering<br>- MEMS/NEMS integration |
| University of Hyogo | - X-ray lithography<br>- 3D microstructures |
| Kyushu University | - Electronic nose<br>- Bio-mimetic taste sensor<br>- Chemical sensors<br>- Nano heater/sensor<br>- Micro thruster |
| National Institute of Advanced Industrial Science and Technology (AIST) | - Sensor integration<br>- High aspect ratio fabrication process<br>- Smart materials<br>- Microfluidic devices<br>- Microfactory |

## Korea

| University/Institute | Research Topics |
|---|---|
| Seoul National University | - Implantable biomedical sensors (BioMEMS)<br>- RF wireless modules (RF MEMS)<br>- Integrated electro-chemical lab chip<br>- Inertial Measurement Units<br>- Electro Beam Lithography<br>- Wafer Level Packaging |
| Pohang University of Science and Technology (POSTECH) | - Microfluidics<br>- High aspect ratio MEMS<br>- Stereo Lithography<br>- Bio-MEMS<br>- Piezo-MEMS<br>- Micro System Integration<br>- Micro Manufacturing |
| Korea Advanced Institute of Science and Technology (KAIST)<br>Digital Nanolocomotion Center | - “Bio-inspired digital nano-locomotion devices and systems” – high-precision control and cost-effective manipulation of non-electrical information carriers (i.e. mechanical, thermo-fluidic, opto-radiative, biochemical energy, nano substances)<br>- PowerMEMS |
| Korea Institute of Science and Technology (KIST)<br>Microsystem Research Center | - Micro/Nano machining technology<br>- Micro/Nano biotechnology<br>- Microcomponent integration technology<br>- Micro/Nano robot technology<br>- Micro/Nano manipulation technology<br>- Flat panel display |
| Korea Electronics Technology Institute (KETI)<br>NANO Mechatronics Research Center | - Silicon micromachining<br>- LIGA<br>- Micro display<br>- Micro power technology<br>- Nanotechnology |

## Taiwan

| University/Institute | Research Topics |
|---|---|
| National Taiwan University (NTU)<br>Center for Nano Science and Technology | - NEMS Design – Design of nanoparticles used in high energy devices; Synthesis of fullerenes and carbon nanotubes<br>- NEMS Metrology<br>- NEMS Manipulation – Use SPM as a nano manipulator to move nano-sized particles<br>- NEMS Fabrication – Novel fabrication technologies using unique properties of nanofilms and nanoparticles<br>- Colloids and Interface Science & Technology |
| National Ting Hua University (NTHU) Institute of MEMS | - BioMEMS<br>- Optical MEMS<br>- RF MEMS<br>- Information Technology MEMS<br>- Nanotechnology (NEMS) |
| National Cheng Kung University<br>Center for Micro/Nano Science & Technology (CMNST) | - BioMEMS (Micro grippers for cell manipulation; Portable chip PCR system; Protein microarray; Integrated micro flow cytometer)<br>- Oxygen sensor<br>- 3D fabrication techniques for MEMS/NEMS<br>- Selective growth of ZnO nanowires<br>- Nanomaterials for solid oxide fuel cell<br>- Nanomaterials for dye-sensitized solar cell applications |
| Industrial Technology Research Institute (ITRI) | - MEMS technology development, licensing, and transfer<br>- Shared user facilities offering wet etching, dry etching and PECVD, PVD, photolithography, furnace, assembly and testing, bulk micromachining, packaging and testing, reliability testing, micro-electroforming, micro molding, and system integration capabilities. |

## Singapore

| University/Institute | Research Topics |
|---|---|
| National University of Singapore | - Nano/Micro fabrication<br>- Proton beam technology<br>- X-ray lithography<br>- Laser nanofabrication<br>- Advanced tool-based nano/micro machining<br>- RF MEMS, PowerMEMS |
| Nanyang Technological University<br>MicroMachines Centre | - MEMS, NEMS, and micro/nano fabrication (Material development, Process development, MEMS characterization, Micro sensors, Optical MEMS, BioMEMS, Microfluidics) |
| Institute of Microelectronics | - Fine pitch wafer level packaging technology<br>- System-in-packaging (SiP) technology (opto-electronic modules & optical interconnects, RF module, 3D SiP)<br>- Nano-structured materials and self assembly processes in packaging<br>- Microfluidics, labs-on-a-chip, patch clamps (for high-speed screening of drug candidates)<br>- Biosensors, healthcare sensors, bio imaging (for diagnosis) |
| Singapore Institute of Manufacturing Technology | - Microsystems packaging<br>- Prototypes of optical MEMS switch<br>- Packaging and assembly for optical MEMS components and subsystems<br>- Wafer-level packaging<br>- Prototypes of micro electrical power generation systems, including micro turbine engine and piezoelectric power converter |
| Institute of Bioengineering and Nanotechnology | - Microfluidics<br>- BioMEMS |

## China/HK

| University/Institute | Research Topics |
|---|---|
| Peking University, Department of Microelectronics & Institute of Microelectronics<br>National Key Laboratory of Nano/Micro Fabrication Technology | - High aspect ratio silicon etching<br>- Wafer bonding<br>- Accelerometers<br>- Gyroscopes<br>- Tunable capacitors<br>- Micro relays<br>- Chemical sensors |
| Tsinghua University, Institute of Microelectronics & Micro/Nanometer Technology Research Center | - Sensors and actuators<br>- Nano devices<br>- Biochips<br>- Micro fuel cells |
| Shanghai Institute of Microsystem and Information Technology, CAS | - Optical MEMS<br>- Communication technology system<br>- Functional materials and devices |
| Hong Kong University of Science and Technology | - Basic physics<br>- Microfabrication technology<br>- Devices and integrated systems<br>- MEMS packages<br>- Silicon sensor design, modeling, fabrication, characterization, and process integration (solid-state gas sensors and integrated sensor technology)<br>- Nanofabrication |
| The Chinese University of Hong Kong Center of Micro and Nano Systems | - BioMEMS (polymer-based microactuators, microfluidic compoments)<br>- MEMS fabrication and assembly<br>- MEMS applications<br>- Nanotechnology (manipulation of carbon nanotubes) |