SINTEF REPORT

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Final Activity Report

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ABSTRACT

The microBUILDER consortium has established a flexible manufacturing service for polymer-based and silicon-based microsystems. The technologies and their applications are described in a master design handbook and training material. The service has been actively disseminated and the technologies have been used by both European and non-European companies.

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µBUILDER

An integrated modular service
for microfluidics

µBUILDER

INTEGRATED PROJECT
CONTRACT NUMBER: IST-027175

SIXTH FRAMEWORK
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Abstract:

The microBUILDER consortium has established a flexible manufacturing service for polymer-based and silicon-based microsystems. A standard method for silicon-polymer integration has been established. Mixed technologies for e.g. bio-functionalization of surfaces and biocompatible sealing of polymer chips or functional layers for miniaturized pumps, valves and sensors has been established and tested. These mixed technologies increase, the functionality of the microsystems. The technologies and their applications are described in a master design handbook of almost 500 pages. Training material for self learning and courses are also available.

The consortium has mainly concentrated the marketing activity to the fields within microfluidics, where microBUILDER technologies are suitable for e.g. lab-on-a-chip applications, drug delivery systems, miniaturized pumping, inkjet actuators, miniaturized valves, sensor systems (gas sensors, biosensors), and medical devices. The service has been actively disseminated trough six arranged workshops with different themes, presentations at many conferences and fairs, and most of all by direct customer contacts and discussions on the feasibility of using microBUILDER technology for the companies development. The service and technologies have been used by both European and non-European companies and by universities worldwide.

The developed microBUILDER technologies, design handbooks, software and training material will be available through the continued microBUILDER web-page and through the partners after the end of the project. This report provides information on the technologies and the work performed in the project.

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microBUILDER Consortium

microBUILDER (Contract No. 027175) is an *Integrated Project* within the 6th Framework Programme Priority 2 IST-2004-2.4.2 - Technologies and devices for micro/nano-scale integration. The consortium members are:

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2009-09-20	1.0	Liv Furuberg	First version

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1 Introduction

This report sums up the results from the microBUILDER project that was funded by the European Commission (IST-027175) in the period April 2006 to September 2009.

This report is divided into two parts. The first part gives an overview of the technologies, design handbooks, modelling tools and training material that have been developed in microBUILDER. This first part is useful for SMEs and universities wanting to take advantage of the developed technologies and design / training material, also after the end of the project. Part two of this report describes the technologies and the work performed in the project in more detail.

microBUILDER is a consortium of nine European partners having many years of experience in developing and manufacturing diverse products based on microsystem technology. microBUILDER offers industry as well as academic users easy access to manufacturing services ranging from prototyping to series production. The goal behind this offer is to facilitate the use of micro and nano technology in the development of new and innovative products with a focus on microfluidics applications.

The core offer is silicon and polymer fabrication processes that are supplemented with additional technologies needed for functional devices such as biological surfaces and piezoelectric coating for actuators. Polymer and silicon chips can also be integrated for reduced cost and optimal functionality.

The microBUILDER consortium offers a standardized microfluidic development platform for standardized chip-to-world fluidic connections, based on the polymer fabrication technologies offered by thinXXS. Different fluidic modules can be combined to a complete fluidic handling system. To complete the service portfolio, microBUILDER provides CAD and modelling tools, design & engineering services as well as dedicated training courses.

The consortium has mainly concentrated the marketing activity to the fields within microfluidics, where microBUILDER technologies are suitable for e.g. lab-on-a-chip applications, drug delivery systems, miniaturized pumping, inkjet actuators, miniaturized valves, sensor systems (gas sensors, biosensors), and medical devices. The service has been actively disseminated trough six arranged workshops with different themes, presentations at many conferences and fairs, and most of all by direct customer contacts and discussions on the feasibility of using microBUILDER technology for their development. The service and technologies have been used by both European and non-European companies and by universities worldwide.

1.1 Vision and objectives

When the project started in 2006 the project had the following vision and objectives:

Vision

The vision of microBUILDER is to increase the commercial success and competitiveness of European SMEs by introducing mixed technology devices and sub-systems as key components in their products. microBUILDER should establish a one-stop shop for easy access to the technology.

Scientific objective

To lower the threshold for SMEs and academic users to develop prototypes and products based on silicon / Glass / polymer / mixed micro technology, with microfluidics as a key application area.

Commercial objectives

- To provide cost efficient access to mixed-technologies based on:
  - silicon/glass technology through standard and semi-custom multi project fabrication,
  - polymer technology,
  - various qualified add-on processes, like bio-functionalization, functional films, hydrophilisation, etc.,
- To allow easy access to qualified microfluidic components and systems through a modular development platform
- To establish a commercial infrastructure for design & engineering services, advanced tools and mixed technology manufacturing through one single customer interface
- To develop pre-normative standards for the integration of different components and technologies, specified in a master design handbook
- To undertake joint promotion and training activities in order to ensure that the service will be able to reach the whole European market.

1.2 Results achieved

The microBUILDER project has established a set of micro technologies that are essential for microfluidic applications. The technologies have been made available for and used by customers for manufacturing of prototypes or products. The application examples of the technologies are e.g. medical sensors and pumps, in-vitro diagnostic platforms based on lab-on-a-chip, miniaturized and automated chemical analysis platforms and cell positioning systems.

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PART I: microBUILDER technology and service offer

The microBUILDER consortium has established manufacturing processes for mixed technologies. Based on discussions with workshop participants and current and potential customers, on what they need for the next step of their product development, a set of technologies have been chosen. Some of the mixed technologies have been proven to work integrated in the ThinXXS microfluidic construction kit modular platform by demonstrators.

This first part of the report gives an overview of technologies, design handbooks, modelling software and training courses, as well as the microBUILDER model for customer handling during the project and after October 2009.

2 Overview of the manufacturing technologies

The key microBUILDER technologies, products and services are:

- Microfluidic construction kit for fluidic integration of several polymer slides (with or without silicon chips)
- Silicon sensor / actuator microfluidic integration in polymer chip
- Silicon / glass Multi Project Wafer and custom runs
- Polymer chip manufacturing
- Mixed technologies for enhanced functionality of polymer and silicon chips:
    - Bio-layers for specific binders, surface modification of polymers, gold and Silicon dioxide
    - Biolayers for anti-binding (polymers and silicon dioxide)
    - Dried reagents storage on-chip
    - Hydrophobic patterning of micro-channels
    - Biocompatible sealing of polymer chips
    - PZT piezoelectric thin films (MoveMEMS)

Some of the possible combinations of the technologies are visualized in the following figure (next page).

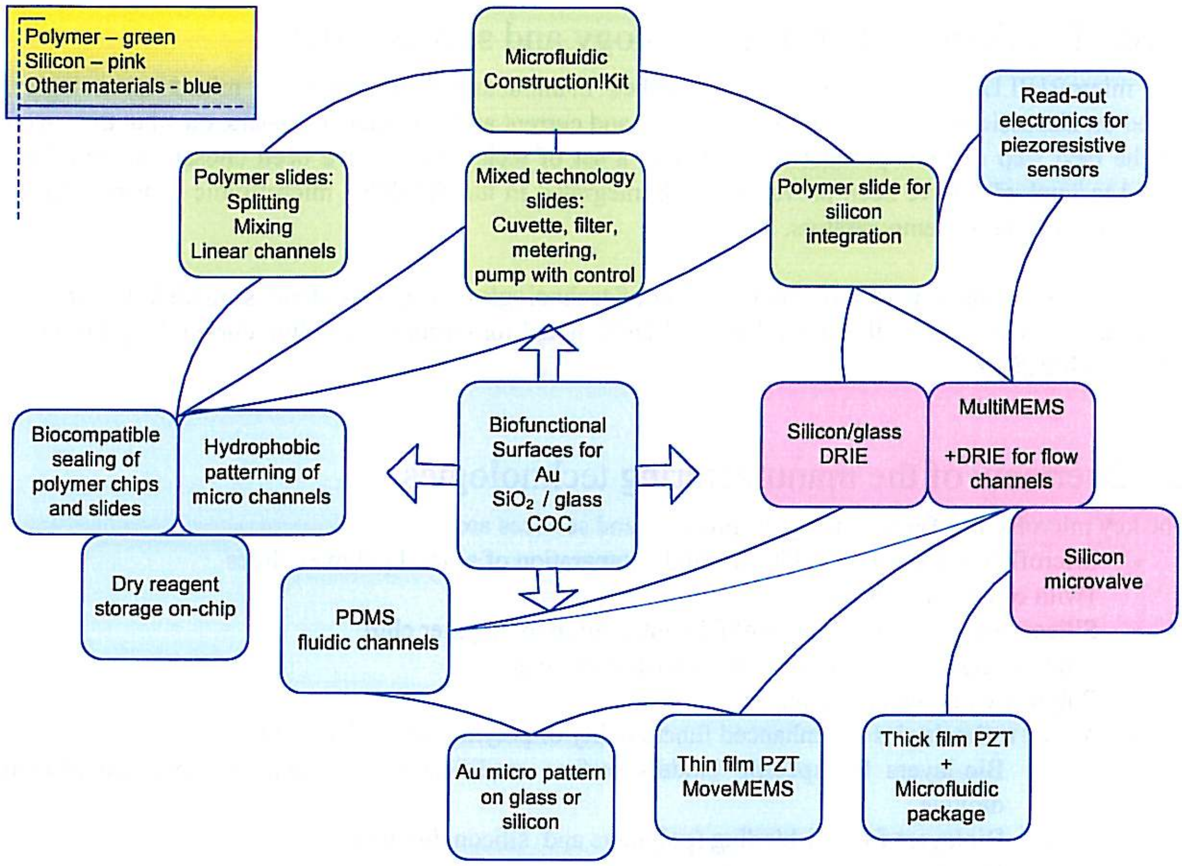
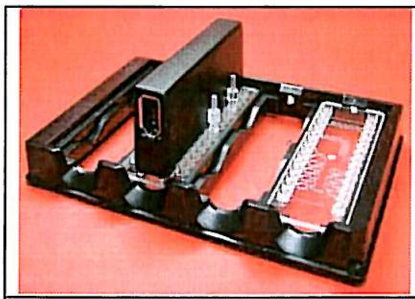
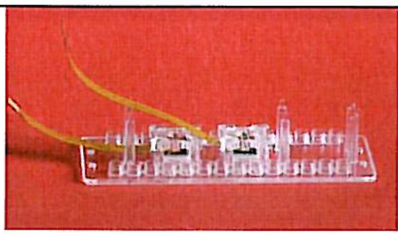
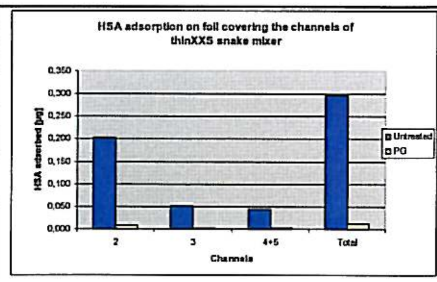


Figure 1: The green boxes are the ThinXXS polymer construction kit, the polymer slides and the mixed technology slides. One of the new slides is a standard polymer slide for integration of silicon sensors / actuators that only functions in contact with a liquid. The three silicon manufacturing technologies are shown in pink. Elements manufactured in SensoNor MultiMEMS +SINTEF and Tronics DRIE have been integrated in polymer chips. All the blue mixed technologies based on other materials can be combined with standard silicon processes, standard polymer processes or both, adding enhanced functionality. Biofunctional surface activations have been developed for SiO2 / glass, for COC (co)polymer as well as for gold.

		
Microfluidic construction kit, showing a packaged flow sensor module and a mixer slide. Other available modules are pumps and filter slides.	The flow sensor module: two silicon flow sensors are integrated in a polymer slide and with electric wires. The polymer provides fluidic connections to the silicon.	The surfaces of Cyclic Olefin Copolymer (COC) microchannels and silicon surfaces (with native oxide) can be treated for reduced binding of proteins.

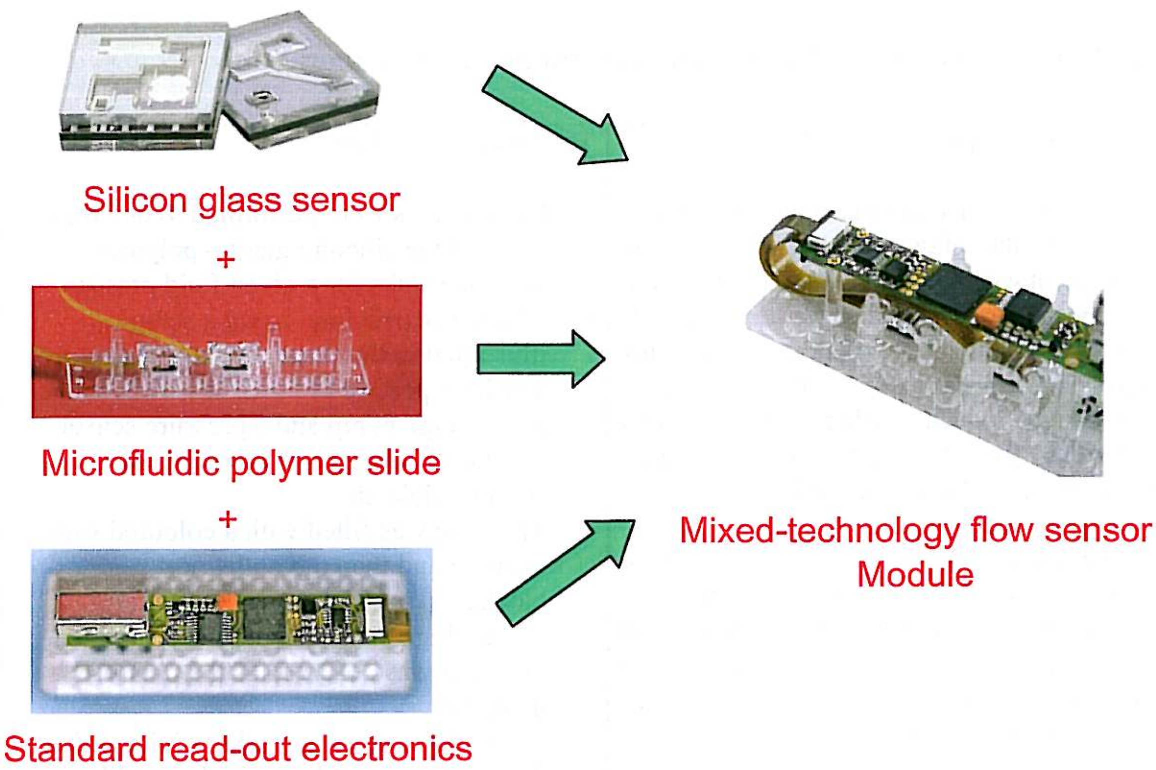
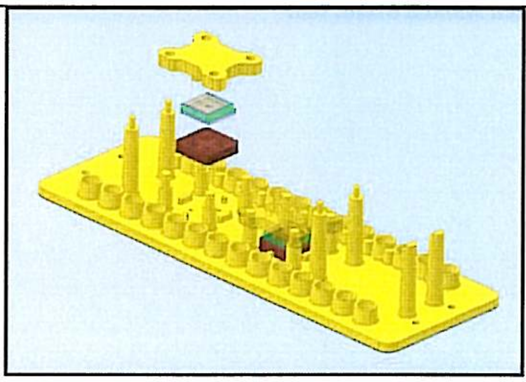
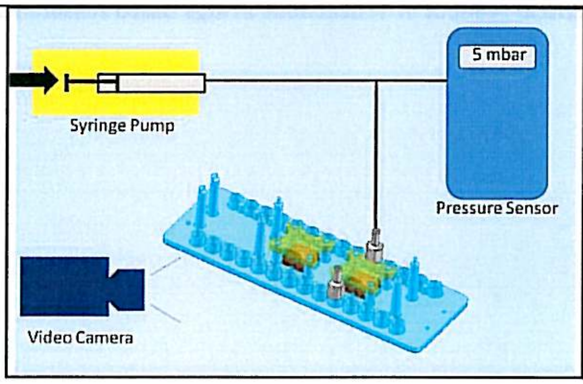


Figure 2: Can your sensor or actuator element be integrated in the fluidic integration slide? If needed, electrical readout of Wheatstone bridge based sensors has been standardized, too.

2.1 Standard polymer slide module for silicon / glass integration

Purpose / use / applications of slide	Test procedure of slide
The integration of other materials (e.g. silicon sensors) in the plastic module is one new development within the microBUILDER project. The module provides an established and cost-effective prototyping platform for any microfluidic application utilizing silicon / glass components, which adhere to standard dimensions for chip and fluidic openings described in part II of the design handbook. The standard design has space for two separate sensors. Sealing the sensor is accomplished by sandwiching an elastomeric gasket between the sensor chip and the fluidic slide. The clamp is held in place by a heat-fixing technique, which provides long-term compression of the gasket.	• Experiments were performed to determine whether the silicon / glass – polymer interface leaks for a given fluid pressure. • This was carried out using a setup illustrated in the figure below. • The inlet port on the slide was connected to a syringe pump and a pressure sensor via rubber tubing with a volume of compressible air. • The slide was filled with a coloured water solution and then the outlet port was blocked. • The syringe pump was activated and the interface was observed as the pressure increased. • With adequate compression of the gasket, the fluidic assembly was able to withstand 1bar (gauge).
 Image of the silicon/glass-polymer assembly.	 Image of test setup for leak-pressure testing.

3 Master design handbook

The microBUILDER master design handbook provides information on the manufacturing processes / procedures, material specifications, process parameters, and the layout rules for all microBUILDER technologies. In addition it describes the CoventorWare design kits for three microBUILDER processes and gives detailed examples on devices that have been designed using microBUILDER technology.

The microBUILDER manufacturing technologies available after the end of the project are, in short:

- SensoNor piezoresistive process (more flexibility is now available for the custom runs)
- Tronics MEMSOI process, DRIE and silicon valve processes
- ThinXXS polymer chip manufacturing
- Silicon / polymer integration
- SINTEF MoveMEMS piezoelectric process
- microBUILDER mixed technologies

The design handbooks are thus a good tool also after October 2009.

An overview of the valid versions of the different microBUILDER design handbook modules at the end of microBUILDER is given in the table below.

Module	Description	Version no	Date
Module Ia:	Introduction to the microBUILDER service, overview of manufacturing and add-on processes, and demonstrator design examples	3.0	April 09
Module Ib:	Silicon and Polymer integration	1.0	March 09
Module II:	MultiMEMS Multi Project Wafer manufacturing process (SensoNor Technologies)	4.2	March 09
Module III:	MicroBUILDER mixed technologies and add-on processes (including MoveMEMS)	2.0	April 09
Module IVa:	60 µm SOI High Aspect Ratio Micromachining (Tronics)	1.1	Sept. 06
Module IVb:	DRIE (Tronics)	1.0	April 09
Module IVc:	Silicon Passive Microvalves (Tronics)	1.0	April 09
Module V:	Plastics Molding Design Handbook (thinXXS)	2.0	Dec. 08
Module VI:	Microfluidics Construction Kit Design Handbook (thinXXS)	2.0	Dec. 08
Module VII:	CoventorWare Design & Modeling Tools for microBUILDER	2.0	April 09
Module VIII:	Device examples (SensoNor, Tronics, thinXXS)	5.0	Feb. 08

All parts of the design handbook are relevant also after the end of microBUILDER. The SensoNor MultiMEMS MPW will be stopped, but the process will be available on a custom-run base. The custom runs will give more flexibility than the process described in the MultiMEMS design handbook.

The master design handbook is an open document, with the exception of module II MultiMEMS (SensoNor) and one part of module III: MoveMEMS (SINTEF). These parts are available after signing a non-disclosure agreement (NDA). The master design handbook, or parts of it, is available from the partners or through the microBUILDER we page www.microBUILDER.org.

4 CoventorWare process design kits

Design kits are available in standard CoventorWare Designer software (also sold through EUROPRACTICE). Design kits are available for three microBUILDER processes:

- SensoNor piezoresistive process (previously MultiMEMS MPW)
- Tronics HARM SOI process
- SINTEF piezoelectric process (MoveMEMS)

The process design kits consists of a set of customized CAD files:

- Process file for detailed emulation/simulation of the manufacturing flows
- Material property database (process specific)
- Layout template and design rule check
- Example designs

Virtual prototyping based on detailed process emulation will is offered complementary to the process design kits. It allows the design review before actual fabrication.

Two detailed hands-on design tutorials have been developed for MultiMEMS and SOI-HARM.

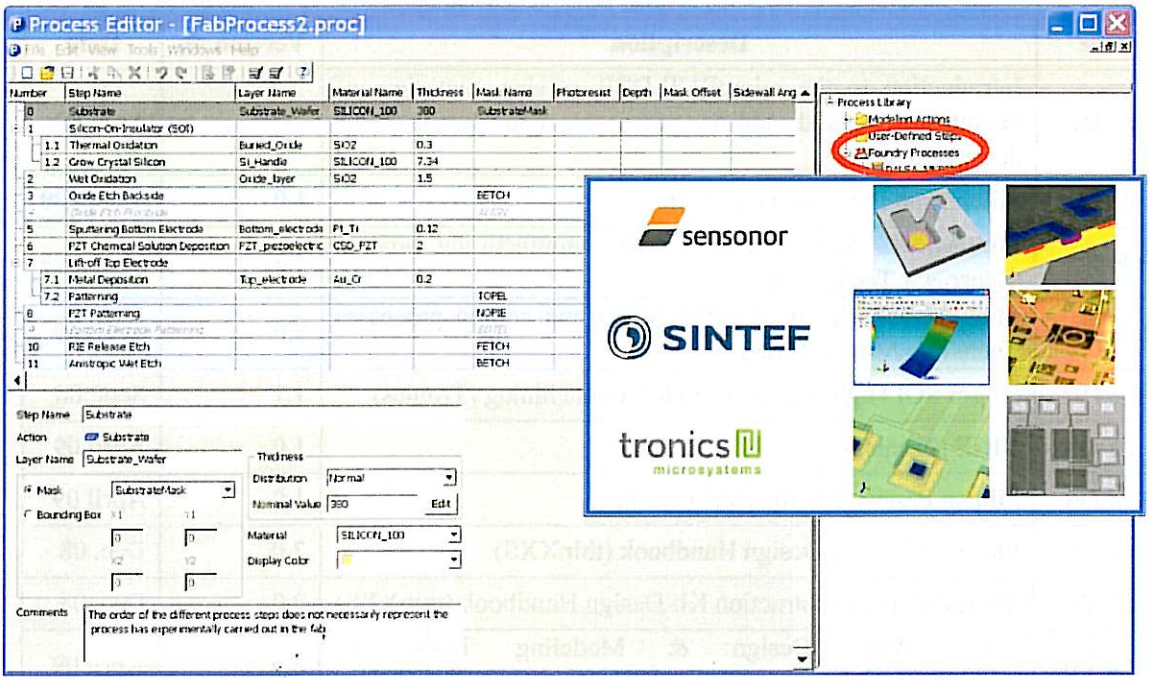


Figure 3: Library of MicroBuilder Processes implemented into Coventor's Process Editor (MultiMEMS, Tronics HARM SOI, SINTEF MoveMEMS PZT).

5 Training courses and training material

Training courses and training material for the microBUILDER technologies are available through contact with the partners, through the microBUILDER web page and through EuroTraining. Different types of courses and training material have been developed:

- In-depth technology courses on silicon, polymer and mixed technologies
- Hands-on design courses using CoventorWare and other state of the art software packages
- Six video-lectures available at the microBUILDER web page and on DVD
- Master education teaching material on technologies and microfluidics
- Web based training, at the microBUILDER web page

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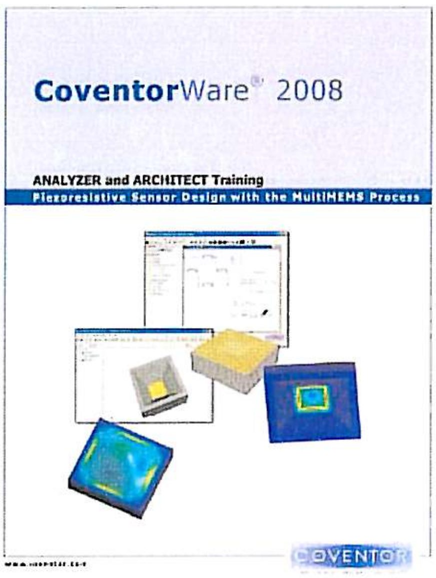
<td>
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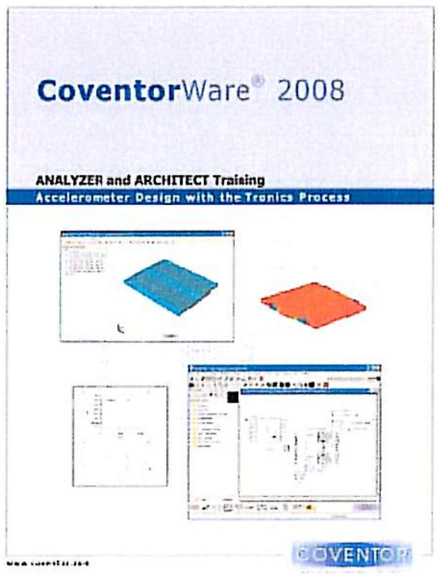
<td>
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<tr>
<td>Front page of 75 page design tutorial for the MultiMEMS foundry service/CoventorWare used for hands-on training</td>
<td>Front page of the 56 page design tutorial for the TRONICS foundry service/CoventorWare used for hands-on training</td>
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6 Examples of devices using microBUILDER mixed technologies

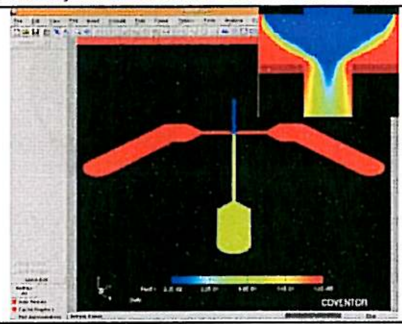
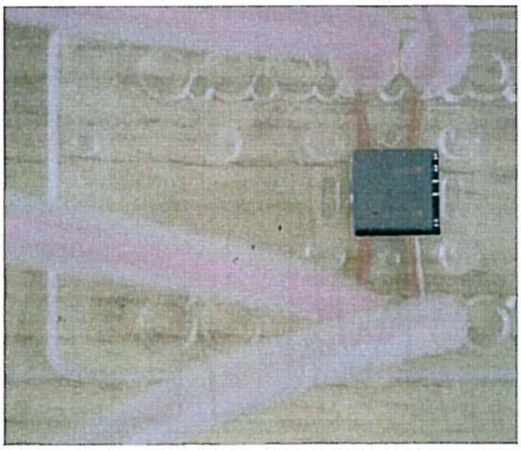
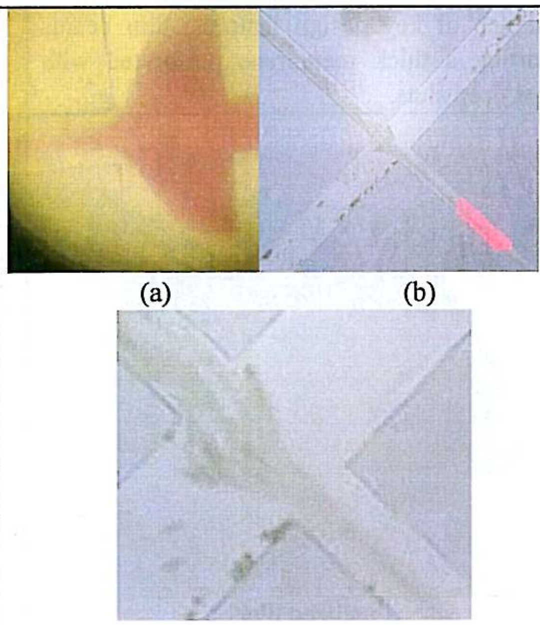
This section illustrates the combination of microBUILDER technologies by device examples. The examples help companies and universities to understand some manufacturing possibilities and inspire them to get ideas on new devices. All these examples and a few more can be accessed from the microBUILDER web page under the button "Examples of microBUILDER technology".

6.1 Hydrodynamic cell focuser for Red Blood Cell counting

The hydrodynamic cell focuser creates an ordered flow of cells, lining cells up in the centre of a micro-channel. The input to the focuser is a fluid sample containing cells. The hydrodynamic cell focuser has a microfluidic geometry shaped as a cross. The cell sample is inserted in a central channel and water is inserted in the two lateral channels. With controlled pressures and flow rates, focusing is induced, obtaining a "virtual" smaller fluidic channel. Previously the microBUILDER consortium manufactured a Coulter cell counter. The cell focuser and the cell counter are integrated in a new chip design. The focused flux is passed through two electrodes built in the microfluidic channel, where the cells are registered and counted.

The chip is planned to be a part of the sample preparation module in a full biochemical analysis including sample collection, preparation, reactions and detection. The device has been designed, modelled and manufactured within the microBUILDER consortium. The functionality of the chip has been tested on red blood cells. These activities have been developed in the frame of a wider project ("Telematic control system of patients for home chemotherapy") in cooperation with the Molinette Hospital of Torino.

The partners involved were
1. COREP: design and characterization
2. Coventor: device simulations
3. SensoNor: manufacturing using MultiMEMS technology
4. ThinXXS: silicon integration slide, microfluidic interconnections

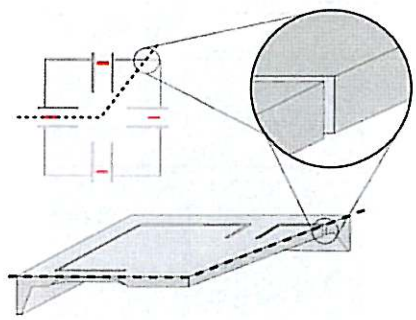
	
Chip schematic and photo of the chip	CoventorWare simulations of the cell focuser
	 (a) (b) (c)
The chip inserted in the ThinXXS system for microfluidic management	Experiments done with (a) red ink, (b) and (c) dog's red blood cells

6.2 Piezoresistive microphone for photo-acoustic gas detectors

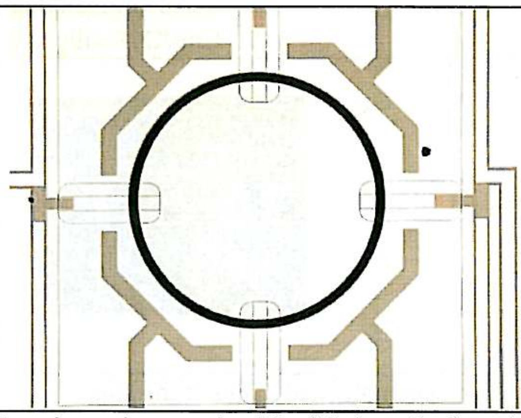
The piezoresistive microphones presented here for photo-acoustic gas sensors aims at decreasing the size and increasing the sensitivity for CO_2 monitoring in ventilation systems. Because the system must be small to fit inside the valves of the ventilation system, the commonly used method of signal enhancement, acoustic resonance cannot be used and hence must the microphones be even more sensitive if miniaturization is to be successful. By releasing the microphone membrane along its edges, compliance is increased. To further enhance low frequency performance, the openings resulting from the release should be as narrow and deep as possible. By combining the MultiMEMS MPW process and the DRIE process offered as a add-on by SINTEF, microphones with 23 μm deep opening along the membrane perimeter has successfully been fabricated. For these first generation devices, characterization shows a potential for very high performance microphones, but that challenges with respect to the frequency response, remains.

The partners involved were

1. VUC: design and characterization
2. COREP: design and characterization
3. SensoNor: manufacturing using MultiMEMS technology
4. SINTEF: DRIE add-on processing

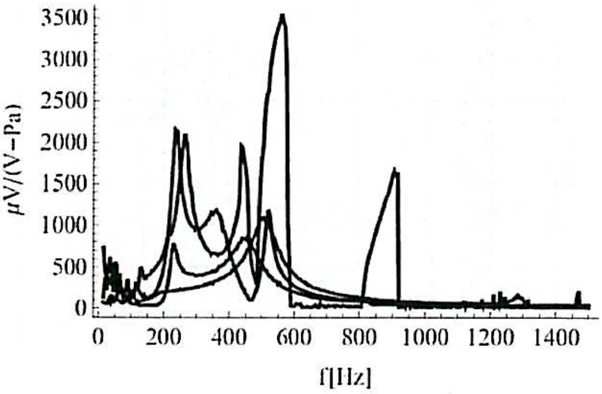


3D sketch of key design features: thin beams supporting a thick membrane perforated with narrow deep slots.



Top view micrograph of the fabricated microphone.

Finalized die.

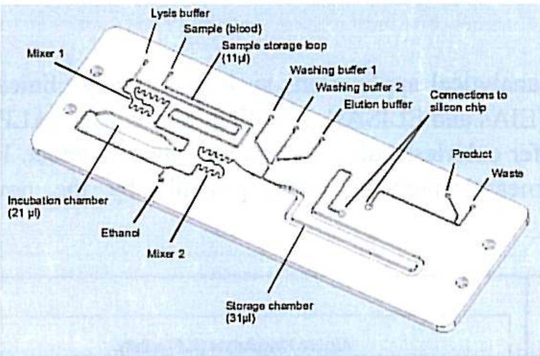


Measured sensitivity for 4 microphones
(a) red ink, (b) and (c) dog's red blood cells

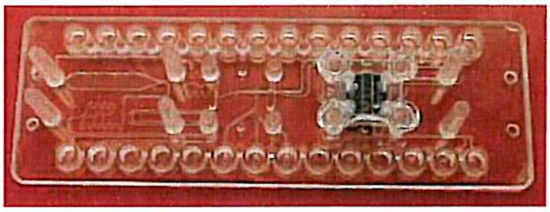
6.3 DNA extraction from whole blood in a polymer / silicon module

A DNA based analysis of a patient sample is based on a protocol with many operations: sample collection, cell concentration, DNA purification, DNA amplification, and finally detection. The ThinXXS microfluidic construction kit allows for modularization of these operations, so that e.g. DNA purification can be performed in one slide, while amplification is performed in the next.
The microBUILDER consortium fabricated and tested a polymer slide module for DNA extraction from whole blood samples.
The efficiency compared to a commercially available standard DNA extraction kit (Qiagen) was about 10% without any optimization or design iterations. The overall potential for further optimization and improvement was identified and could be tested and implemented in further development steps and design iterations.
The partners involved were

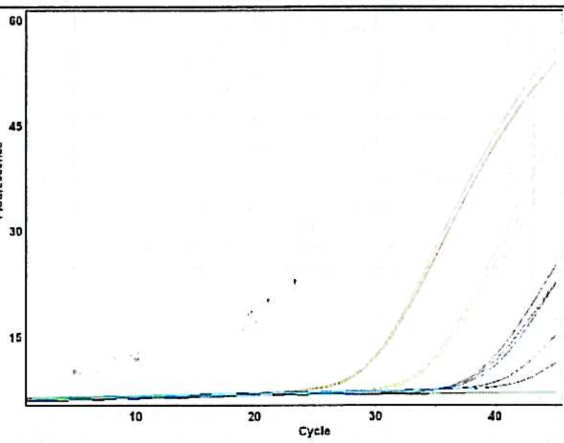
- HSG-IMIT: design and characterization
- Tronics: manufacturing of silicon chip using the microBUILDER DRIE process
- thinXXS: manufacturing of silicon integration slide, microfluidic interconnections and fluidic management

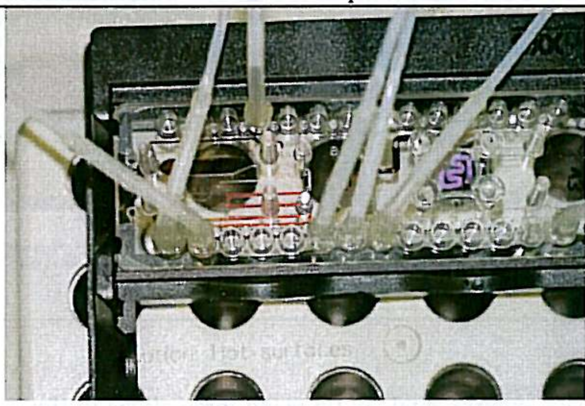


Design of the polymer module



Polymer module with integrated silicon chip with silicon dioxide pillars





Left: Results of qRT-PCR (quantification) of extracted DNA. Intensity fluorescence (normal scale) vs. number of PCR cycles. Colour code: yellow (a, b): reference extractions using commercial Qiagen Kit (a = 200 µL blood, b = 10 µL blood), blue ©: several extractions using demonstrator 2 (10 µL blood), green (d): negative control ("NTC"; no blood).
Right: The slide with fluidic connections for sample insertion, lysis buffer and wash buffers.

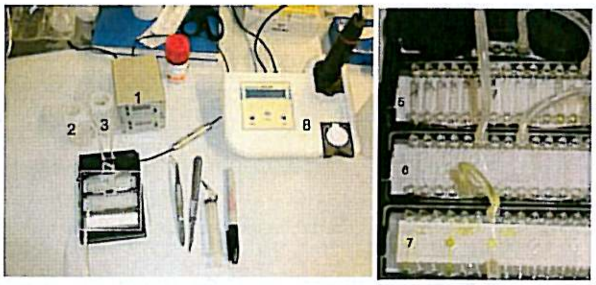
6.4 Test platform for bio-analytical assays

The "thinXXS Construction kit" contains basic microfluidic processing components such as a pump slide and polymer slides for mixing and splitting as well as fluidic connections between slides. The kit has through the microBUILDER project been further expanded with new slides with new functionalities. Further, mixed technologies as developed and supplied by microBUILDER partners have substantially expanded the usefulness of this kit as a basis for development and testing of a variety of new bio-analytical systems.

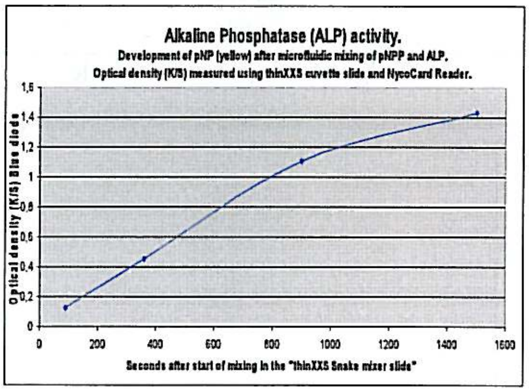
In the following is shown an example of how elements and mixed technologies as developed by different partners through the microBUILDER project fit together creating a useful toolbox for testing and designing bioassays into microfluidic systems.

- Three different slides of the Microfluidic Construction kit as supplied by **thinXXS** were combined: Snake mixer slide, Cuvette slide and Reagent slide of which the two last were designed within the microBUILDER project.
- A dry reagent formulation of an active enzyme, Alkaline Phosphatase (ALP), was prepared by **HSG-IMIT** and deposited in the reagent storage slide.
- Anti-binding treatments of the mixer- and cuvette slides, as well as the experimental set up were performed by **SINTEF**.

Measurement of optical density is widely used in bio-analytical applications such as in many clinical chemical assays and a variety of enzyme immunoassay (EIAs and ELISAs). Alkaline Phosphatase (ALP) is an enzyme used in a variety of assays as it can transfer colorless substrates into a yellow product. In this experiment the usefulness of precise colour measurement as made possible by the new microBUILDER technologies is demonstrated.



The figure shows the microfluidic set up including thinXX cunstructionkit with: Control unit 1) ,TBS (TRIS buffer Saline) 2) , pNPP substrate solution 3), pumps 4) , Reagent storage slide 5), Snake mixer slide 6) , Cuvette slide 7), NycoCard Reader 8) as well as the coloured response as obtained after enzyme and substrate mixing



The experimental set up using three slides in fluidic series and the results obtained show that the mixed technologies and the elements as developed by different partners within the microBUILDER consortium allow for transferring for example typical microtitre plate based assays into microfluidic designs.

6.5 Acoustic piezoelectric gas sensor

The reliable integration of piezoelectric thin films into MEMS is a key enabling technology for a wide range of future products. Examples include ultrasonic imaging transducers, pressure and flow sensors, accelerometers, acoustic wave devices, energy converters, micro-motors, micro-pumps, and micro-sensors for chemical analysis. Piezoelectric materials allow energy conversion between the electrical and mechanical domain. Several sensor structures utilize both the direct effect (conversion from the mechanical to the electrical domain) and the converse effect (conversion from the electrical to mechanical domain (i.e. actuation)).

Applications can be classified according to those employing:

- Solely the converse effect → Linear actuators, ultrasonic motors
- Solely the direct effect → Sensors, energy scavengers
- Both effects → Combined sensor/actuators, resonant transducers

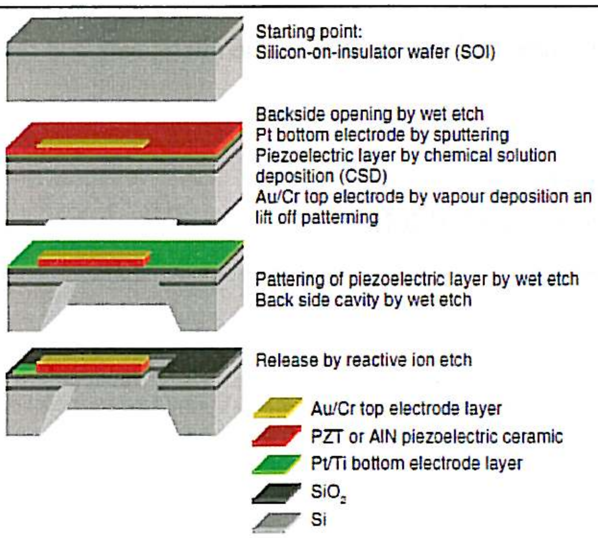
The SINTEF MoveMEMS process offers a PZT thin-film chemical solution deposition process which is integrated with a standard micromachining process.

An acoustic, piezoelectrically actuated gas sensor was manufactured.

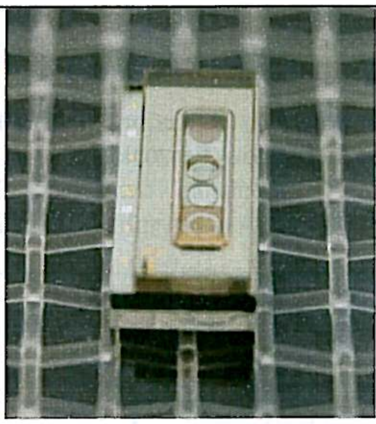
CoventorWare modelling, MoveMEMS design kit (Coventor)

Silicon manufacturing and piezoelectric PZT manufacturing by MoveMEMS (SINTEF)

Glass manufacturing (SensoNor)



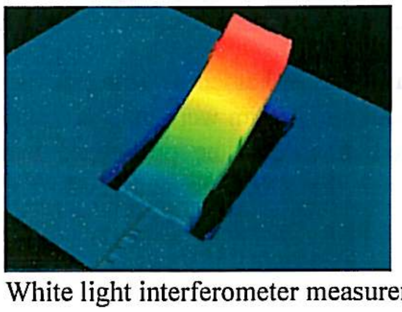
Process flow of the MoveMEMS process



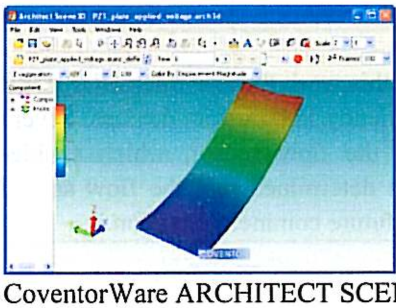
Acoustic gas sensor fabricated in the MoveMEMS process with glass from the MultiMEMS process

Due to their complex electro-mechanical behaviour it is inevitable to model the devices.

The CoventorWare models have been verified with test results from measurements on cantilevers as test devices. The modelling delivered also valuable input for determining the built-in stress in the different layers. The MoveMEMS design kit for CoventorWare is now available based on this work.



White light interferometer measurement image of a MoveMEMS actuated cantilever



CoventorWare ARCHITECT SCENE3D simulated

6.6 Controlled flow micro-dispenser

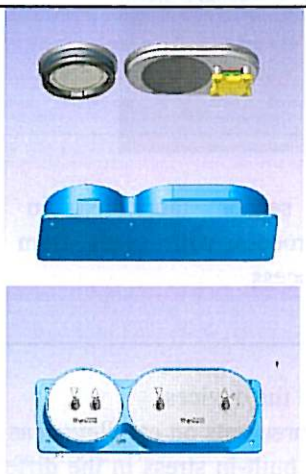
thinXXS Microtechnology has developed an integrated micro dispenser module that combines a thinXXS micro-diaphragm pump and the microBUILDER flow sensor. The driving force behind the development was a BMBF (Germany – 'Mikrosysteme') sponsored project for development of peripheral technologies/devices for micro fuel cells. As a power source for portable electronics, the market for micro fuel cells is expected to achieve significant growth with improvements in production and lower costs.

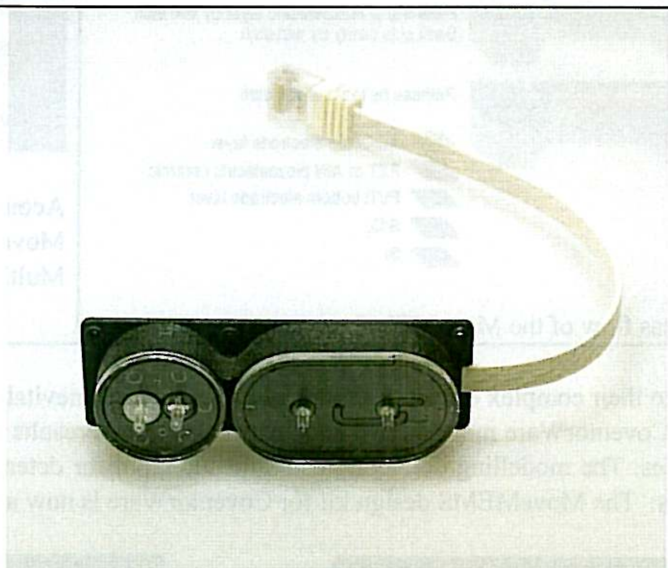
The application itself requires a device which supplies a controlled flow of methanol to the fuel cell including temperature compensation. The thinXXS diaphragm micropump was selected and further developed for custom performance and to integrate a filter membrane in the housing. For the feedback control of the pump, the microBUILDER sensor was selected due to the novel design and existing interfacing standards. The sensor was mounted in a custom integrated polymer housing using the standards created for the mixed technology slide for silicon/glass integration.

The module was characterized and successfully demonstrated to maintain a desired flow under fluctuating backpressure and fluid temperatures. The micro dispenser-pump is suitable for a wide range of applications where precise control of flow in the range of 0.1 – 10ml/min is necessary.

The microBUILDER consortium partners who contributed to the integration of the micropump and flow sensor include:

- Sensor design & fabrication (SINTEF)
- Sensor fabrication (SensoNor)
- Assembly components - flexboard (HSG-IMIT)
- Module fabrication, assembly, and characterization (thinXXS)





It is demonstrated in this work that the microBUILDER flow sensor and standard assembly interface can be implemented efficiently into custom devices. Several members of the consortium were involved with the development of the flow sensor, which enabled the integrated module to be prototyped and characterized. It was determined that the flow sensor compliments the thinXXS micropump and has distinct potential for future commercialization.

6.7 Flow sensor slide module

The data sheet for the flow sensor slide module:

FSS_0809
Silicon element flow sensor

thinXXS MICROTECHNOLOGY

Main features
- small dimensions
- extremely light
- wide flow range
- compatible with microfluidic construction kit platform

The thinXXS flow sensor module, developed through collaborating partners of the microBuilder Consortium, consists of two silicon flow sensor chips, read-out electronics with analogue and digital output and polymer packaging containing standardized fluidic connectors. The module fits into the thinXXS Microfluidic Construction Kit - a modular platform enabling the easy setup of microfluidic systems by combining available modules, each designed to perform microfluidic operations like pumping, mixing and splitting.

Technical specifications

Number of sensors	2
Maximum flow	30 ml/min
Calibrated minimum flow	0.3 ml/min
Resolution	15 (µl/min)/digit
Pressure drop (at max. flow)	~70 kPa
Pressure range	0 – 90 kPa
Reproducibility	0.5+ % (rel. to full scale) 2.0% (rel. to measured scale)
Overpressure resistance	100 kPa (depends on packaging)
Flow detection response time	< 50 ms
Digital sampling time	min. 0.25 ms (depends on settings)
Operating temperature	5° - 50 °C
Temperature coefficient	50 % of max. flow
Wetted parts	COC (Topas), TPE (Uniprene), Silicon/Glass
Dimensions	75.5 x 25.5 x 28.1 mm

Application areas

Beside the use in the microfluidic construction kit, the flow sensor module can be used for proof of principle investigations for all kinds of application fields where liquid (and gaseous) flows have to be precisely measured and controlled, such as:

- **Laboratory equipment**
- **Medical technology**
- **Ecology and Biotechnology**

Flow and pressure range, electric and electronic interfaces, as well as the packaging can be adapted to specific applications or integrated to suit typical OEM requirements.

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FSS_0809
Silicon element flow sensor

thinXXS MICROTECHNOLOGY

Connections

Electronics

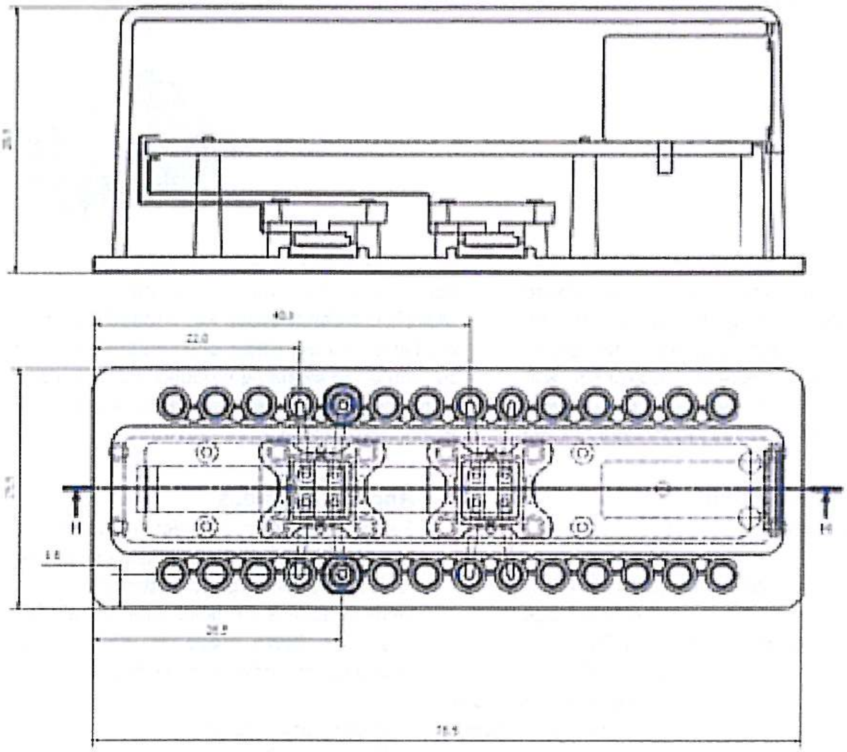
Power supply	5 – 18 V DC
Analogue output	0 – 2.5 V
Digital interface	RS232
Cable	custom – provided

Fluidics

Standard thinXXS fluid connector ports

Recommended tubing

Siltube TR60



Order information:

Please contact thinXXS's sales representatives for more information.

microBuilder contributing partners:

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eMail: sales@thinxxs.com

Specifications may be subject to change without further notice.

7 Web page and customer interface

At the beginning of the project a dedicated web page (www.microBUILDER.org) was designed. The web page contains information on the technologies and services and has been continuously updated with newly developed mixed technologies and examples. Also the MPW schedule has been announced and for MultiMEMS SensoNor developed a web page with protected customer information on the progress of the manufacturing of their device. Upcoming microBUILDER workshops and training courses have been announced on the web page and training material and video lectures are available through links. During microBUILDER there has been a web based contact form where potential customers have contacted the consortium with wishes on information on technologies, design handbooks or training material.

The microBUILDER web page will be maintained by SINTEF for at least 5 years after the project end. Information on the technologies and training material, as well as contact data will be available.

Figure 4: www.microBUILDER.org

During the project period, the microBUILDER services have had a single user interface. Marketing and customer contact was performed to spread the knowledge of the consortium's offer. After the project end, all previous partners will perform marketing of their own technologies and when applications demand mixed technologies also for the other partners and the established collaborative manufacturing.

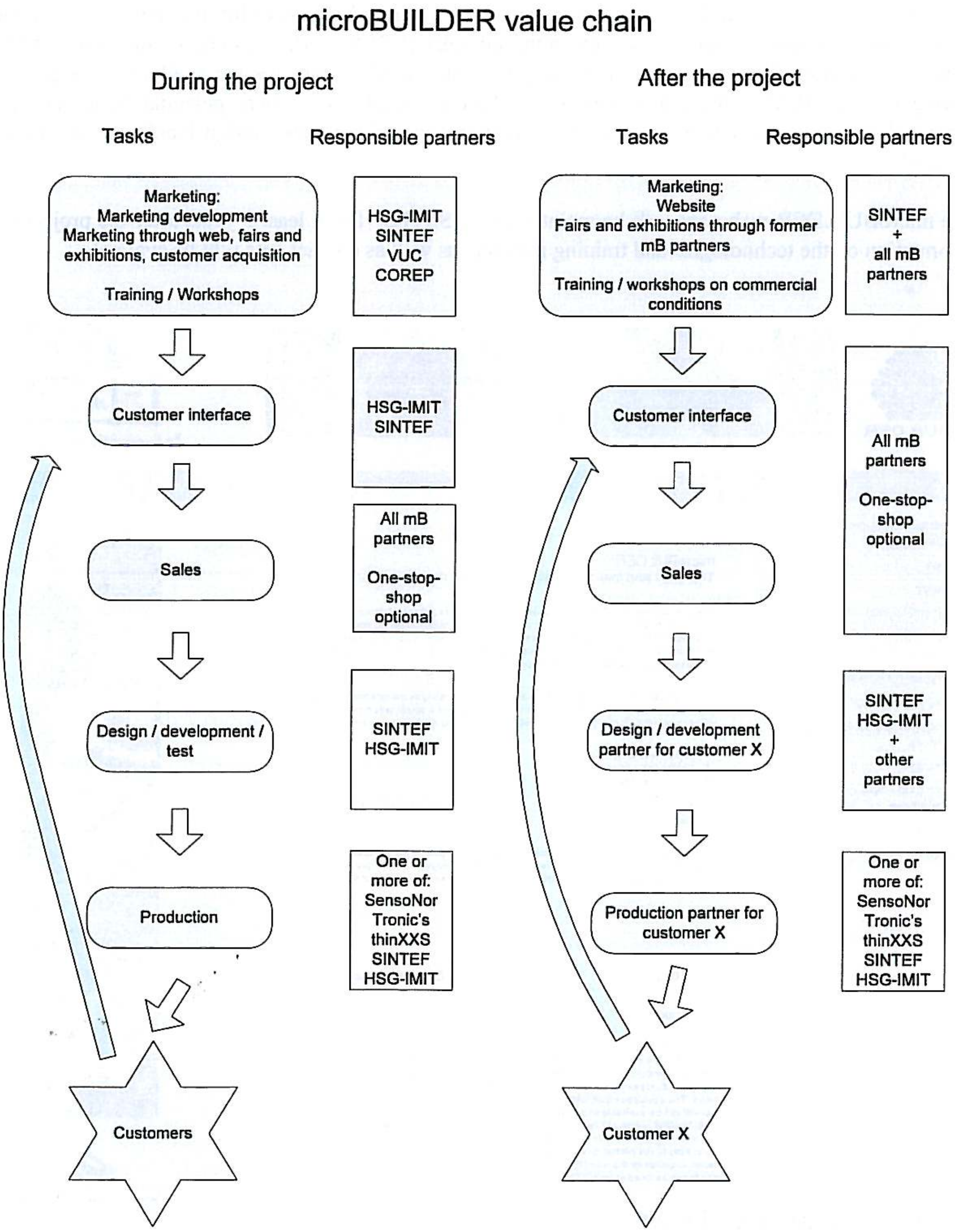


Figure 5: microBUILDER value chain during the project and after the project is finished

PART II, work performed in microBUILDER

8 Demonstrators

8.1 Demonstrator 1: Flow sensor module

The first demonstrator is a silicon flow sensor integrated in a ThinXXS slide that can be used either in a modular lab-on-a-chip system for monitoring the flow of different reagents, or as a test bench for flow sensors used for monitoring and control of the flow rate of e.g. implantable pumps. The selection of the flow sensor module as the first demonstrator was based on:

- The significant market for flow sensors for many different applications. Due to a market study from Yole[1] the total market for flow management components is expected to grow from 2.1 b$ in 2008 to 3.0 b$ in 2011 and further to 4.2 b$ in 2014 (flow controllers 32%, pumps 14%, valves 19%, flow sensors 23% and pressure sensors 14%). Although there are already MEMS based flow sensors available on the market, there is especially a need for robust flow sensors which are able to precisely measure liquid flows with a short response time.
- The flow sensor module for the microfluidic construction kit can easily be used by potential customers to run first feasibility tests themselves.
- The realisation of the flow sensor module shows the mixed technology capability of the consortium, since different technologies (silicon/glass, polymer, electronics) will be used and are combined in a modular way. This has the advantage that each technology can be used also for other applications. Furthermore, the polymer slide used for the flow sensor module can be used to integrate other silicon / glass chips which have to be connected fluidically (e.g. pressure sensor, cell counter, etc.).

The flow sensor module which was developed comprises of the following components:

- Silicon flow sensor chip, designed by SINTEF and fabricated by SensoNor and SINTEF
- Basic polymer module designed and fabricated by thinXXS.
- Readout electronics designed and fabricated by HSG-IMIT
  In a first step, a few modules were fabricated and tested. In Figure 6 a CAD model of the flow sensor module is shown.

[1] "Micro Fluid Management Technology - Market and technology analysis of pumps, valves, sensors and controllers for Microfluidics Applications", Yole Developpement, November 2008

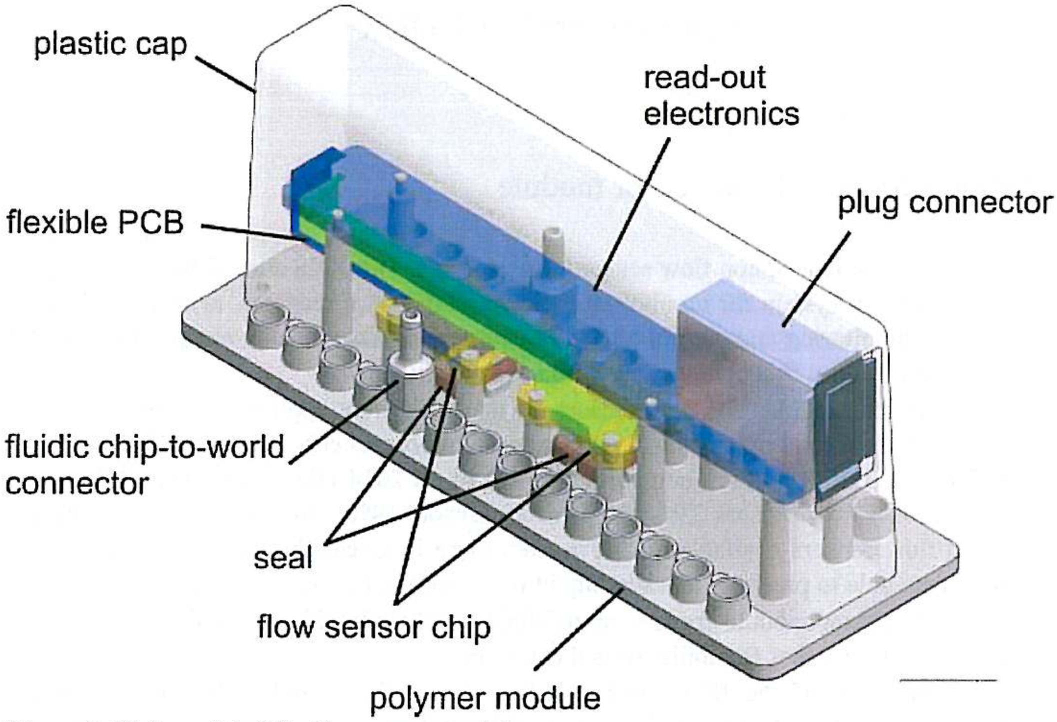


Figure 6: CAD model of the flow sensor module.

The flow sensor module consists of two silicon flow sensor chips, which are fluidically connected to the polymer module which contains appropriate channels for the connection of the inlet and outlet of the flow sensor chip with the fluidic chip-to-world connectors. For fluidic sealing an elastomeric seal is placed between flow sensor chip and polymer module. This stack is mechanically fixed by plastic clamps. Wire bonding is used for electrically connection of the flow sensor chip to a flexible PCB containing contacting paths and bond pads. This flexible PCB is glued on top of the silicon chip. The other end of the flexible PCB is plug in special flexboard plug in connectors on the electronics board which is placed on top of the sensor chips onto plastic posts which are part of the polymer module. The electronics contains a standard Firewire plug connector for power supply and digital as well as analogue signal output. A plastic cap covers the whole flow sensor module. Figure 7 shows a realized flow sensor module.

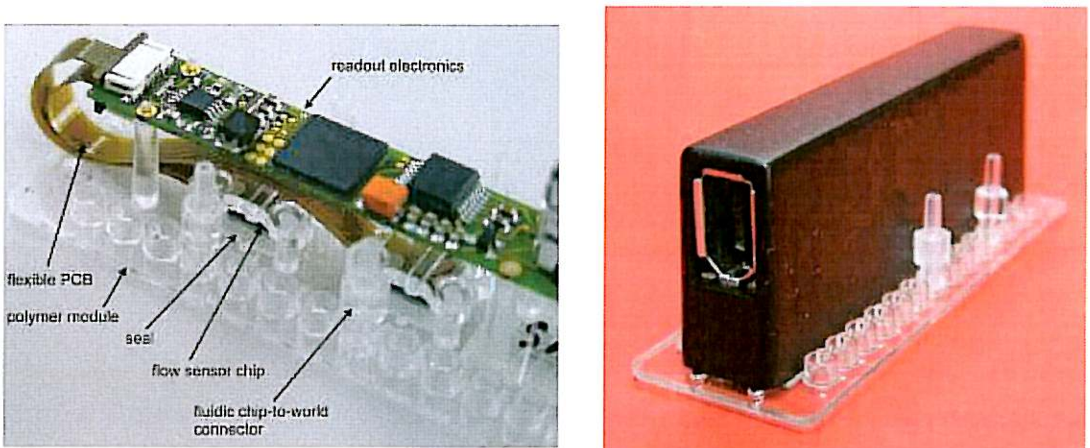


Figure 7: Pictures of a flow sensor module. Left: details without plastic cap. Right: Module with plastic cap.

To simplify PC communication a LabView program was developed supporting the following functions:

- Start / stop measurements and save results to file
- Change settings like averaging function, sampling rate, etc.
- Calibration of the flow sensors
- Calibration of the analogue output interface

First tests with the flow sensor modules showed that it works in principle and that it can measure constant liquid flows of up to 30 ml/min with an inaccuracy of ~ 5 % (Figure 8).

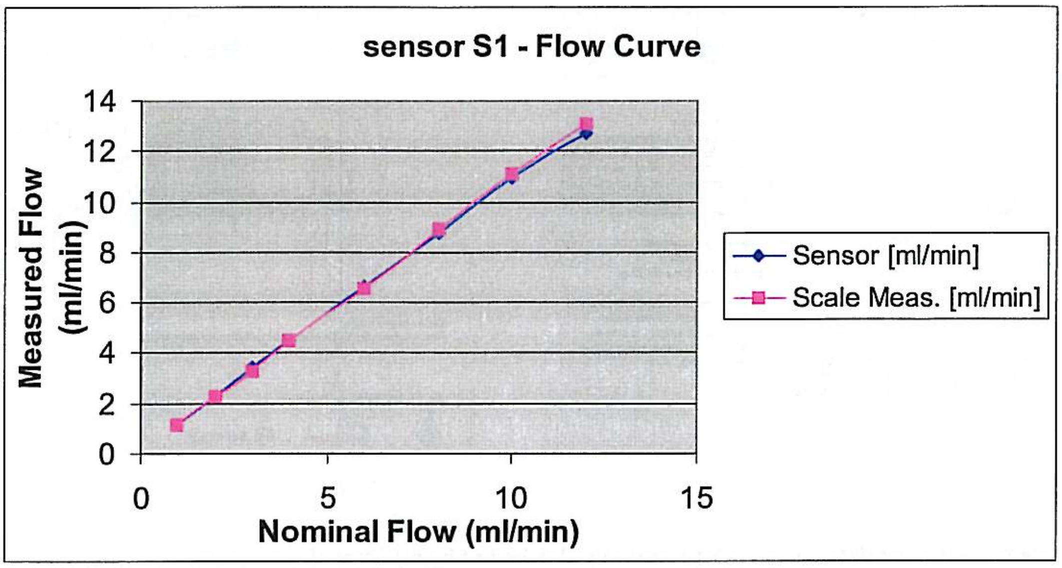
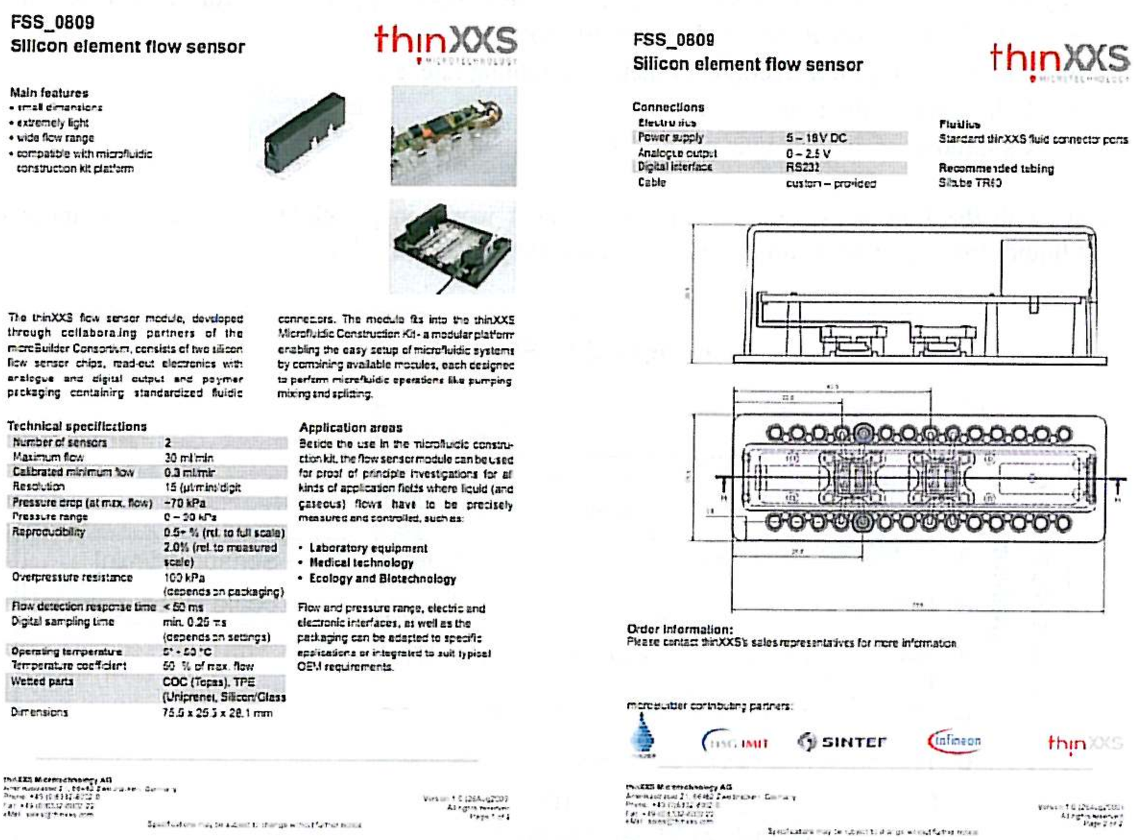


Figure 8: Flow curves for sensor S1 of module E08S10. Recorded with analog signal and compared to flow rates calculated using a mass balance.

To test the capacities of microBUILDER to offer "Efficient small scale production" further flow sensor modules were fabricated and characterized. Based on characterization results a data sheet was produced and published (Figure 9).


FSS_0809
Silicon element flow sensor

thinXXS

Main features

- small dimensions
- extremely light
- wide flow range
- compatible with microfluidic construction kit platform

The thinXXS flow sensor module, developed through collaborating partners of the microBuilder Consortium, consists of two silicon flow sensor chips, read-out electronics with analogue and digital output and polymer packaging containing standardized fluidic connectors. The module fits into the thinXXS Microfluidic Construction Kit - a modular platform enabling the easy setup of microfluidic systems by combining available modules, each designed to perform microfluidic operations like pumping, mixing and splitting.

Technical specifications

Number of sensors	2
Maximum flow	30 ml/min
Calibrated minimum flow	0.3 ml/min
Resolution	15 (µl/min)/digit
Pressure drop (at max. flow)	~70 kPa
Pressure range	0 – 30 kPa
Reproducibility	0.5+ % (rel. to full scale) 2.0% (rel. to measured scale)
Overpressure resistance	100 kPa (depends on packaging)
Flow detection response time	< 50 ms
Digital sampling time	min. 0.25 ms (depends on settings)
Operating temperature	5° - 50 °C
Temperature coefficient	50 % of max. flow
Wetted parts	COC (Topas), TPE (Uniprene), Silicon/Glass
Dimensions	75.5 x 25.5 x 28.1 mm

Application areas

Beside the use in the microfluidic construction kit, the flow sensor module can be used for proof of principle investigations for all kinds of application fields where liquid (and gaseous) flows have to be precisely measured and controlled, such as:

- Laboratory equipment
- Medical technology
- Ecology and Biotechnology

Flow and pressure range, electric and electronic interfaces, as well as the packaging can be adapted to specific applications or integrated to suit typical OEM requirements.

FSS_0809
Silicon element flow sensor

thinXXS

Connections

Electronics

Power supply	5 – 18 V DC
Analogue output	0 – 2.5 V
Digital interface	RS232
Cable	custom – provided

Fluidics
Standard thinXXS fluid connector ports

Recommended tubing
Silube TR40

Order Information:
Please contact thinXXS's sales representatives for more information

microBuilder contributing partners:

SINTEF
Infineon
thinXXS

Figure 9: Technical data sheet (sides 1 and 2) published at http://www.thinxxs.com/news/case-study-ubuilder.html.

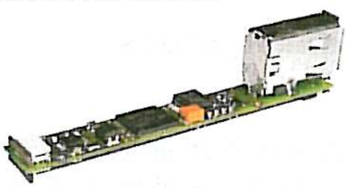
In total 23 sensor modules (46 sensor chips) were fabricated. These modules were used for characterization resulting in the sensor specification listed in the following table:

Parameter	Condition	Value	Units
Maximum flow		30	ml/min
Calibrated minimum flow		0.3	ml/min
Resolution		15	(µl/min)/digit
Pressure drop	at maximum flow	~70	kPa
Reproducibility		0.5 + 2.0	% related to full scale % related to measured value
Overpressure resistance	depends on packaging	100	kPa
Flow detection response time		< 50	Ms
Digital sampling time	depends on settings	min. 0.25	Ms
Operating Temperature		5 … 50	°C
Temperature coefficient	50 % of max flow	< 1.5	% measured value / K

A questionnaire was developed for providing feedback on the flow sensor module from customers. An experienced company was provided with the module to get a first feedback. The fist feedback can be summarized as follows:

While some of the responses in the survey were not entirely positive, the end result is actually quite encouraging. The range of flow for which the sensor is calibrated is actually quite wide and comparable to commercially available products. However, the flow range is application specific and will not fit every purpose The Company needed a sensor with an extremely wide range, so the microBUILDER flow sensor did not fit the application.

The following table shows how the different technologies used for the flow sensor module can also be used for other applications.

Technology	Use for other applications
Flow sensor chip 	• The flow range can be adapted to customer specific applications by adapting the calibration range (possible if small changes are required). • The flow range can be adapted by changing the fluidic resistance inside the flow sensor chip if the flow range has to be changed significantly
Polymer module 	The polymer module can be used for the integration of fluidic silicon / glass chips as long as the specifications regarding chip size and position of the fluidic ports of the chips are considered. Hence, other fluidic silicon / glass chips like pressure sensors, cell counters, biosensors, gas sensors, etc. can easily be tested.
Readout electronics 	The electronics is designed as an interface between piezoresistive sensors (fabricated using SensoNor's MPW technology) and the user or a measurement system. So in principle the electronics can be used to read-out all sensor elements fabricated with SensoNor's MPW service.
Electrical connection of sensor chip and readout electronics	The flexboard and wire bonding based technology used for the flow sensor module can be used for any sensor chip to be connected to the read-out electronics

8.2 Demonstrator 2: DNA extraction module

The development of a DNA extraction module, able to purify DNA from human whole blood samples , was selected as second demonstrator based on the following considerations:

- Based on the analysis of market studies and discussions with companies active in the diagnostics market, nucleic acid based analysis was identified as a very important field with many diagnostic applications and a big market potential for integrated Lab-on-a-Chip solutions. Especially sample preparation (nucelic acid purification) was identified as one very important key technology for the successful development of integrated Lab-on-a-Chip solutions.
- Nucleic acid based analysis of a patient sample (whole blood, urine, saliva, etc.) is based on a protocol with three main operations: NA purification, NA amplification, and finally detection. The thinXXS microfluidic construction kit allows for modularization of these operations, so that e.g. DNA purification can be performed in one slide, while amplification is performed in the next. The DNA extraction slide as part of the microfluidic construction kit can be used by potential customers to run first feasibility tests themselves.
- The mixed technologies and also the designs used to realize the DNA extraction module can be used for further Lab-on-a-chip solutions like purification of DNA or RNA also from other body fluids (e.g. urine and saliva).

The DNA extraction module consists of the following components:

- A microfluidic slide made of polymer compatible with thinXXS′ microfluidic construction kit containing:
    1. a silicon/glass chip as stationary phase for DNA extraction designed by HSG-IMIT and fabricated by Tronics
    2. Network of channels and chambers designed and fabricated by thinXXS
- External syringe pumps were used for liquid transport

The used DNA-extraction assay is based on the reversible binding of DNA molecules to a silicone dioxide surface under adequate buffer conditions (so called "Boom Chemistry"). The complete procedure consists of four main steps:

1. *lysing* of the sample, i.e. cracking the cell membranes
2. *binding* of DNA molecules to SiO_2 surface (stationary phase)
3. *washing* of the solid phase while maintaining the binding of the DNA
4. *eluting* the DNA, i.e. detaching of the DNA molecules from the stationary phase into solution

To reduce development risks, all biochemical agents were taken from a commercially available kit for DNA extraction (QIAamp DNA Blood Mini Kit from Qiagen). The standard procedure of this kit (using spin columns and standard laboratory equipment) was used to run reference measurements. Figure 10 shows the design of the bottom side of the DNA extraction module without silicon chip.

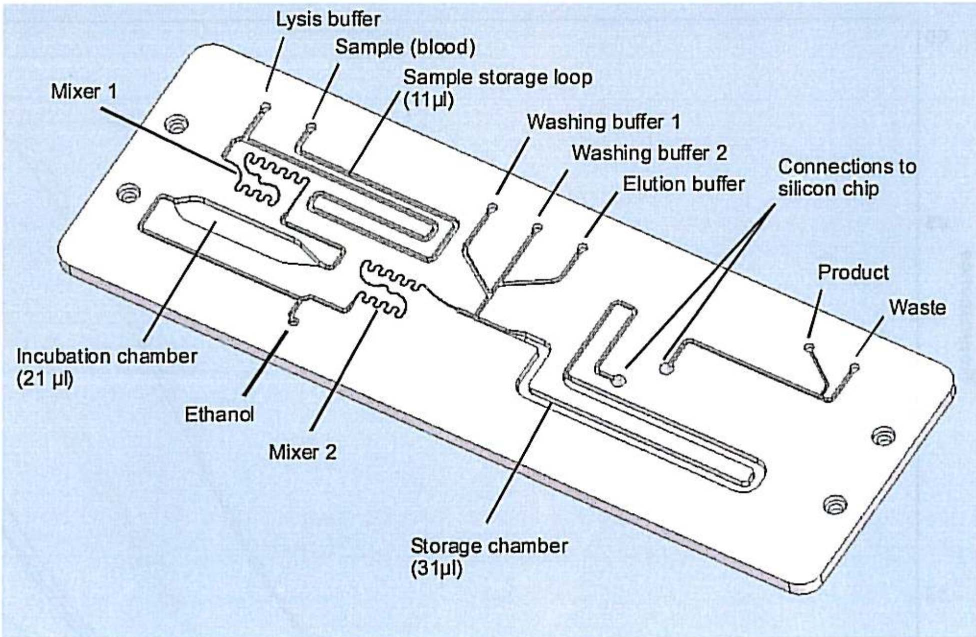


Figure 10: Design of the DNA extraction module without silicon chip.

The bottom side of the slide contains all microfluidic elements necessary to run the DNA extraction assay on chip. Sample (whole blood) and all required reagents are entering the chip through different inlet ports. Sample is first stored in a long channel (loop) before it is mixed with lysis buffer in "Mixer 1" which is realized as a snake mixer. The second storage chamber (incubation chamber) is designed as a wide channel section with smooth transition from the small to the wide channel width and back. "Mixer 2" which is used to mix the lysed blood with ethanol has exactly the same design as "Mixer 1". The third storage chamber is realised as a long wide channel again with smooth transitions of channel widths. After passing through the silicon chip where the DNA molecules bind to the silicon dioxide surface inside the chip, the lysed blood mixed with ethanol is transported to the waste outlet. In the next steps, washing buffer 1 and 2 are pumped through the silicon chip to the waste outlet. In the last step elution buffer is pumped through the chip removing the bound DNA and transported to product outlet. Figure 11 shows a completely assembled DNA extraction module.

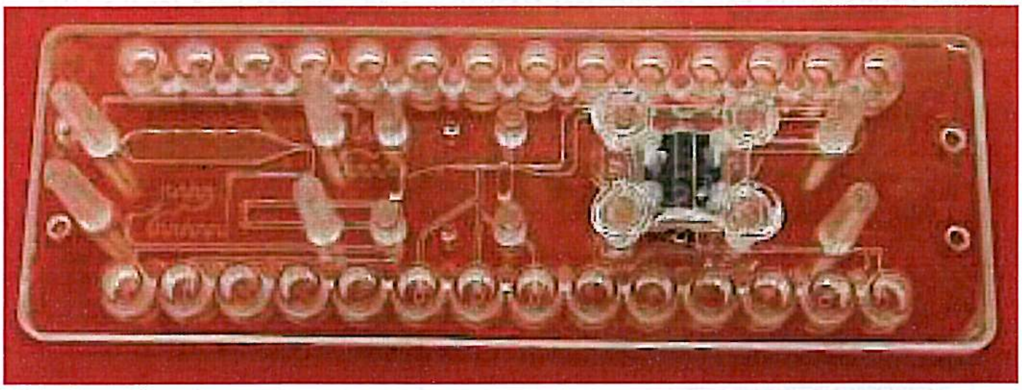


Figure 11: Completely assembled DNA extraction module containing a silicon chip as stationary phase for DNA extraction.

Figure 12 shows results of quantitative realtime PCR (qRT-PCR) measurements carried out with DNA extracted from whole blood samples with the DNA extraction module compared to DNA extracted with the standard Qiagen kit from the same blood sample.

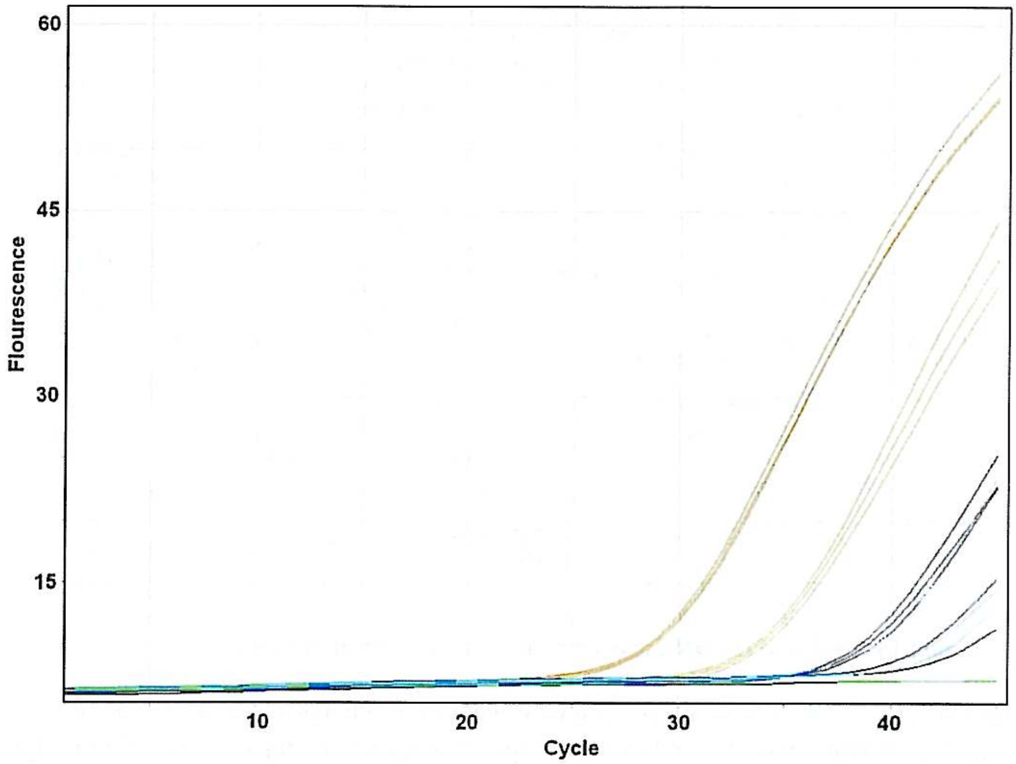
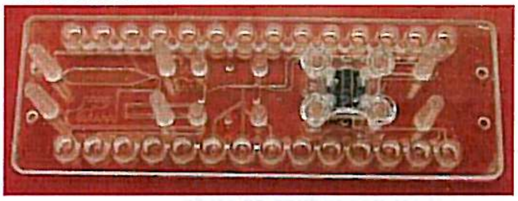
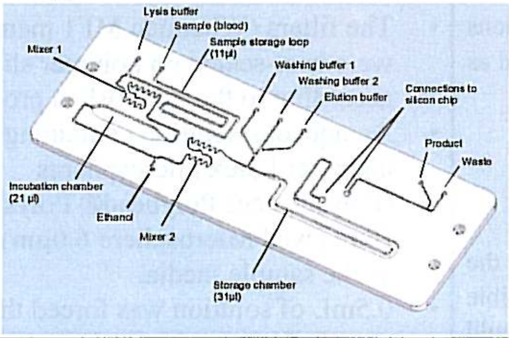
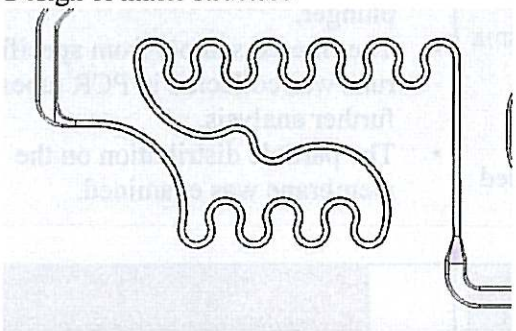


Figure 12: Results of qRT-PCR (quantification) of extracted DNA. Intensity fluorescence (normal scale) vs. number of PCR cycles. Colour code: yellow (a, b): reference extractions using commercial Qiagen Kit (a = 200 µL blood, b = 10 µL blood), blue (c): several extractions using demonstrator 2 (10 µL blood), green (d): negative control ("NTC"; no blood).

The efficiency compared to a commercially available standard DNA extraction kit (Qiagen) was about 10% without any optimization or design iterations. Hence, with demonstrator 2 the proof of concept regarding DNA extraction from whole blood samples including sample preparation could be successfully demonstrated. The overall potential for further optimization and improvement was identified and could be tested and implemented in further development steps and design iterations.

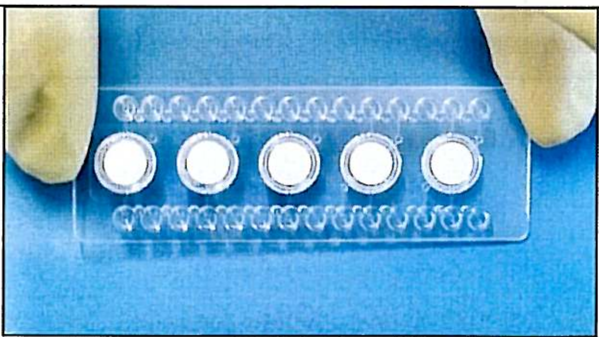
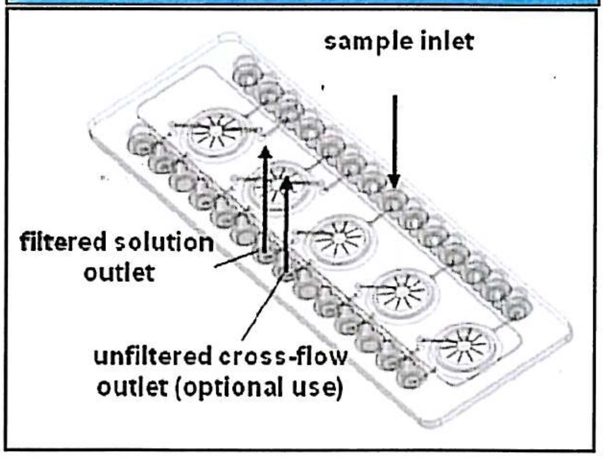
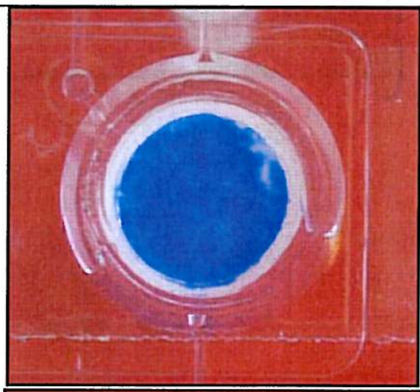
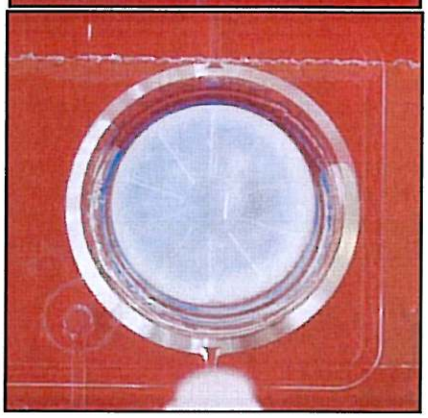
The following table shows how the different technologies and designs used for the DNA extraction module can also be used for other applications.

Technology / design	Use for other applications
Silicon DNA extraction chip 	Pillar structures could in principle also be used as filter elements (e.g. for plasma separation)

DNA extraction module 	By adapting the microfluidic design (mainly mixer, storage chambers, number of inlet ports) the DNA extraction module could also be used to run DNA or RNA extraction based on other samples (e.g. urine or saliva) and/or other extraction assays (kits).
Design of DNA extraction module 	The design of the DNA extraction module could be combined with designs of further modules (e.g. PCR and detection) for the realization of an integrated Lab-on-a-chip solution for nucleic acid based analysis → "from sample to result on one substrate".
Design of mixer structure 	The mixer structure is able to mix human whole blood samples with lysis buffer and ethanol, respectively. The mixer design can be used for other Lab-on-a-chip solutions where blood needs to be mixed with other buffers.

9 Polymer slides with mixed technologies

9.1 Sample filtration slide

Sample Filtration Slide	
Purpose / use / applications of slide The filter module can be used in many situations where liquid (and gaseous) flows must be filtered as part of a fluid handling system: • To remove particles according to size • To protect sensitive equipment • To improve measurement readings. Integration of different filter membranes in the polymer module for specific applications is possible upon request. Potential applications which would benefit from custom membrane integration include: • Plasma separation for removal of plasma from whole blood • DNA extraction for molecular diagnostics • Functionalized membranes for specified particle filtration/extraction.	Test procedure of slide • The filters (Whatman MF1 membrane) were heat-sealed on polymer slides according to the established procedure. • An aqueous solution containing blue 6um diameter Latex microspheres (Polysciences Polybead® Polystyrene Blue Dyed Microsphere 6.0µm) was used as the sample media. • 0.5mL of solution was forced through the sample filter by depressing a syringe plunger. • The filtered sample from specific test runs was collected in PCR tubes for further analysis. • The particle distribution on the membrane was examined.
  Image of the filtration slide and a flow schematic for use of the slide.	  Image of the membrane (bottom and top-side) with after test with microbeads.

9.2 Sample metering slide

Sample Metering Slide

Purpose / use / applications of slide

Many diagnostic applications require a defined volume of sample to be isolated from a larger supply volume. The metered volume can then be transported to connected functional elements or extracted for further processing.

Typical processes requiring a known volume include among others:

- Mixing/reactions
- Sample analysis
- Reagent dispensing

Test procedure of slide

- The polymer slide (COC Topas) was first coating locally with a Teflon solution according to the technique established by HSG-IMIT.
- Characterization of the passive valves was carried out by filling the channel until the hydrophobic valve. The pressure was increased slowly until the seal of the valve was compromised. The pressure at the breaking point was recorded.
- Metering tests were conducted by filling the metering channel, closing a valve located on the filling line, then purging the fluid with air to the outlet.

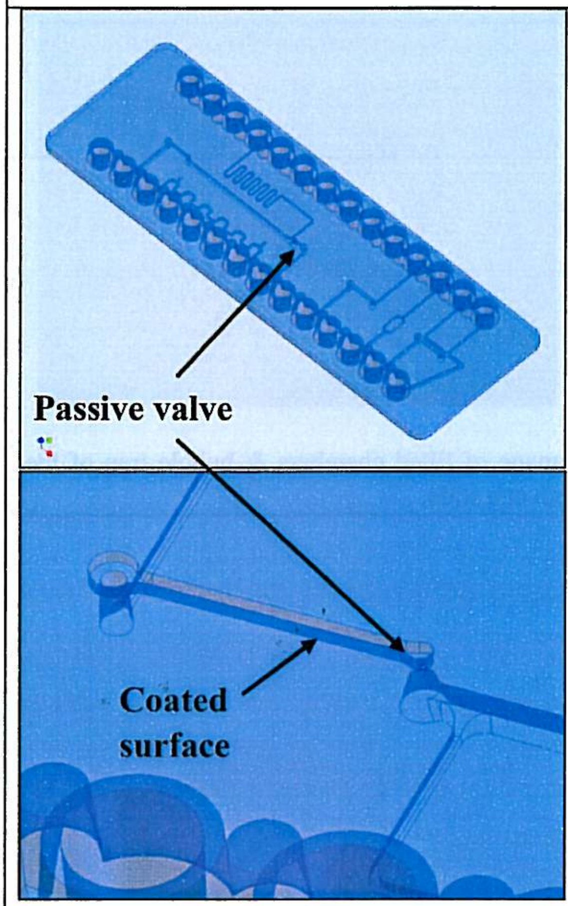
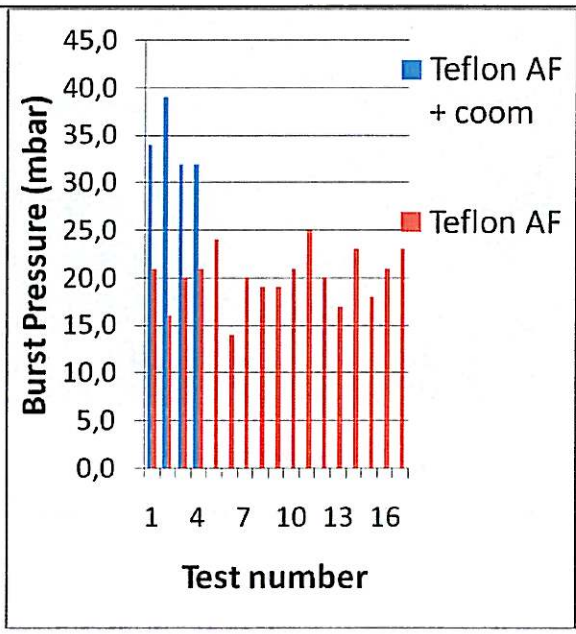
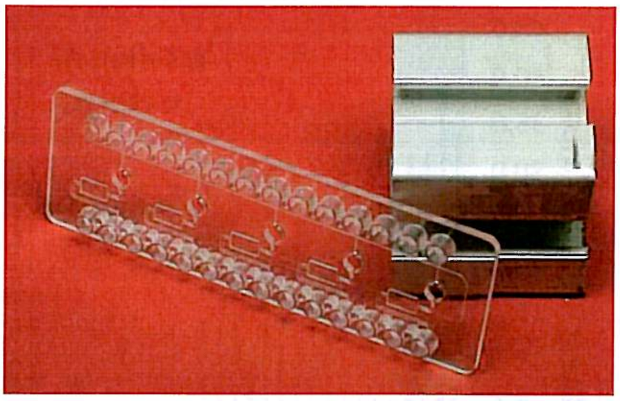
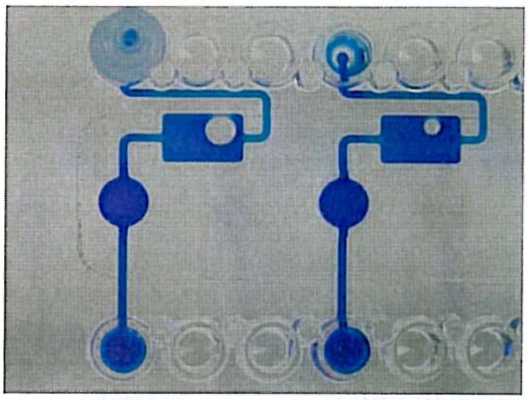


Image of the metering slide and passive valve.



Data from passive valve tests with localized hydrophobic coatings.

9.3 Cuvette slide

Cuvette Slide	
Purpose / use / applications of slide Optical analysis and visualization of samples and real-time reactions are extremely common techniques in life science applications. The cuvette slide consists of multiple chambers that provide users with good optical clarity (ie. low self-fluorescence of material) and the flexibility to implement their own chemistry and bio-materials. Application fields that could use this slides include: pathology (eg. human blood, cells), anatomy (eg. major tissues and organs), biology (eg. plants, animal tissues), and immunology (eg. immunofluorescence assays).	Test procedure of slide • Assembled slides were tested for fluidic functionality. • Sample was introduced into the slide using a variety of techniques, including: pipette, tube & connectors, and syringe & adapter. • Function of bubble trap was verified by entraining pockets of air in the sample. • The slide was used for the real-time visualization of an enzymatic reaction.
 Image of the assembled cuvette slide.	 Image of filled chambers & bubble trap of the cuvette slide.

10 Mixed technologies

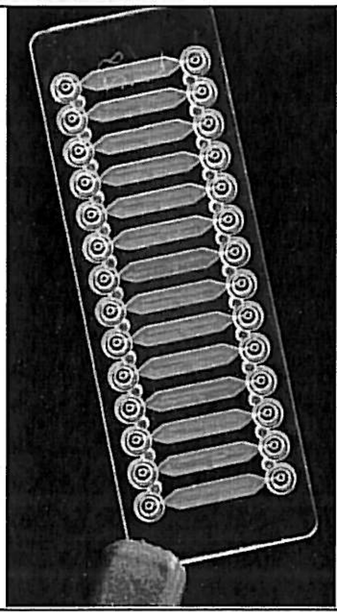
The mixed technologies were chosen on the basis of discussions with existing and potential customers in order to understand their need for mixed technology processing and on marked reports. The manufacturing was then established and the technology was functionally tested in combination with silicon chips or polymer chips or both. This section describes shortly the selected mixed technologies and some of their applications, as well as short notes on the functional testing procedures performed. The Master Design Handbook Part III "microBUILDER mixed technology and add-on processes" gives a detailed description on the manufacturing processes, material properties and specifications as well as layout rules and test results from the functional device testing. In the end of this section there is a table giving an overview of possible combinations of the mixed technologies.

10.1 Biocompatible Sealing of Polymer Chips

Microfluidic devices usually have to be covered, e.g. to realise closed channel or camber structures. The sealing process offered through the microBUILDER partners HSG-IMIT and thinXXS is an indispensable technology for the leak-tight closing of such microfluidic structures. The sealing process needs to be biocompatible in order not to destroy any reagents or enzymes stored in the microfluidic structures ahead of the sealing process.

The offered standard sealing method is a Solvent Diffusion Bonding process. This process is chosen as standard because it offers very high bond strength with high fluidic tightness (i.e. no leakage). The sealed microfluidic devices have a very high optical quality. Moreover, the covering foil is applicable for temperatures up to 100 °C. No adhesive or intermediate layers are necessary and as so the Solvent Diffusion Bonding process is a simple procedure. The biocompatibility of the process has been examined by the activity of a stored enzyme (alkaline phosphatase) before and after the sealing processes.

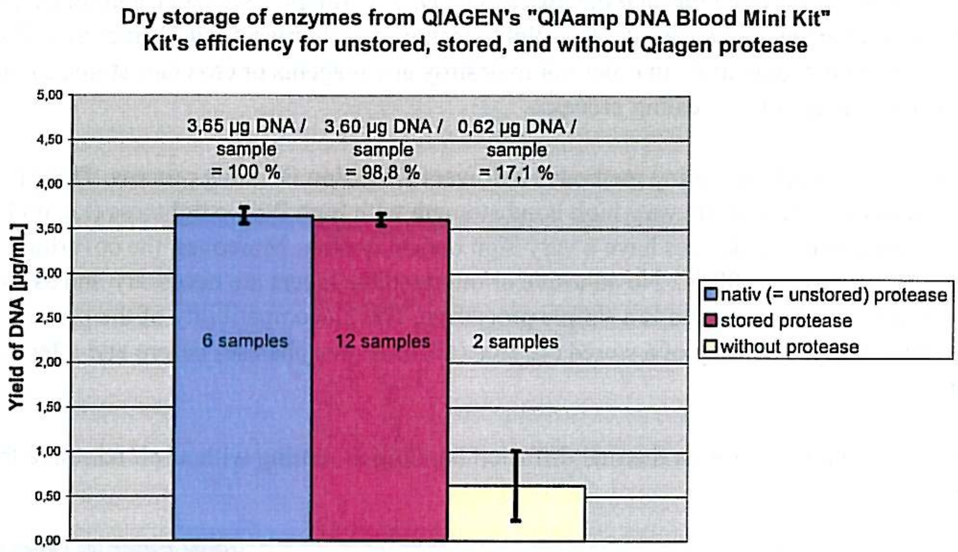
Other sealing processes as thermal diffusion bonding or sealing with a self adhesive foil are available on request.

Functional test: thinXXS slides with dried reagents in micro chambers (shown right) were sealed using solvent diffusion bonding (and other methods that were concluded to be less suitable for this application). The activity of the biological reagents was monitored after sealing and the bond strength of the seal was measured.	

10.2 Reagent storage

The storage of reagents is a key feature for lab-on-a-chip systems in medical technology and the life sciences that will be used by untrained personnel. It enables devices to be ready-to-use and only the sample has to be added to perform the system's assay. As many assay systems tend to become mobile and partially disposable, methods to store reagents on the disposable part are of great importance.

In general, reagents can be stored both in liquid and solid state. While liquid storage is a milder procedure for less stable reagents, solid storage is suitable for long term storage. There can be no general approach to reagent storage as each reagent has specific requirements. Enzymes, however, are interesting reagents for dry storage as they are included in nearly all biochemical assays. They are a key component in various detection systems based on immunology, e.g. ELISA, PCR, and NASBA techniques. The amount of enzyme for an assay is relatively small, which allows for storage directly within the system's fluidic network. Technology for dry storage of enzymes is therefore available through the microBUILDER consortium.

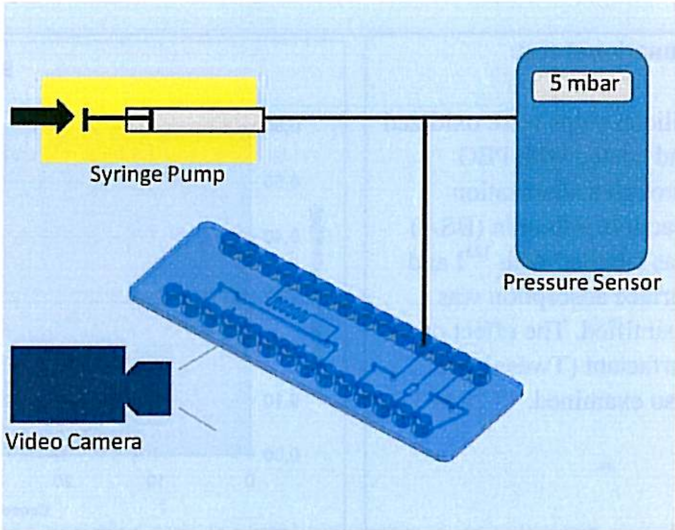
Functional test: The enzyme Alkaline Phosphatase was applied to channels in ThinXXS slides and dried. The activity of the enzyme was measured after re-hydration on-chip.	

10.3 Hydrophobic patterning

Valves and metering structures are core parts in medical and biotechnological devices used for diagnostics and/or for dosing. Valve structures able to stop and release flows are needed to e.g. ensure that reagents are dosed at the right time. Defined volumes of sample and reagents are a prerequisite to get analytical results. In microfluidic elements such valves and metering structures can be realized by hydrophobic patterns.

Hydrophobic patterns (patches) in microfluidic structures are areas with water repellent behaviour due to hydrophobic coatings (contact angle > 90°). In such areas the capillary movement of a liquid can be manipulated. Micro channels with hydrophobic patches can act as passive valves or for metering since self-priming by capillary force is stopped and an additional pressure is needed to re-establish the flow over the patched area.

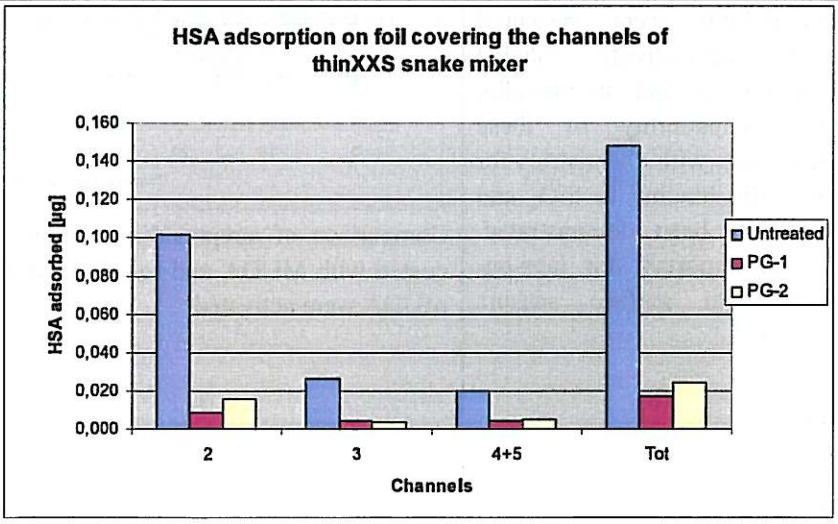
Precise volume and position spotting of fluoropolymer-based solutions e.g. TEFLON AF is offered. The hydrophobic patches can be applied to surfaces after hydrophilization with e.g. PETOX or PEG.

Functional test: ThinXXS polymer slides with fluidic channels have been hydrophobically patterned by Teflon spray coating. The burst pressures of the hydrophobic valves in the channels were measured. Right: Measurement setup used to measure the burst pressure of passive valves in metering structures.	

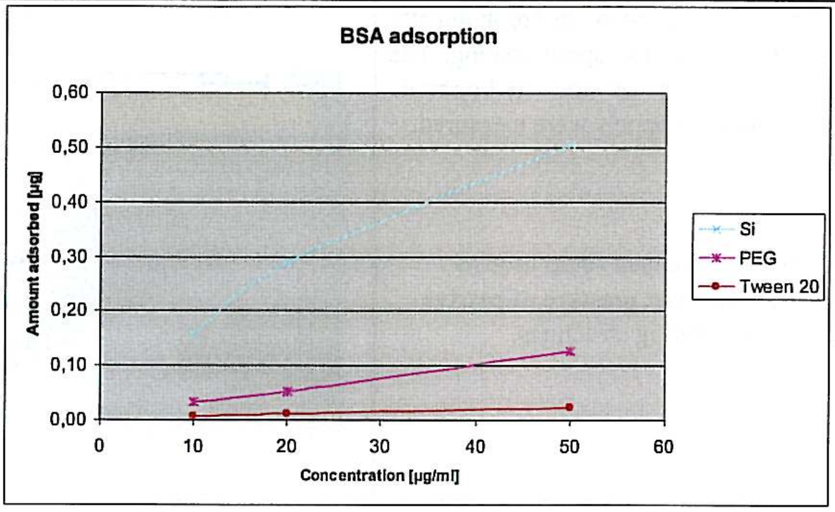
Coatings for anti-binding or specific binding of bio macro-molecules on polymer and silicon chips and gold patterns on silicon or glass

SINTEF is offering a variety of well documented coating and chemical coupling procedures for modification of the surface materials used in microBUILDER microsystems. These include the modification of polymeric materials such as COC (cyclic olefin copolymer) and typical silicon based chip materials such as silicon dioxide, glass and gold. For these materials SINTEF supply chemistries that may either to be used for chemical coupling of biospecific macromolecules such as proteins (e.g. antibodies, streptavidin or enzymes) and nucleic acid strands (DNA / RNA) or be used for establishing coatings that will minimize unspecific binding.

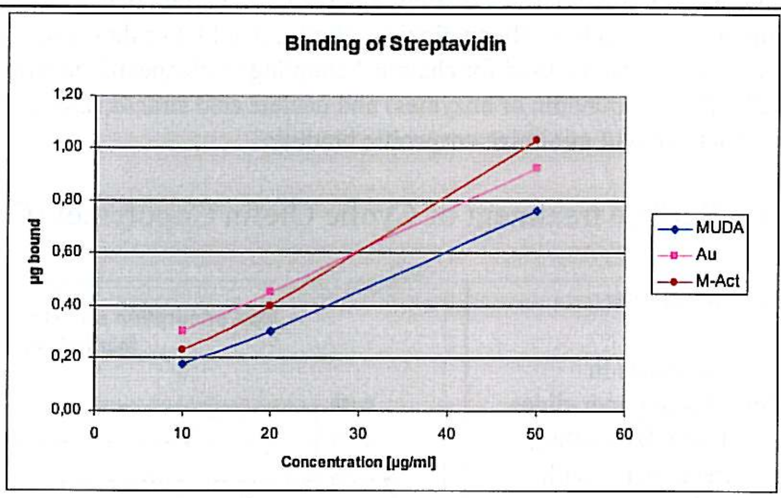
10.4 Surface treatment of Cyclic Olefin Copolymer (COC) – non-binding

Functional test: Micro channels in ThinXXS polymer slides as well as COC sealing foils were coated with a range of different molecular layers (e.g. photografted PEG, Dextrane and Tween) for prevention of unspecific protein binding. Different proteins were labeled with radioactive ^{125}I and the surface adsorption was quantified.	

10.5 Surface treatment of silicon dioxide and glass to avoid unspecific binding

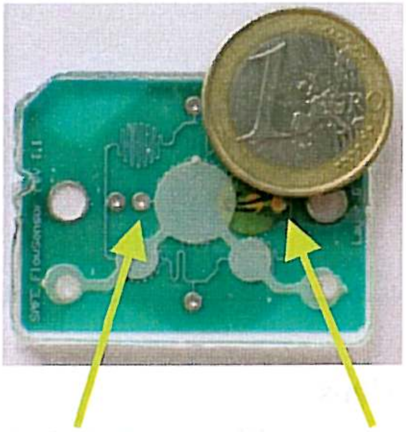
Functional test: Silicon chips were oxidized and coated with PEG through a silanization reaction. Albumin (BSA) was labelled with ^{125}I and surface adsorption was quantified. The effect of surfactant (Tween) was also examined.	

10.6 Surface treatment of gold patterns on silicon for specific binding

The thiol reagent MUDA have been specifically attached as anchor layer to gold patterns on silicon chip surfaces and used for coupling of biospecific molecules. Quantification and bioreactivety of bound Streptavidin and F(ab)2 anti-thyroglobulin were measured using radioactively labeled thyroglobulin and streptavidin. The compatibility of these chemistries with chemistries for unspecific binding to SiO_2 and COC has been demonstrated. This is important for labs-on-chips with surface sensors integrated.	 Comparison of streptavidin immobilized directly to gold, to gold coated with MUDA and to gold / MUDA where the acid groups on MUDA were activated

10.7 PDMS microfluidic structures

The microBUILDER partner BME-ETT has developed a laser manufacturing process for the realization of microfluidic channels in poly(dimethylsiloxane) PDMS. The offered laser processing technology is convenient for fast prototyping of PDMS microfluidic channel structures. The advantage of using PDMS as base material for fluidic structures is that sealing to any smooth surface can be realized by pressing the PDMS and the glass or silicon substrate together with relatively low force. The inlet and outlet connection, thus the micro-macro interfaces, can also be realized without additional sealing gaskets.

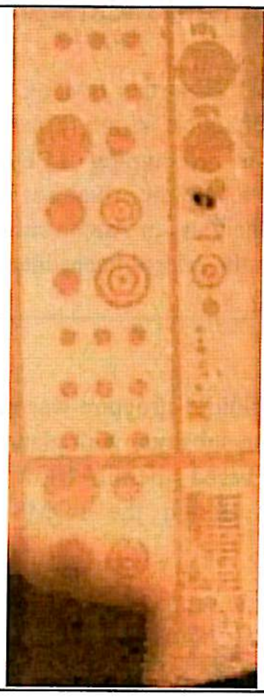
Functional test: A PDMS microfluidic structure was manufactured and sealed onto a substrate with planar electrodes. The electrode based thermal flow rate sensor measured flow trough the PDMS channels / chambers.	

10.8 Gold patterning on silicon and glass

Gold patterns on surfaces are combined with microfluidics in a wide variety of applications, both for commercial use and for research devices. Gold patterns on flat surfaces can be used for positioning and immobilization of cells, e.g. fruit-fly embryo. In sample preparation and particle / cell concentration chips, fine structured electrodes are used for di-electrophoresis (DEP) where e.g. bacterial cells can be retained. If the gold electrodes are patterned on a glass wafer, the glass wafer can later be bonded to a silicon wafer with channels, cavities and integrated sensors. The rare cells / bacteria can then be concentrated at the gold electrodes, while the rest of the sample is flushed away. Cell preparation and bio assay can then be carried out in the shared silicon / glass / gold system.

Gold electrodes can be used for electrical field generation in electro-osmotic pumps, in electrochemical sensors or as heaters. Gold surfaces are also used for surface plasmon resonance (SPR) detection of specific binding reactions. Gold patterns are often used as binding areas for thiol self-assembled monolayers, onto which specific molecules for biochemical assays can be attached.

The gold patterning process on silicon can be further developed to yield freestanding structures, e.g. cantilevers and membranes, with gold on top. Thiol and / or bio functional layers can later be added and the structures can then be used as mechanical biosensors. Complementary antibodies or DNA strands can bind to the attached receptor molecules and the molecular binding can be monitored by external, optical detection (color, fluorescence or beam bending) or by piezoresistive sensing as an integrated part of the sensor.

Functional test: Gold was patterned on cantilevers with PZT layers and on flat silicon surfaces. Binding of thiol and proteins to the gold pattern was performed. Right: gold pattern with thiol	

Piezoelectric Films

MicroBUILDER offers two different technologies for piezoelectric films; the MoveMEMS SINTEF thin film process and the Tronics thick film PZT process. The two processes are different in the manufacturing approach with respect to the piezoelectric film thickness and quality and thus the resulting actuation/sensing voltages and the mechanical forces. The application areas are therefore different. Please consult the microBUILDER partners for choosing the best technology for your application. Some of the key differences between SINTEF and Tronics PZT processes are summarized below:

	MoveMEMS thin PZT (SINTEF)	**Thick PZT (TRONICS)**
Displacement / Force	Low	High
Drive voltage	Low	High
Key feature	Integrated deposition process on flat surface	Adhesive bonding within cavity

10.9 MoveMEMS PZT - Piezoelectric thin film

The reliable integration of piezoelectric thin films into MEMS is a key enabling technology for a wide range of future products. Examples include ultrasonic imaging transducers, pressure and flow sensors, accelerometers, acoustic wave devices, energy converters, micro-motors, micro-pumps, and micro-sensors for chemical analysis. Piezoelectric materials allow energy conversion between the electrical and mechanical domain. Several sensor structures utilize both the direct effect (conversion from the mechanical to the electrical domain) and the converse effect (conversion from the electrical to mechanical domain (i.e. actuation)).

Applications can be classified according to those employing:

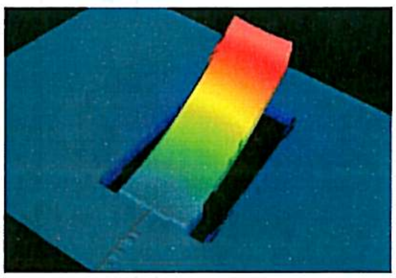
Solely the converse effect → Linear actuators, ultrasonic motors

Solely the direct effect → Sensors, energy scavengers

Both effects → Combined sensor/actuators, resonant transducers

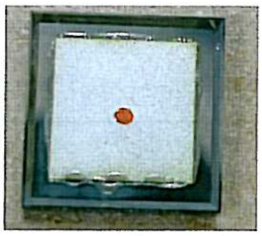
Direct effect: Sensors, energy conversion (AC coupled)	**Converse effect:** Linear Actuators	**Converse effect with Resonant ultrasound excitation**	**Both effects in resonance:** resonant transducer
· Vibration sensor · (accelerometer) · microphone · acoustic sensors · energy scavenging from vibrations	· Optical scanner · Optical switch · Micro, nano probe · Switch – Relay, RF switch · Valve · Droplet ejector, inkjet	· Ultrasonic stator for micromotor · Liquid delivery	· **Thickness Bulk waves:** ultrasonic imaging (thick films), RF filters (thin films), transformers · **Ultrasonic waves in pMUTs:** ultrasonic imaging, proximity sensors
Active damping			

Several material systems of piezoelectric materials exist. The two most interesting alternatives for MEMS applications are aluminium nitride (AlN) and lead-zirkonium-titanate (PbZrTiO, shortened to PZT). Deposition of AlN is easy to industrialize, while the deposition techniques for PZT are far behind in maturity. However, PZT has an electromechanical coupling that is approximately 10 times higher than AlN and SINTEF has therefore developed the MoveMEMS PZT Chemical Solution Deposition (CSD) process.

Functional test: Cantilevers with PZT and gold were manufactured and the deflection was measures as function of the actuation voltage. The measured values were used as input to the CoventorWare design kit on MoveMEMS. Right: White light interferometer measurement image of a MoveMEMS actuated cantilever	

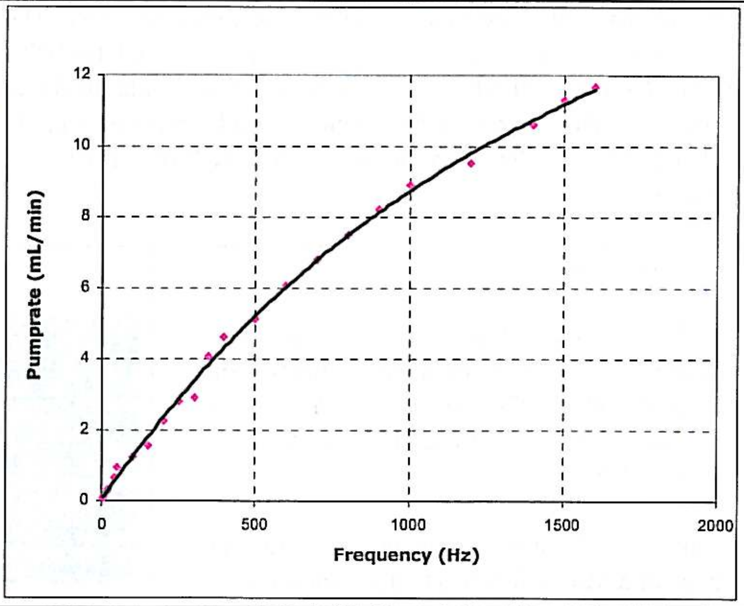
10.10 Piezoelectric thick film PZT

Within the framework of microBUILDER thick piezoelectric material is used as an actuator where electrical voltage is transformed into mechanical deformation. A piezoelectric disk glued onto a thin silicon diaphragm has been used as a micropump. A voltage applied to the piezoelectric actuator causes the silicon diaphragm to bow away from the pump chamber beneath and fluid will be drawn into the chamber. The pump-rate of a piezoelectric micro-pump can easily be changed by altering the actuation frequency.

Functional test: Membranes manufactured in the silicon valve process and with thick film PZT integrated, were electrically actuated. The displacement of the membranes was measured. Left: Piezo actuators glued on a thin silicon diaphragm	

10.11 Test assembly for microvalves

microBUILDER has developed a microfluidic interface polymer slide for integration of silicon based sensors and microfluidic polymer slides into the thinXXS microfluidic construction kit/prototyping platform. An alternative solution for testing silicon microvalves manufactured by the microBUILDER partner Tronics, with placement and dimensions of inlet/outlet ports different from the microBUILDER standard, has been developed. This alternative solution makes possible testing of microfluidic features of a silicon die before shipment to customers.

Functional test: Micro-pumps manufactured in the silicon bulk valve process with integrated thick-film PZT were fluidically packaged and actuated at different frequencies. The pump rates were measured. Left: Pump-rate as a function of actuation frequency	

10.12 Hot embossing

Through the injection molding process offered by thinXXS, the microBUILDER customer has access to a low cost state-of-the-art technology for micro moulding of medium to high volumes of polymer devices. However, since design and fabrication of the needed molding tool is relatively time consuming and expensive, injection molding is not ideal for prototyping or for production of a smaller number of pieces.

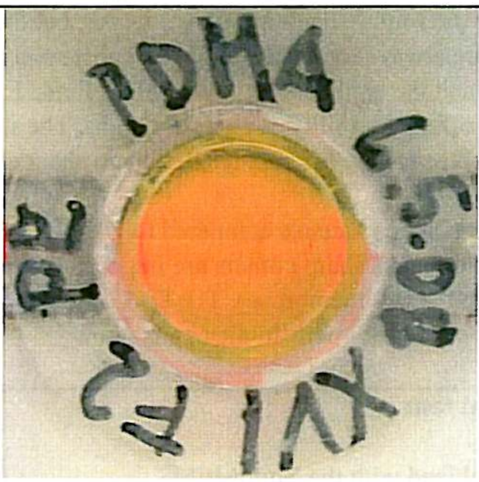
The hot embossing technology developed at HSG-IMIT is a technology which ideally meets the needs for prototyping, as it is less expensive for smaller volumes and offers more flexibility with respect to the outer dimensions of the polymer components. Furthermore, hot embossing is compatible with mass production processes.

The hot embossing process is established for various substrate formats, e.g. rectangular standard microscope slide or CD-format disk, and for a selection of materials, e.g. COC, COP or PS.

Functional test:

A polymer slide for blood analysis was manufactured by hot embossing. The slide was used for on-chip dilution of blood and subsequent reaction and on-chip measurement of the reaction products.

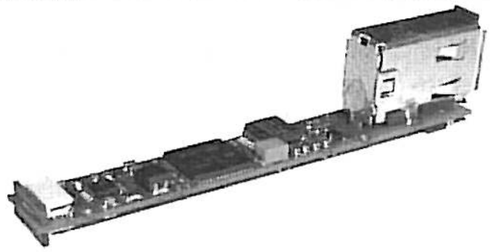
Left: Mixture of diluted whole blood and reagents flowing through the sensor area of the microfluidic blood analysis slide.



10.13 Standardized read-out electronics for piezoresistive sensors

Piezoresistive electro-mechanical transduction is widely used in micro-machined sensor elements. In such elements changes in mechanical stress can be detected as a change in resistivity. The change in resistivity is therefore directly related to changes in the parameter which is to be measured, e.g. pressure. A Wheatstone bridge configuration with four resistors is widely used, utilizing the high gauge factor of the silicon resistors.

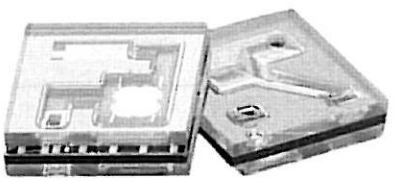
The SensoNor MultiMEMS MPW process offers buried conductors, piezoresistors, thin silicon diaphragms and cantilevers, elements which are typical in several types of piezoresistive sensors. Standardized read-out electronics for such sensors provides an easy-to-use interface for the customer. The microBUILDER read-out electronics can be used for temperature compensation, calibration, linearization and amplification of the voltage signal from the inherent Wheatstone bridge. The amplification factor can be easily adapted to different sensor designs.

Functional test: The standardized read-out electronics was tested in demonstrator one, the flow sensor polymer module	

10.14 Deep Reactive Ion Etch of fluidic channels

The maximum depth of RIE silicon channels processed by the standard SensoNor MultiMEMS MPW is limited to 10 µm. For most microfluidic applications these channels are too shallow. Glass channels offered by the MultiMEMS MPW are deeper, but the depth is fixed to 310 ± 15 µm. Moreover the glass channels are always rounded and have a substantial amount of under-etch and a high etch depth tolerance, and the applications are therefore limited. The new DRIE add-on process offered by SINTEF / SensoNor offers flexibility of channel depths. The standard depth is 100 µm, but shallower and deeper channel depths can be offered. DRIE silicon channels can be made with an aspect ratio up to 1:15.

Benefits of silicon channels compared to glass or polymer channels are precisely defined dimensions with sharp corners. Sharp corners are important for several applications, e.g. for valves and for cell lysis (to dissolve the cell membrane). The DRIE process is optimized to obtain smooth surfaces which are highly important for microfluidic applications.

Functional test: DRIE combined with the MultiMEMS manufacturing was used for the first microBUILDER flow sensor module demonstrator.	

10.15 Combinations of technologies

The table below indicates the possibilities for combinations for microBUILDER technologies. Many of the combinations have been established in demonstrators or customer work.

	microBUILDER technology offered	Combination with the other technologies	Partners
	Modular platform		
1	*Microfluidic construction kit*	*2, 3, 4, 5, 6*	*ThinXXS*
	Platform modules		
2	*Polymer slide for integration of silicon chip*	*1, 7, 8*	*ThinXXS*
3	*Polymer slide with filter*	*1*	*ThinXXS*
4	*Polymer slide with hydrophobic valves*	*1, 20, 21*	*ThinXXS + HSG-IMIT*
5	*Polymer slide with glass cuvette*	*1, 20, 21, 22, 23*	*ThinXXS*
6	*Polymer slides with mixer, splitter, valve, chamber, pumpr*	*1, 10, 20, 21,22, 23*	*ThinXXS*
	Chip manufacturing		
7	*Silicon / glass MultiMEMS sensors*	*2, 13, 16, 18*	*SensoNor*
8	*Silicon DRIE fluidic structures*	*2, 18*	*Tronics*
9	*Silicon passive valve*	*15, 17, 18*	*Tronics*
10	*PDMS*	*6, 7, 8, 12*	*BME*
11	*Polymer chips (injection molding / hot embossing)*	*20, 21, 22*	*ThinXXS HSG-IMIT*
	Mixed technologies		
12	*Gold micro- pattern on silicon or glass*	*8, 10, 19*	*SINTEF*
13	*DRIE for MultiMEMS fluidics*	*7, 16, 18, 2*	*SINTEF*
14	*PZT piezoelectric thin film*	*7 (glass), 19, 2*	*SINTEF*
15	*Piezoelectric thick film*	*9, 17, 18*	*Tronics*
16	*Read out electronics for piezo-resistive sensors*	*7, 2+1*	*HSG-IMIT*
17	*Microfluidic packaging of silicon valves and pumps*	*7, 14, 18*	*Tronics*
18	*Surface biochemistry for SiO2 and glass*	*7, 8, 9*	*SINTEF*
19	*Surface biochemistry for gold (Au) patterns*	*12, 14*	*SINTEF*
20	*Surface biochemistry for COC chips*	*2, 3 ,4, 5, 6*	*SINTEF*
21	*Hydrophobic patterning of micro-channels*	*4, 11, 8*	*HSG-IMIT*
22	*Biocompatible sealing of polymer chips and slides*	*2, 4, 6, 11*	*HSG-IMIT*
23	*Dry reagent storage on-chip*	*6, 11*	*HSG-IMIT*

Table showing combinations of microBUILDER technologies

11 Silicon / glass technologies

SensoNor and Tronics have been the silicon / glass chip providers of microBUILDER. At the start of the project there were two Multi Project Wafer processes available: MultiMEMS and SOI-HARM.
For these two, Coventor design kits have been developed (MultiMEMS) and improved (SOI-HARM) and design rule checkers were developed. These design kits are now offered as a standard design kit that is available trough all licenses.

The MultiMEMS handbook has had a major revision with additions, restructuring and layout. Also a professional web-site for MultiMEMS was developed. The process parameters relevant for microfluidic applications, such as the optical properties of the micro machined surfaces, have been measured and documented at SensoNor and SINTEF. A deep RIE (DRIE) process has been developed at SensoNor and SINTEF, tailored to fit the needs of those customers desiring devices that handle liquids.

SensoNor has offered in total 5 MPW runs in which 41 different projects were manufactured.
Tronics' has offered in total 7 MPW runs with more than 30 designs.
Users of all MPW services were supported with design checks and, in some cases, with further customisation of the technology to include established add-on processes.

A new Silicon/Glass DRIE technology platform was established at Tronics', with associated design handbook with process parameters, layout rules and material properties compatible with targeted applications of DNA extraction and PCR. This process has been used in custom runs. Implementation of the Silicon/Glass technology platform, with delivery of more than 30 designs to several academic customers.

A new silicon technology platform "Micro-valves" was established at Tronics. The process is compatible with the fabrication of one valve or two back-sided valves. A design handbook with process parameters and layout rules as well as material properties was written. The valve technology can be mixed with the "thick PZT" technology leading to active valves or micro pumps. Delivery of a large number of dies to several commercial customers was done.

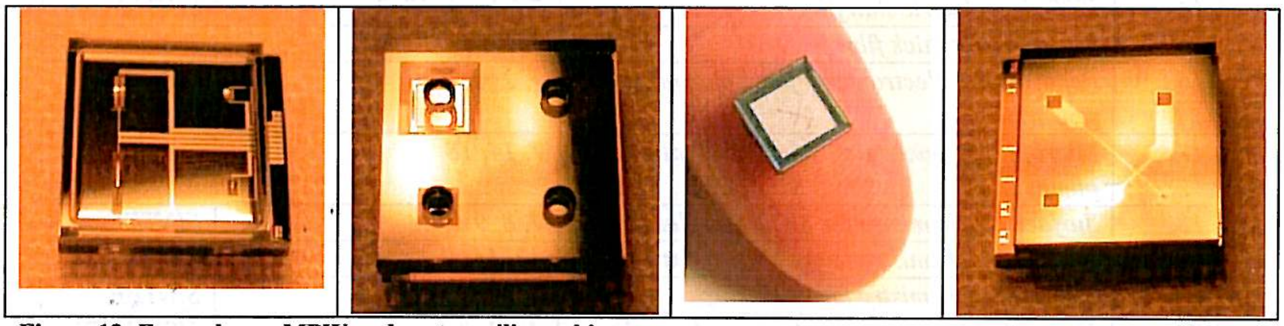


Figure 13: Examples on MPW and custom silicon chips

12 Training

Training activities are organized in three sections:

- Web training
- Master and PhD training stimulus
- Provision of courses and development of training material.
- Development of training material based on Coventor design kits.

The main responsible partners for the above sections are BME, COREP, VUC and Coventor, respectively. In addition the foundry and engineering service providers has contributed with material to all of the sections.

12.1 Training courses

Courses have been delivered at three levels:

- Awareness.
  - Project and technology overview.
  - Insight to the basics of each of the technologies is given.
  - Suitable as a project overview for trained professionals and academic staff.
  - Suitable as an introduction to foundry modules for Master and PhD students.
- Technology.
  - Detailed insight to the technologies is given in the form of detailed process descriptions, design considerations and design rules.
  - Suitable as detailed technology description for trained professionals and academic staff.
- Design hands on training.
  - Design and simulation for the MultiMEMS and Tronics MPW services using Coventor.
  - Design training using a partially finished layout of demonstrator 1 along with a 3D scale model to demonstrate the relationship between layout and resulting structure.
  - Suitable for learning microsystem design in general and specifically for the services offered.

12.1.1 Training material

Training material has been developed to fulfil the needs for the three levels of training activities. A comprehensive walk through the details of each single module is outside the scope of this document, and only a general overview of the structure of the training material will be provided

12.1.2 Awareness modules

The goal of the awareness modules is to present the basics of the technologies of all the project partners. This has been done through a consortium presentation, providing a brief introduction to each of the technologies, typical applications and some device examples. In addition, introductions to microfluidics and phenomena commonly used in micro fluidic systems have been compiled. One such example is a short, 10 slides introduction to microfluidics, used when the audience has a weak or no background in microfluidics. Among the awareness modules, you also find presentations on the demonstrators fabricated in the project, presenting how the various technologies are combined to form a sample system. The following presentations are considered "Awareness level"

- microBUILDER project presentation
- Presentation on design and characterization on the microBUILDER flow sensor (Demonstrator 1)
- "10 slides on microfluidics": A brief introduction to microfluidics, typical applications, benefits and challenges.

- Design tools: Presentation on Coventor modules suitable for the microBUILDER services and microfluidics

For awareness courses that were not followed by separate days for technology modules, a subset of the slides from the technology module was also used at awareness courses.

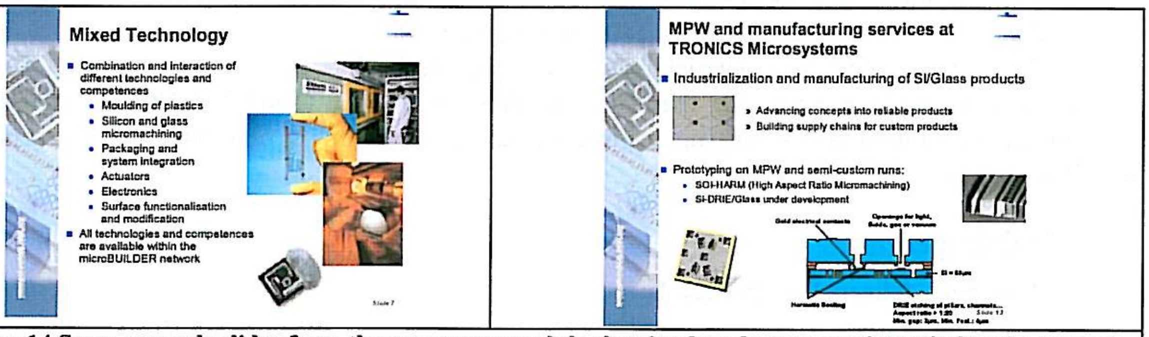


Figure 14 Some example slides from the awareness module showing how key expressions vital to the project is defined and used within the project.

12.1.3 Technology modules

The technology modules are mainly based upon information available in the design handbook. There is one presentation for each of the consortium MPW providers, SensoNor and Tronics, including thinXXS and a presentation describing the add-on and mixed technology processes. The technology level presentations provide the audience with all the technical details required to evaluate the usefulness of the offer as well as design considerations required if one wish to make use of the services.

The following presentations are considered 'Technology level':

- Presentation of thinXXS technology
- All presentations on MultiMEMS
- All presentations on Tronics
- Presentation on mixed technologies and add-on technologies.

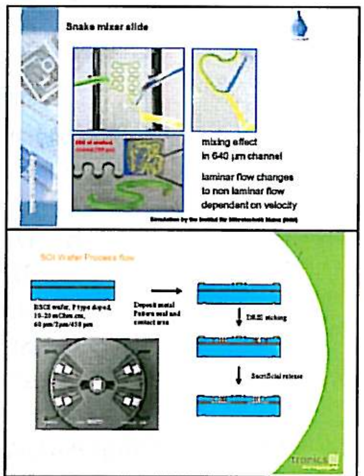


Figure 15 Sample slides from the presentation on thinXXS and Tronics MPW service

12.1.4 Design hands-on training modules

The design hands-on training modules can be organized in two sections:

- Design tutorials based upon the Coventor modules developed in the project for Tronics and MultiMEMS foundry Services.
- Design tutorials for based on Demonstrator 1: the microBUILDER flow sensor and based on Demonstrator 2, DNA extraction from whole blood.

12.1.5 Coventor design tutorials

The design tutorials based on the Coventor modules provide the course participant with useful insight into how to design for the MPW service of interest using Coventor software modules efficiently. The tutorials highlight important aspects of the modelling for the specific process and enable the user to not only estimate the performance of the designed device, but also enhance the understanding of the functionality and parameter dependence.

	
Front page of 75 page design tutorial for the MultiMEMS foundry service/CoventorWare	Front page of the 56 page design tutorial for the TRONICS foundry service/CoventorWare

12.1.6 Demonstrator 1 and 2 design tutorials

The design tutorials for demonstrator 1 and 2 have been developed to demonstrate how the microBUILDER services can be used to design mixed technology modules effectively. Based upon the actual fabricated devices, the basic principle of the tutorials is to spend more effort on why design choices have been made instead of how to implement them. This is done through providing the course participants with semi-complete versions of the design and gives them a series of assignments where they finish the design according to a tutorial.

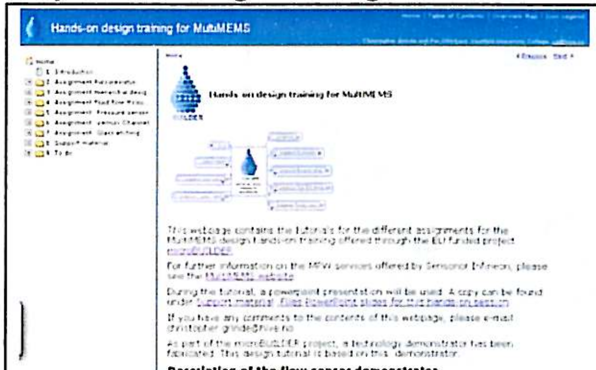
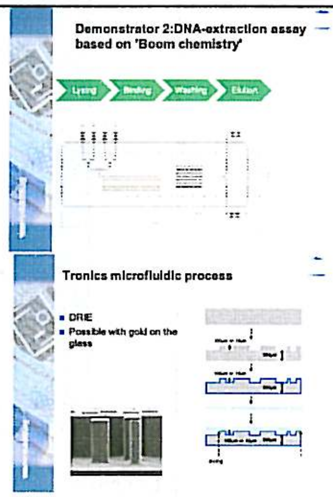
	

Figure 16 First page of web interface hands-on design training based on demonstrator 1.	**Figure 17 Selected slides from design tutorial based on demonstrator 2.**

12.1.7 Evaluation of the training material

At several of the training events, feedback has been collected. On a scale from 1 to 10, 10 being the best, training participants ranked the training modules to be good.

Table 1 Average scores and corresponding standard deviation for evaluation collected at a subset of the training sites.

	Module	Average score. Scale 1-10	Standard deviation
Module	Awareness	8,2	0,89
	Technology	8,212505	1,191888
	Hand-on	8,65	0,98

In addition to the evaluation of the training material, the participants were also requested to evaluate the lecturers; the degree the course addressed the stated objectives and provides comments and feedback. For all sites where evaluation was collected, the average score was in the range 7.5 to 9.9 for both the level of knowledge of the instructors and meeting stated objectives. Some of the comments provided by course participants are listed below

- Interesting examples of MEMS applications and their working principles
- Excellent technology overview
- [Training material] could be improved with movies
- A good opportunity to learn more about Coventor software
- Very good, but the tutorial could be more detailed
- Instructors made a remarkable effort in their support to the students.

12.1.8 Achievements

In the training program of microBUILDER, 1799 course units[2] have been given at 31 unique sites with 23.8 participants per course in average.

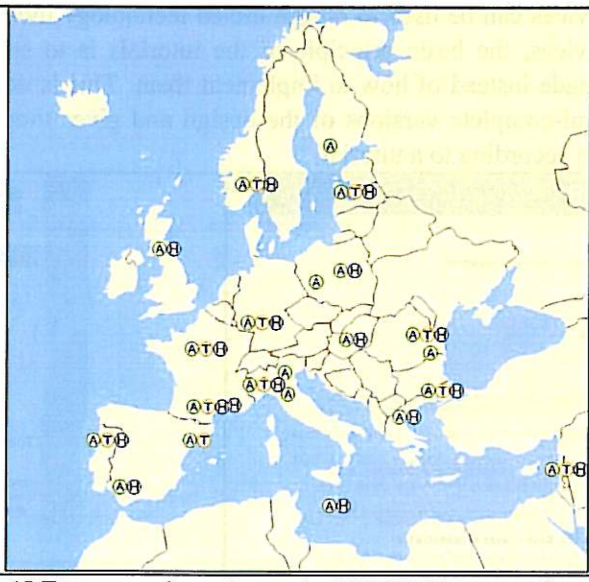


Figure 18 European sites where miroBUILDER courses have been given.
Legend:
-A for Awareness
-T for technology
-H for hands-on
In addition courses have been given in Xiamen, China, world micromachining summit Korea and Berkeley Sensors and Actuators Center (BSAC) at University of California at Berkeley.

[2] One course unit is counted as one person being given training in one module spanning one day. If one person attends a three days course with Awareness, Technology and Hands-on training, this is counted as three training units.

Table 2 Numbers on key performance indicators.

	Performance indicator of	Target M42	Logged M42
Training	Total number of courses	45	76
	Awareness		34
	Technology		14
	Design hands-on		28
	Total number of participants	450	1799
	New member states	12	15
	Member states	27	49
	Non-member states	6	13
Sales	Participants that have made use of MB services	45	3
	Universities that have adopted material	15	8

12.1.9 Example usage: a typical training event

A typical training event spans two or three days with 6-7 hours of training per day. The event starts with an awareness section, providing a general overview of the technologies and some typical application examples. All of the microBUILDER technologies are presented before going into depth with the technology for which the hands-on session will be given.

Table 3 Sample agenda from two-day training event (Warsaw, March 2008).

Session starts	Day 1	Day 2
09:00	Introduction	thinXXS technology presentation
	10 min break	10 min break
	MultiMEMS services and process	thinXXS design tutorial
12:00	Lunch	Lunch
13:00	Tronics services and process	thinXXS design tutorial cont.
	10 min break	10 min break
	Mixed technologies and device examples	thinXXS design tutorial
16:00	End	End

Depending on which tutorials used for the design hands-on training, the approach varies a little. For the CoventorWare based tutorials, the process is reviewed and a general description of the device is given before the participants are set to work on the tutorials in teams of two. If it is found that a major number of the participants lack key knowledge to understand key concepts of the tutorial, a short session in plenum is included at a relevant time in the design hands-on session. If only few participants lack this knowledge, the instructor provides the necessary knowledge on a person-to-person basis.

For the tutorials based on Demonstrator 1 and 2, the design hands-on session starts with a detailed description on the motivation for the demonstrator chosen for the session. Then an overview of what the participants have to do during the session is presented before the participants are set to work with the assignments of the provided tutorial. While the participants work with the assignment, instructors probe around to pick up questions before a solution for the assignment is presented by, preferably one of the participants, or the instructors. The session then moves on to the next assignment which is performed in a similar fashion. For each assignment, a file with the solution from the previous assignment is provided to the participants in order to ensure the possibility for equal progress for all participants.

For the tutorial based on Demonstrator 1, macro models have been made. These models are used in session in order to help the participants understand the translation from 2D layout to 3D via the process description.

12.2 Web training

A website providing training on microfluidics and mixed technologies as offered by the microBUILDER consortium is offered through the microBUILDER website under the buttons training/WEB training: http://www.sintef.no/Projectweb/Microbuilder/Training/WEB-training/. It is also available through http://it-assistant.eu/mbcd/. The website is complemented by an E-learning website available at http://www.ett.bme.hu/~bojta/develop/claroline183/ or via the web pages of ETT-BME who will maintain both websites after the end of the microBUILDER project.

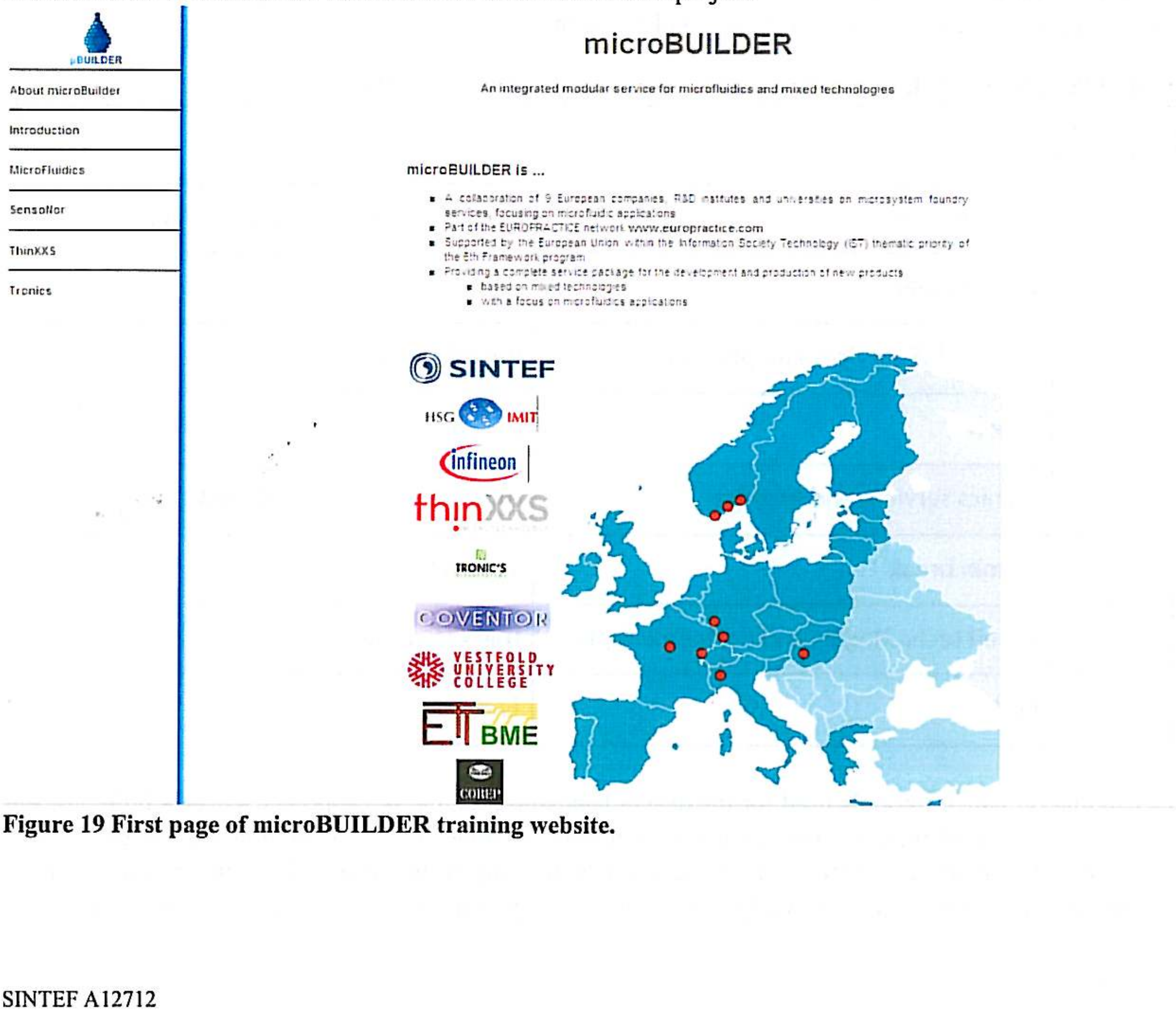


Figure 19 First page of microBUILDER training website.

12.3 Master and PhD level training

A DVD with material to stimulate education activities within mixed technologies and microfluidics has been compiled. Figure 20 show the structure and organization of the material included.

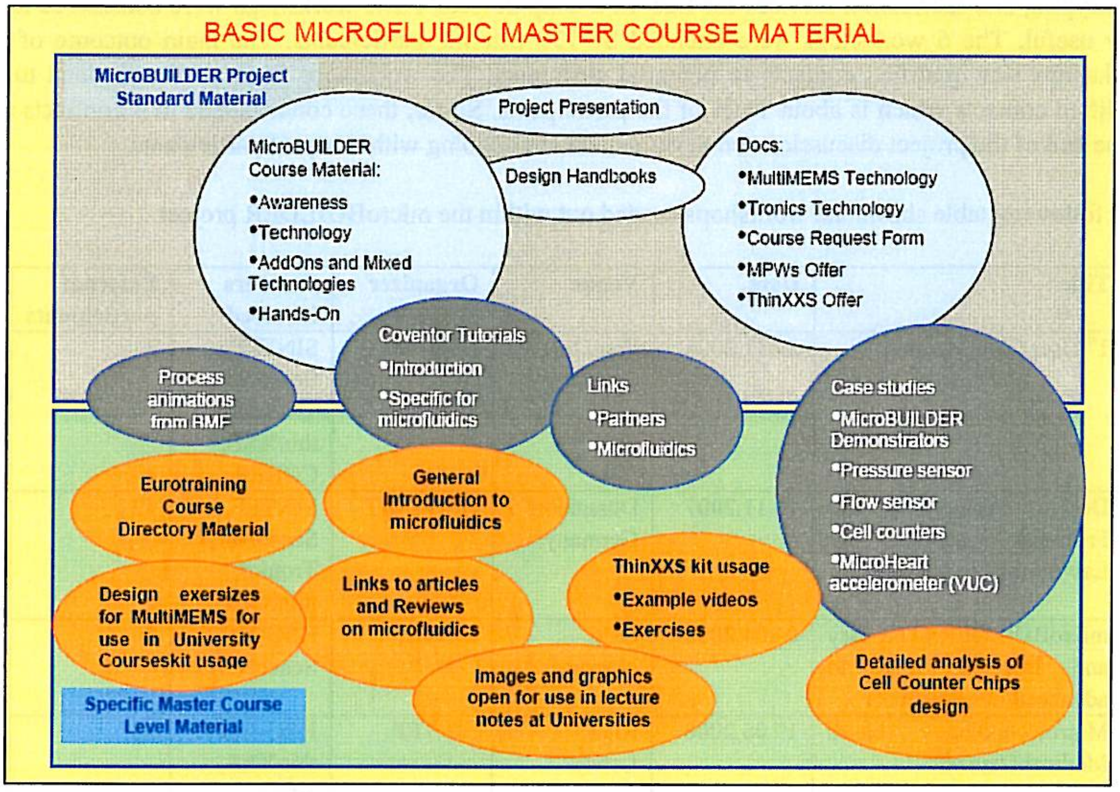


Figure 20 Structure of material collected on DVDv for Master and PhD level education.

The material included on the DVD can be summarized as follows

- A brief microBUILDER project presentation.
- A presentation of all technologies offered by the project.
- Multimedia section providing
  - Videos of course presentations from the Tel Aviv course.
  - Videos of the thinXXS construction kit in use.
  - Flash based animations of the MultiMEMS, thinXXS and Tronics MPW process.
  - Flash based animation of the technologies of Demonstrator 1.
- Case studies and presentations of device examples.
- Selected material from the EuroTraining website.

Training material for Master and PhD level education has been adopted by eight different Universities in Europe and is available trough COREP

13 Workshops arranged

The microBUILDER consortium arranged six workshops for companies interested in technologies for microfluidic and sensor / actuator applications. Each workshop had a selected theme such as "Microtechnology based medical devices", "Microsystems for Drug Delivery Devices" and "Design, prototyping and fabrication services for Lab-on-a-Chip devices". The workshops were considered to be very useful. The 6 workshops were attended by 139 external participants. The main outcome of the workshops was qualified contacts to potential customers. The workshops in total directly lead to 22 qualified contacts which is about 16 % of the participants. So far, these contacts lead to 3 contracts and at the end of the project discussions on development are ongoing with many of participants.

The following table shows the workshops carried out within the microBUILDER project

#	Title	Date	Venue	Organizer	Partners involved	External participants
1	1st User Club Meeting	29.11.2006	Frankfurt / Germany	HSG-IMIT	SINTEF, SensoNor, Tronics, thinXXS, COREP	3
2	Design, Prototyping and Fabrication services for Lab-on-a-Chip devices	16.11.2007	Düsseldorf / Germany	HSG-IMIT	SINTEF, SensoNor, Tronics, thinXXS	42
3	microBUILDER: The easy and low-cost road to advanced microsystems	04.04.2008	Oslo / Norway	SINTEF	HSG-IMIT, SensoNor	20
4	Microtechnology based Medical Devices	19.06.2008	Riga / Latvia	SINTEF	HSG-IMIT, thinXXS, VUC	28
5	Microtechnology based Medical Devices	24.09.2008	Copenhagen / Denmark	SINTEF	HSG-IMIT, thinXXS	23
6	Microsystems for Drug Delivery Devices	21.11.2008	Düsseldorf / Germany	HSG-IMIT	SINTEF, thinXXS	23
					Total:	**139**

14 Roadmap

A roadmap for mixed technologies, including a definition of the technological offer of microBUILDER was developed. The roadmap addresses application fields where the technologies can be further developed and combined to give an enhanced functionality. According to the overall strategy of microBUILDER the roadmap focuses on developments in the field of microfluidics but is not limited to it. Therefore, the roadmap has a special focus on mixed technologies for microfluidic applications, but other application fields where the mixed technology can be utilized are partly also addressed.

The following roadmapping approach was used:

- Selection of the most relevant markets for microBUILDER
- Analysis of the market demands and current hurdles
- Inventory of the technological offer of microBUILDER (at the time the roadmap was developed)
- Definition of the future technological offer in order to meet the identified market needs

Based on the outcome of the roadmap mixed technologies were selected. As recommended by the reviewers, an updated version of the roadmap including time scales for expected future product developments was developed. As Lab-on-a-chip was analysed to be the most relevant topic for microBUILDER, special emphasis has been given to this field. Beside others, a time scale for key technology developments building the basis for future lab-on-a-chip product developments was developed and is exemplarily presented in Figure 21.

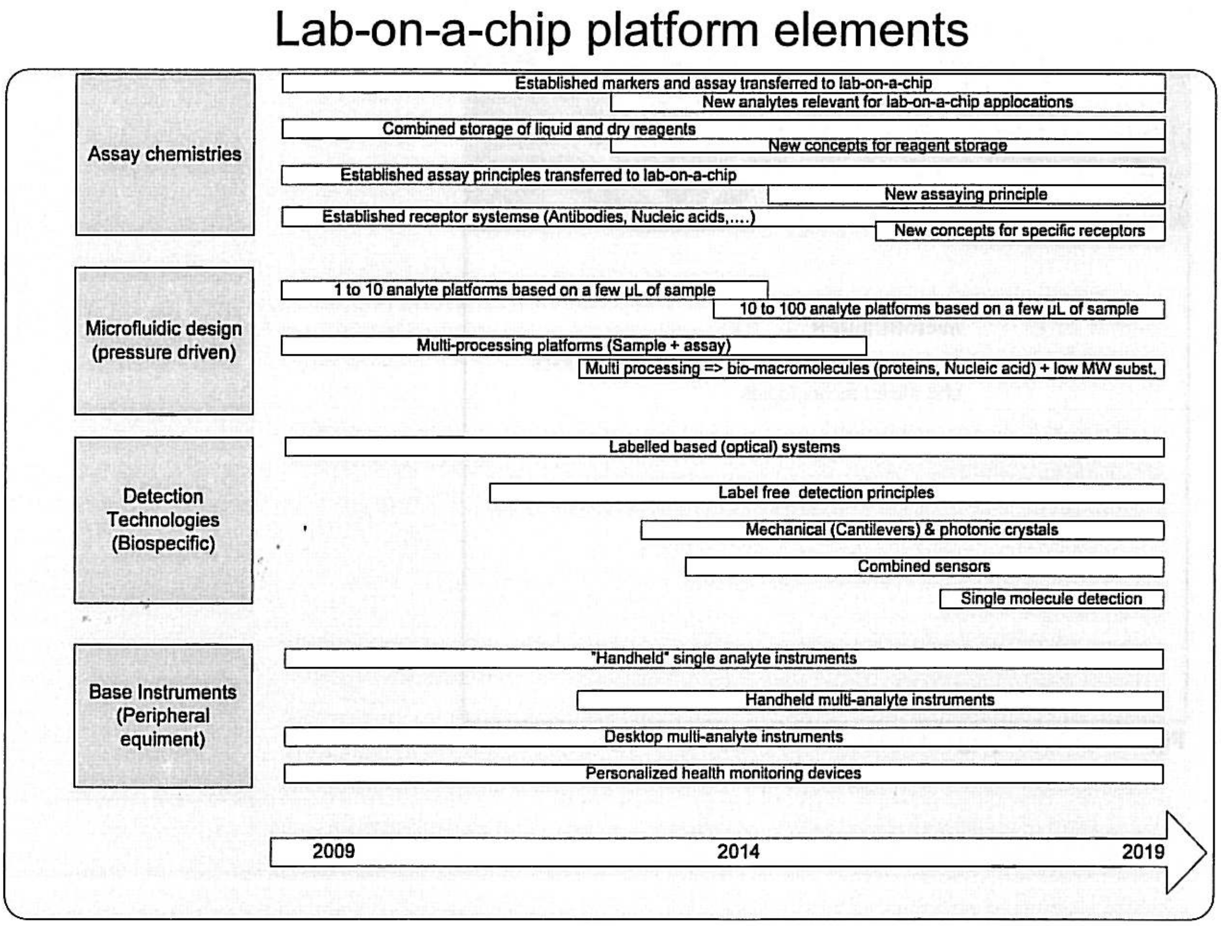


Figure 21: Time scale for some key technology developments which build the basis for future Lab-on-a-chip product developments.

15 Dissemination

During the microBUILDER project, the partners have has oral presentations of microBUILDER at 35 different workshops and conferences (in addition to the microBUILDER workshops). Also, we have been presented with stands with demonstrators or posters at 20 different fairs and exhibitions. These conferences and fairs have been geographically spread around Europe. In addition to this, the microBUILDERs have concentrated on customer meetings and have had discussions with a very large number of potential partners.

For the information about microBUILDER, a brochure was designed and printed. As part of the brochure a corporate design (CD) for the microBUILDER project was developed. This CD was used for all microBUILDER promotion material. The brochure was distributed via customer visits, fairs, exhibitions, workshops, etc. The brochure contains general information about microBUILDER, the service offer and the partners of microBUILDER. Figure 22 shows the front page of the brochure.

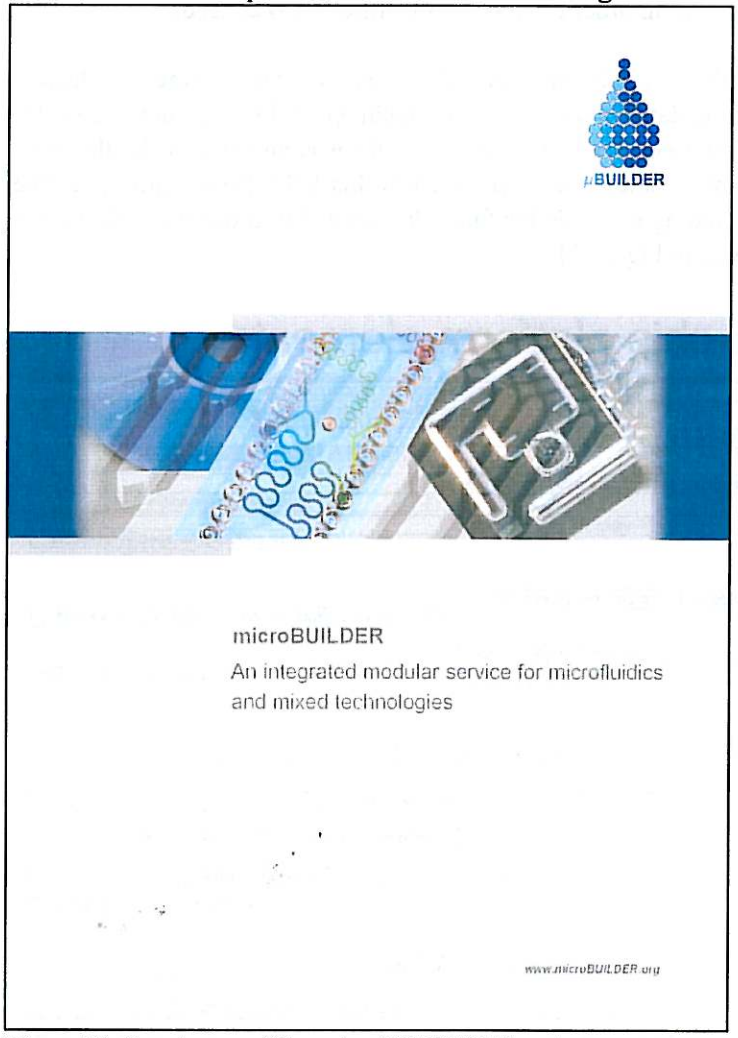


Figure 22: Front page of the microBUILDER brochure.

Second microBUILDER poster (2008)

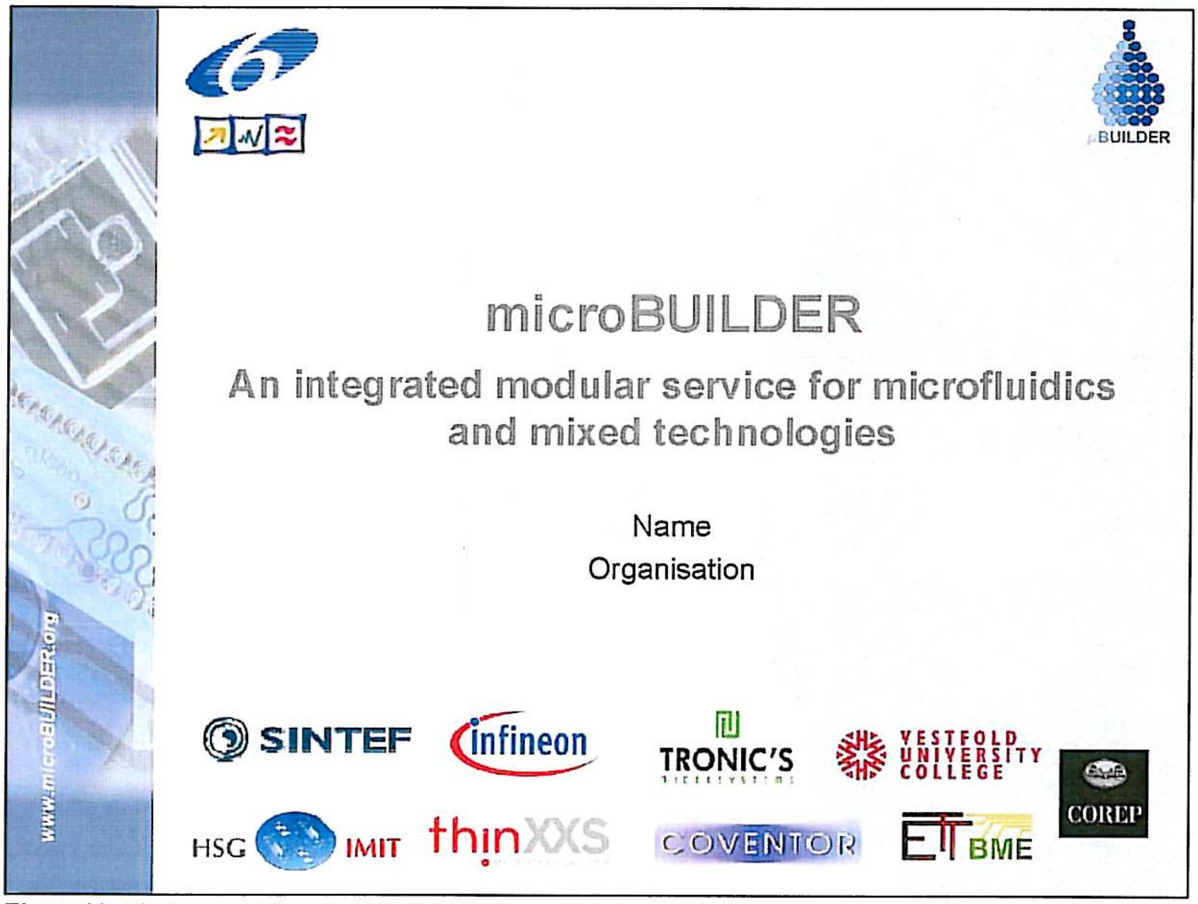


Figure 23: First page of the microBUILDER PowerPoint presentation.

16 Publications

The microBUILDER partners have mainly published papers in relation to conferences where microBUILDER was presented, and magazines like MST news which may be read by customers in need of technology. But there are also scientific papers on devices such as the cell counter / cell focuser, the microphone and lab-on-a-chips as well as for functional materials and on the "training of MEMS" approach used at the hands-on courses.

Magazine/Journal	Title	Number	Year
MST News	MicroBUILDER - A new Europractice Type Project for Micro/Nano-scale Integration	2	2006
MST News	Micro/Nano-scale Integration	2	2007
European Medical Device Manufacturer	Microsystems Production to the Power of Nine	2	2007
EP Glossy report 2007	microBUILDER: Flow sensor module for a microfluidic platform		2007
MST News	microBUILDER: A Flow-sensor Module for a Microfluidic Platform	6	2007
MST News	Diagnostics and Sensing, Microfluidics in Practice	1	2008
MST News	microBUILDER : upcoming training events and workshops	2	2008
Smart Systems Integration Conference Proceedings	The microBUILDER technology platform: building a microfluidic flow sensor		2009

Microsystem Technologies : Micro- and Nanosystems Information Storage and Processing Systems	RNA amplification chip with parallel microchannels and droplet positioning using capillary valves	14 (4-5)	2008
Teknisk Ukeblad	Helse i hver sensor	17/10	2008
Elektronikk	Når mikrokomponenter skal bygges	3	2009
MST News	Piezoelectric microsystems for industry	3	2008
EWME2008 - European Workshop on Microelectronics Education	An approach to seminar based MEMS training	Proceedings	2008
Advances in Science and Technology	Microsystems for blood cell counting	57	2008
30th annual international conference of the IEEE engineering in medicine and biology society	Blood Cell Counting by Means of Impedance Measurements in a Microsystem Device	Proceedings	2008
15th IEEE International Conference on Electronics, Circuits, and Systems	MEMS-based blood cell counting system	Proceedings	2008
Langmuir	Quantitative measurements of protein binding to Cyclic Olefin Copolymer (COC) micro-channel surfaces with and without antibinding surface layers.	In preparation.	To be submitted Sept. 2009.
Conference proceedings of Eurosensor 2009	Characterization of two novel low frequency microphones for photoacustic gas sensors		2009
Conference proceedings of Eurosensor 2009	A novel shock absorber condition embedded sensor with a thick silicon membrane for pressure sensing		2009
Proceedings of Micro Mechanics Europe 2009	Fabrication of a MEMS Triaxial Accelerometer Using Novel Post-Processing of an MPW Process		2009
Proceedings of "Symposiumof Design , Test, Integration and Packaging"	A Clover Shaped Silicon Piezoresistive Microphone for Miniaturized Photoacoustic Gas Sensors		2009
Proc. COMS 2009	Design Support for MEMS Foundries – Status and Evaluation	Proceedings	2009
Proc. COMS 2009	Cardiaccs – a Startup for Commercialisation of a 3D Microaccelerometer System for Postoperative Heart Monitoring	Proceedings	2009
Proc. COMS 2009	Experiences and outlook from recent years of developing education in micro- and nanotechnologies at Vestfold University College	Proceedings	2009
MS'08 - AMSE International Conference on Modelling and Simulation	Modeling and Simulation of Micro-Electro-Mechanical System Pressure Sensor for Biomechanical Application	Proceedings	2009

ICECS 2009, the 16th IEEE International Conference on Electronics, Circuits, and Systems	Silicon Implementation of Micro Pressure Sensor	Submitted	2009
microTAS 2009	Rheoplug – Segmented Flow based Viscometer	Proceedings	2009
Transducers 2009	Teflon-carbon black as new material for the hydrophobic patterning of polymer labs-on-a-chip	Proceedings	2009
MST Kongress	Volume measurement of dispensing processes with a novel non-contact and fluid independent procedure	Proceedings	2009
Conference on Multi-Material Micro-Manufacture (4M) 2009	Microfluidic Platforms for Miniaturisation, Integration and Automation of Biochemical Assays	Proceedings	2009
MicroMechanics Europe 2009 (MME 2009)	A novel ultra-planar, long-stroke, and low voltage piezoelectric micromirror	Proceedings	2009

Table 4: List of microBUILDER publications