Exciting product

MEMSland, the first and for a long time largest programme under the Point-One flag has come to an end. In the Closing Symposium, held on 3 December 2009 at TNO's in Eindhoven, the Netherlands, project leaders, participants and others looked back at an extremely successful programme. The co-operation between small and large companies, universities and research institutes was exemplary, resulting in a series of promising business cases, and the Netherlands was firmly put on the MEMS map. However, MEMSland has not yet led to a net increase in MEMS-related jobs.

• *Jan Kees van der Veen* •

MEMSLand

In his opening speech, Jan Eite Bullema of TNO, host of the meeting, stated that the MEMSland programme has given our country a headstart in MEMS and that the Dutch industry is ready to take its share of the expected multi-billion dollar market for MEMS products. Fred van Roosmalen, vice chairman of the Point-One innovation programme for nano-electronics, embedded systems and mechatronics, added that MEMSland is a benchmark for collaboration between companies, universities and research institutes. It is exactly the kind of ecosystem that innovation programmes like Point-One wish to create and MEMSland can, as such, be considered as Point-One in a nutshell.

Point-One vice president, Fred van Roosmalen: "MEMSland is a benchmark for collaboration between companies, universities and research institutes."

ideas, challenging industrialization

During the symposium a selection of successful MEMSland business cases and technology demonstrators was presented. Two business cases (Anteryon's WaferOptics technology and Bluebird's IC packaging) will feature in forthcoming issues of Mikroniek.

Successful in many ways

"Not only was MEMSland a successful programme", stated Peter Magnée, overall MEMSland project leader, looking back at four intensive years, "but it was fun to do as well!" When the programme started back in 2006, its main objective was "to develop, on a national scale, key competencies and technologies for cost-effective MEMS packaging solutions". Companies, universities and institutes were to work together in a number of concrete MEMS development projects, build international partnerships, create knowledge, and recruit and educate people. End target was to realize a sustainable MEMS innovation environment and a strong competitive position of the Netherlands.

Overall MEMSland project leader, Peter Magnée: "Not only was MEMSland a successful programme, but it was fun to do as well!"

At the end of the MEMSland programme, not all business cases have resulted in business (yet), but all have contributed to new MEMS technical know-how. Business case participants exchanged experiences within the framework of seven work packages: technology platforms and business carriers; functional modeling and design; wafer processing and packaging; material characterization and design for reliability; design for manufacturability and

What is MEMS?

MEMS stands for Micro Electro-Mechanical Systems. Another term, often used in Europe, is MST (Micro-Systems Technology). In MEMS, electronic and mechanical engineering – and, incidentally, other disciplines like optics, chemistry and biology – meet at micrometer scale. MEMS covers a broad range of (mechanical, optical, etc.) sensors and actuators with sizes < 1 mm or even < 100 μm, normally integrated in an IC package with additional electronics for processing or communication. If dimensions get smaller, below micrometer-scale, we speak of NEMS (Nano Electro-Mechanical Systems). The biggest issue for MEMS is the packaging: building a working prototype is nice, but the real challenge is cost-effective mass production of reliable products. Where possible, one uses (with special tricks) the well-known and -controlled CMOS-IC process, used for 90% of electronic integrated circuits, but for many MEMS dedicated solutions have to be developed. Often these solutions are also derived from proven semiconductor technology for mass production. The worldwide MEMS market will hit $10B by 2011, doubling from $5B in 2005.

Examples of successful MEMS:

- accelerometers, as used in airbags and in the Nintendo Wii;
- digital micromirror devices, as used in video projectors (Digital Light Processing, DLP);
- pressure sensors for many applications;
- microphones for hearing aids;
- nozzles for inkjet printing.

testability; fast prototyping and industrialization; and dissemination.

When MEMSland started, the initiators had five objectives in mind. Magnée elaborated on these objectives and on the extent to which they have been achieved.

- Put the Netherlands on the MEMS map
  Yes. Publications on various MEMS topics were received well in the world and made our country visible in MEMS. Striking examples are the MEMS-XO Oscillator with world-record Q-factor and BAW (Bulk Acoustic Wave) filters.
- Create new employment
  New jobs were created in MEMS innovation activities, but overall employment in MEMS remained stable. In view of the global crisis this can be considered positive. The step to large-volume manufacturing was not taken; the road to industrialization in Europe is hard!
- Align universities/institutes and industry
  Yes. Cooperation was excellent. Strong and sustainable contacts resulted.
- Stimulate small / medium-sized enterprises
  Yes. Participation of SMEs in the consortium was strong. There was good cooperation between SMEs and large companies like Philips and NXP.
- Contribute to MEMS standardization
  No. MEMS have appeared to be too diverse to be caught under one standardization umbrella. Internationally, this is not a big issue anymore.

Magnée also indicated some pluses and minuses of the MEMSland programme.

+	-
• The co-operation between the partners at business case/ demonstrator level. • The involvement of the SMEs. • Effectively bridging the gap between research demonstrator and industrial prototype. • The 39 scientific publications. • The fun!	• The delays in decisions and approvals. • The administrative burden, particularly the yearly financial reports. • The rather disappointing interaction between participants at work package level.

RF-MEMS

Mobile phones are the driving force behind many developments in electronic miniaturization. One is radio-frequency (RF) MEMS switches. Modern mobile phones have to be able to operate in many frequency bands: GSM, UMTS, WLAN, Bluetooth, GPS, and others. Current state of technology is that a phone has separate RF-circuitry for each band, but it would save space and power, both precious in a mobile phone, to have just one circuit tunable to different frequency bands.

An RF-MEMS switch makes this possible, as explained by Marcel Giesen from Epcos Netherlands in Nijmegen. In fact, it is a miniaturized variable capacitor with moveable top electrode. By applying a DC voltage the two electrodes move towards each other and the electrical capacitance sharply increases; see Figure 1. Electrical characteristics meet RF-requirements (high C_{on}/C_{off} ratio, low losses, high power handling and high linearity). CMOS switches cannot meet these requirements and are unusable. By combining a number of these switches and placing them in the antenna circuit the resonant frequency can be modified to accommodate various frequency bands.

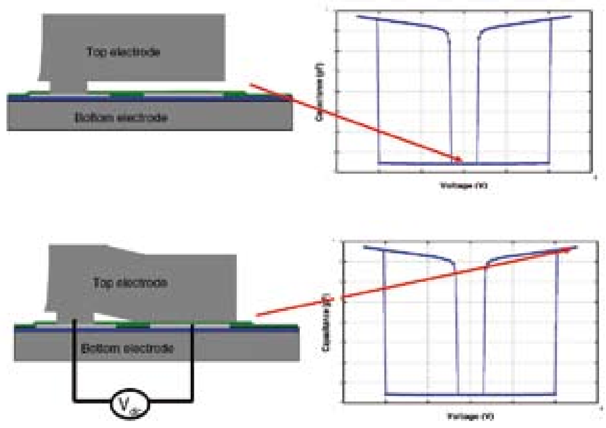


Figure 1. The principle of operation of an RF-MEMS switch.

The RF-MEMS idea is not new. It has for 15 years been a promise, but proved to be too tough to fulfil, until now. Most companies have stopped their activities in this field, mainly due to reliability issues. Epcos Netherlands (originally an NXP development group) has succeeded, within the MEMSland project, but it required many cycles in the development process, perseverance and a lot of time, far more than planned. One of the big issues, solved after several research efforts, was the technology to be used for the sacrificial layer, the layer between the two electrodes that, at a certain moment in the process, is removed ("sacrificed"). Big lesson learned: reliability starts day one of MEMS device development. Reliability testing of early samples is key to steer technology development and it is necessary to have one FTE (full-time equivalent) staff available over the entire project for testing hardware and software.

The outlook for business success of RF-MEMS is excellent. Without MEMSland it would have been impossible to successfully complete this project, considering the long development time and the changing business environment.

Gas chromatography

Another MEMS application is gas chromatography. Vincent Spiering from Enschede-based company C2V presented the C2V-200 micro GC (= Gas Chromatograph). Using MEMS technology, size and weight of the instrument could be brought down an order of magnitude compared to conventional GC's: hand-sized instead of table-top size; see Figure 2. In addition, analysis can be done faster (30 seconds instead of 30 minutes), quality of the result is higher and cost of ownership is lower. Within the MEMSland project a series of demonstrators was built, like the micro TCD (Thermal Conductivity Detector) in 2007, the micro GC cartridge in 2008 and again in 2009, and integrated chip moulding in 2009.
The compact instrument opens up many new application areas for GC and the commercial outlook is excellent (C2V has recently been acquired by US multinational company Thermo Fisher Scientific).

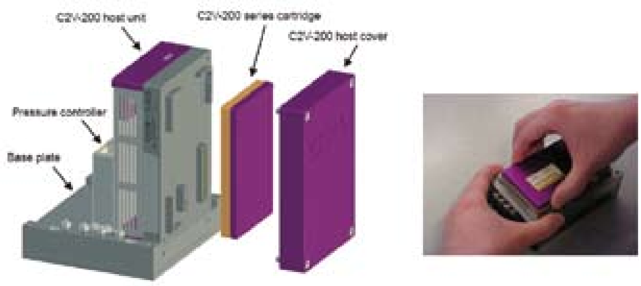


Figure 2. C2V reduced a gas chromatograph to hand size in a MEMSland project.

Liquid metal alloy interconnects

Integrating electronic systems on one chip (SoC) has a disadvantage: above a certain complexity the cost per function and the time to market increase dramatically, see Figure 3. Other, more flexible solutions like System in Package (SiP) or 3D packaging then are preferable. But this requires flexible bonding solutions as well. As set forth by Erik Veninga, TNO has, within MEMSland, done research into a flexible low-temperature bonding solution, using a liquid metal alloy.

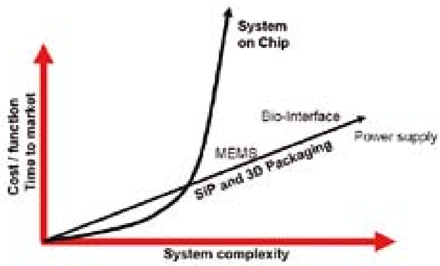
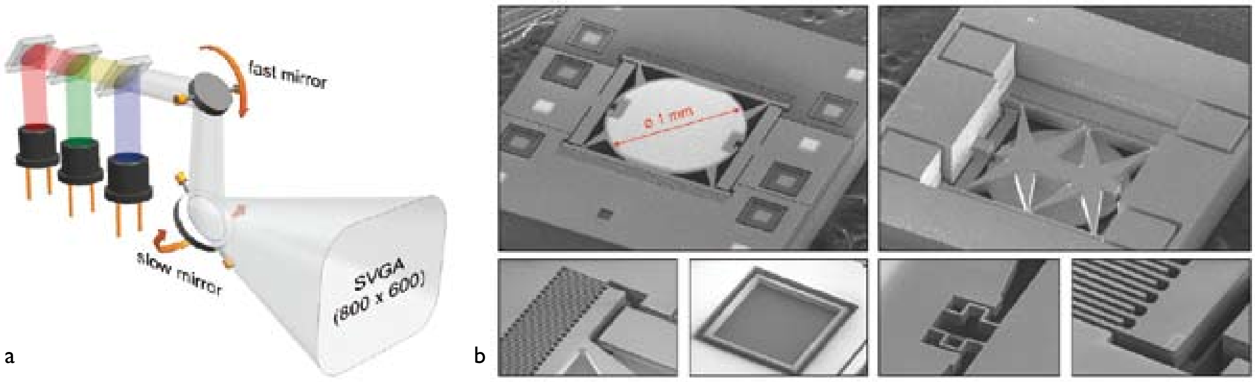


Figure 3. Cost per function and time to market of MEMS increasing with complexity. (Source: Fraunhofer IZM, Berlin, Germany)

The alloy chosen is a Gallium-Indium eutectic composite solidifying at 15.3 °C. Bonding can be done below 100 °C, which offers several advantages: no high-temperature induced reliability issues, easy repair/reuse/prototyping, no problems with CTE mismatches (CTE = Coefficient of Thermal Expansion), and possible use of low-cost materials and heat-sensitive components. Electrical and thermal conductivity of the alloy are reasonable. There was one disadvantage: the interconnection process had to be entirely redesigned. TNO developed a method where cavities are created in the substrate, the cavities are filled with alloy and flip chips are placed upon them and finally glued. The substrate can also be foil material. The first results are promising but a lot of research is still required.

MEMS mirror for miniature laser projection

The miniprojector is a hot new product, applicable in for example cars (head-up display), mobile phones, cameras, laptops, etc. Nikon was the first in September 2009 to launch a camera with built-in miniprojector. Miniprojectors are based on LED beamers, which is a rather bulky concept. As explained by Diederik van Lierop from Philips



a b

In a MEMSland project, Philips Applied Technologies developed the new concept of a miniprojector based on a laser and two scanning mirrors.
(a) Principle of operation.
(b) Realization of the scanning mirror in MEMS.

Applied Technologies, a miniprojector based on a laser and two scanning mirrors can be made much smaller. Additional advantages are high power efficiency, higher contrast, infinite depth-of-focus and lower cost in the long run.

As a MEMSland demonstrator project, full-color miniature laser projection was studied, targeting SVGA resolution (800 x 600 pixels) and a projection module size of only 6 x 8 x 16 mm^3. Scanning is done with two MEMS mirrors (Ø 1 mm, one resonating at > 18 kHz). However, available MEMS mirrors did not meet the requirements: many mirror designs had mechanical shortcomings or neglected basic mechanical design principles. Thus, a new design had to be made; see Figure 4. In collaboration with MEMSland partners, modeling and verification studies were done on control loops, capacitive measuring system, non-linear dynamics, etc. Simulations corresponded nicely with measurements conducted on a prototype.
Collaboration with the partners was fruitful, and essential to achieve these results.

MEMS oscillators

Since several decades, the quartz oscillator is the standard timing reference, the "beating heart" for numerous electronic applications where frequencies must be highly accurate and thermally stable, like radio, TV, watches and computers. With on-going miniaturization the disadvantages of quartz become more and more apparent: quartz crystals are (very) large compared to modern ICs, they are hard to integrate on a chip (System on Chip) or in a package (System in Package) and they are relatively expensive. MEMS oscillators will be the solution to this problem, as explained by Joost van Beek of NXP.

The heart of a MEMS oscillator is a resonating beam in a cavity. The size of the cavity depends on the frequency range and is typically 30 µm high and 100 to 500 µm wide/long. The cavity is vacuum-sealed, pressure inside is below 10 mbar. MEMS resonators can be made on silicon wafers, using regular IC production technologies, with special process steps added. For example, sacrificial layers have to be made, and removed later on in the process to create a cavity. The process is quite complex and took considerable time to develop. On a 200 mm wafer more than 100,000 devices can be made.

MEMS resonators are small (for example a 15 kHz MEMS resonator is 0.4 x 0.4 x 0.15 mm^3 compared to 2.5 x 2.5 x 0.55 mm^3 for a quartz resonator), cheap and scalable, and they allow integration with driving and other electronics in a package. Electronic performance is nearing low- and mid-end quartz: high Q (e.g. ~100.000 for a 26 MHz resonator), low phase-noise, high manufacturing accuracy and low temperature drift.

MEMS oscillators are a disruptive technology in a well-established and growing timing market. NXP and its partners have managed, thanks to MEMSland, to obtain a good position in this estimated 100 M$ market.

Discussion

A plenary discussion, moderated by Jan Eite Bullema, was held to close the symposium.
Some conclusions:

- "No one expects that MEMS technology will create substantial numbers of high-tech jobs in the Netherlands at short term, but maybe in a couple of years. The small companies (start-ups) will have to be the engines in creating new employment."
- "To make MEMS business in the Netherlands more than an academic success, students have to be drawn into it. Push the subject hard at universities. Stimulate entrepreneurship among students. Industrialization is a big problem in our country, it will be extremely hard to

Jan Eite Bullema of TNO, host of the meeting, moderated the concluding discussion of the MEMSland Closing Symposium.

"fill a MEMS foundry", so production will probably go abroad."

- "Creating a MEMS Institute to pull science out of the lab into new products, sounds like a good idea, but there is scepticism whether this will work. What we really, really need is entrepreneurs."
- "Subsidies to make large companies, small & medium-sized companies (SMEs), universities and research institutes work together to make MEMS business more successful are ok to get things "moving", but in the end we should be able to do without them…..!"

Author's note

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MEMSland facts & figures

- First and largest R&D programme under the Point-One flag.
- Programme objective: to develop and integrate all key competencies and technologies for the development of a comprehensive MEMS packaging solution.
- Programme duration: 3.5 years (June 2006 ~ December 2009).
- Total programme 36 M€; Point-One funding 14 M€.
- 22 Partners (universities, institutes, large companies, SMEs)
- Programme organised in seven business cases and four demonstrators, as "carriers" for MEMS knowledge development.

Business Case (BC) / Demonstrator (D)	**Participants (the first partner mentioned is in the lead)**
BC1 BAW filters	NXP, ALSI, Philips Applied Technologies (Apptech), University of Twente
BC2 RF MEMS switch	Epcos, NXP, Fraunhofer
BC3 MEMS XO Oscillator	NXP, Eindhoven University of Technology, Bruco
BC4 microGC gas analyzer	C2V, ALSI, Boschman, AppTech
BC5 Non-volatile memory chip	Cavendish Kinetics, ALSI, IMEC
BC6 Optical sensor	Lionix
BC7 1×32 info planar splitter	Lionix, Boschman, MA3 Solutions
D8 Miniature camera packaging	Anteryon, Boschman, MA3 Solutions, TNO
D9 Fingerprint and pressure sensor	Boschman, TNO
D10 Scanning mirror	Philips AppTech
D11 Large area micro assembly	TNO

www.memsland.nl