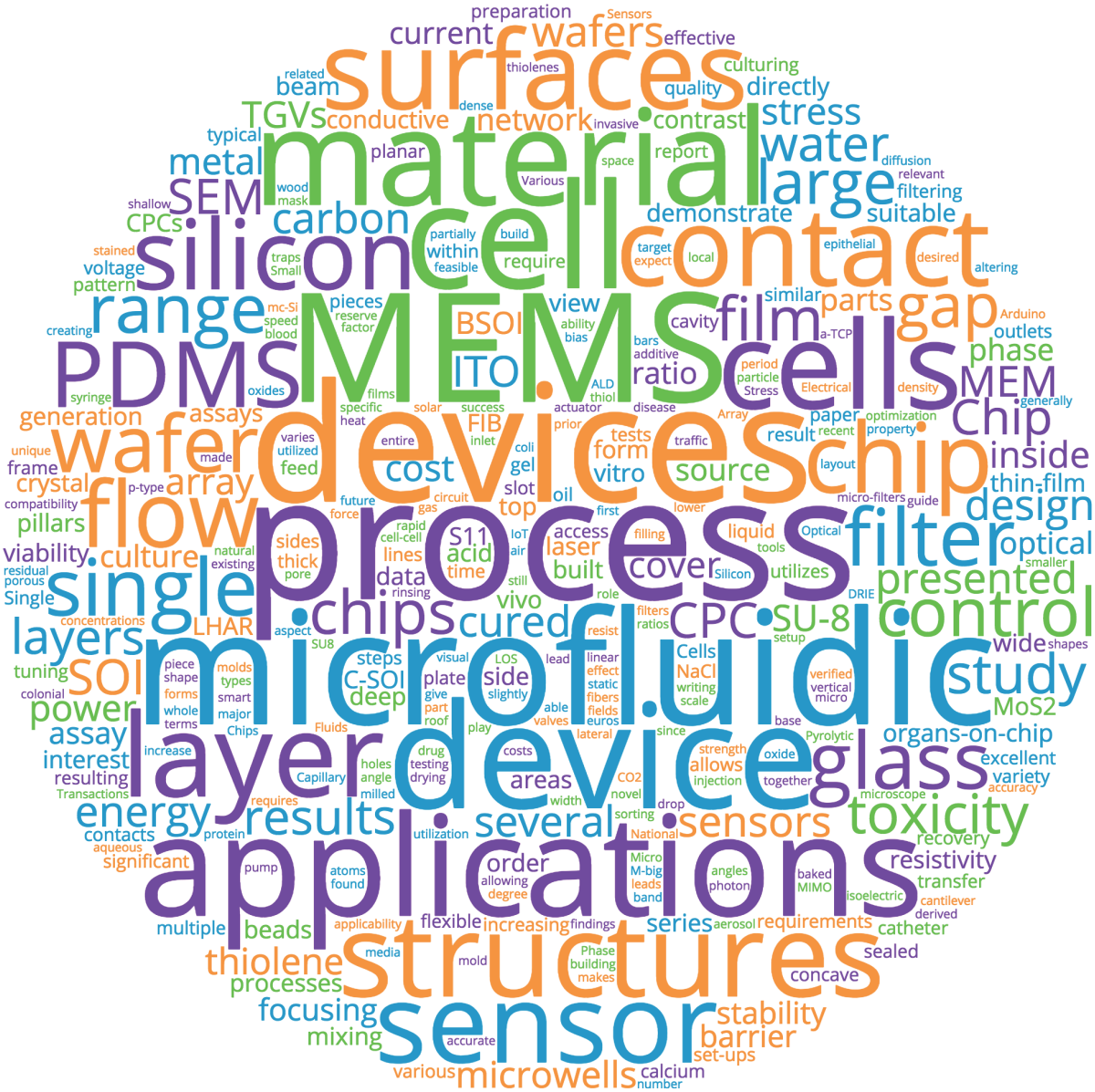
Book of Abstracts

Micronano System Workshop

May 13-15, 2018

Aalto University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Content

Oral presentation abstracts

Session 1

Monday 14th

09:15 - 11:00

SOI based platforms for next generation MEMS manufacturing

Jani Karttunen

Product Manager for C-SOI products,
Okmetic Oy

The rapidly growing IoT industry sets new demands for microelectromechanical system (MEMS) devices, the central building blocks of smart systems. Advanced MEMS devices are commonly built on thick-film bonded Silicon-On-Insulator wafers (BSOI), to gain benefits in precision and control of MEMS structures, device miniaturization and packaging.

Requirements for lower cost and higher volumes are driving towards sensor miniaturization, which requires higher precision BSOI starting materials to maintain existing level of device performance. Requirements for reliability and performance improvements on the other hand drive for improvements in precision of BSOI materials, and use of hermetically sealed structures enabled by Cavity SOI (C-SOI) wafers or wafer level packaging.

Okmetic solutions to these challenges are:

- Enhanced SOI (E-SOI) wafers, which are thick BSOI wafers with superior device layer thickness uniformity, independent of layer thickness.
- C-SOI wafers, which enable part of sensor structures to be built into the SOI wafer as part of the wafer manufacturing process.
- Through Silicon Vias (TSV) for sensor interconnections in wafer level packaging
- Combinations of above technologies

Application examples of these wafer types are shown. In case of E-SOI technology, case studies about sensor miniaturization, reducing variation in existing sensor designs and enabling completely new application areas are presented. For C-SOI, the requirements of industrial manufacturing, such as element level process data are discussed. Application examples for TSV show how Okmetic poly silicon VIAs can be used for wafer level packaging and how they can be combined with BSOI and C-SOI technologies. High resistivity crystal material for radio frequency (RF) applications is used to satisfy the current performance requirements.

Through-Glass Vias for MEMS Packaging

Miku J. Laakso[1], Simon J. Bleiker[1], Jessica Liljeholm[1,2], Gustaf Mårtensson[3], Mikhail Asiatici[1,4], Andreas C. Fischer[1,2], Göran Stemme[1], Thorbjörn Ebefors[2,5], and Frank Niklaus[1]

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[2]Silex Microsystems AB
[3]Mycronic AB
[4]EPFL École polytechnique fédérale de Lausanne, Processor Architecture Laboratory
[5]MyVox AB

Novelty / Progress Claims We have developed a new method for fabrication of through-glass vias (TGVs). The method allows rapid filling of via holes with metal rods both in thin and thick glass substrates.

Background Vertical electrical feedthroughs in glass substrates, i.e. TGVs, are often required in wafer-scale packaging of MEMS that utilizes glass lids. The current methods of making TGVs have drawbacks that prevent the full utilization of the excellent properties of glass as a package material, e.g. low RF losses. Magnetic assembly has been used earlier to fabricate through-silicon vias (TSVs), and in this work we extend this method to realize TGVs[1].

Methods The entire TGV fabrication process is maskless, and the processes used include: direct patterning of wafer metallization using femtosecond laser ablation, magnetic-field-assisted self-assembly of metal wires into via holes, and solder-paste jetting of bump bonds on TGVs.

Results We demonstrate that: (1) the magnetically assembled TGVs have a low resistance, which makes them suitable even for low-loss and high-current applications; (2) the magnetic-assembly process can be parallelized in order to increase the wafer-scale fabrication speed; (3) the magnetic assembly produces void-free metal filling for TGVs, which allows solder placement directly on top of the TGV for the purpose of high integration density; and (4) good thermal-expansion compatibility between TGV metals and glass substrates is possible with the right choice of materials, and several suitable metals-glass pairs are identified for possible improvement of package reliability[2].

[1] M. Laakso et al., IEEE 30th Int. Conf. on MEMS, 2017. DOI:10.1109/MEMSYS.2017.7863517
[2] M. Laakso et al., "Through-Glass Vias for Glass Interposers and MEMS Packaging Utilizing Magnetic Assembly of Microscale Metal Wires," *manuscript in preparation*

Piezoelectric MEMS sensors and actuators - benefits and applications

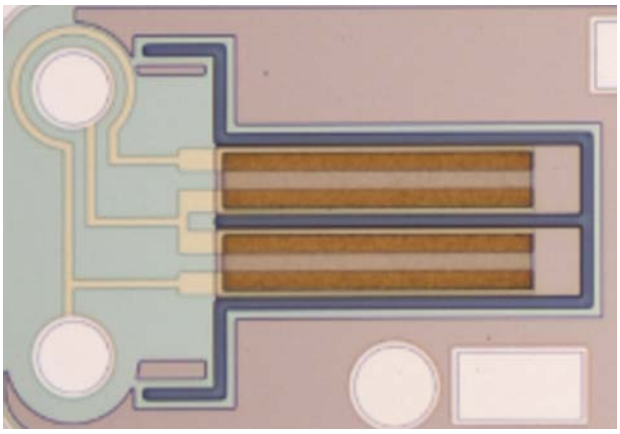
Tuomas Pensala, James Dekker, Panu Pekko, Jyrki Kiihamäki

VTT Technical Research Centre of Finland Ltd

Mainstream of MEMS sensors of the present day are both driven and sensed electrostatically. While allowing for simple manufacturing process flow, downsides include the need for DC bias, sometimes with high voltage, narrow actuation gaps, large actuator structures, and intrinsic nonlinearity.

Piezoelectric transduction using piezoelectric thin film transducers monolithically integrated on the Si MEMS devices offers many advantages. Piezo actuation is intrinsically linear, does not need DC bias and generates high force with low voltage. It offers significant area reduction possibilities in cases where large actuator combs can be replaced by piezo-actuators integrated on the springs of the MEMS device. Tradeoffs include more complex processing, more demanding requirements for packaging, and need for careful stress control of the thin film structures.

VTT has developed a piezo-on-cavity-SOI process platform for e.g. resonant MEMS devices, where AlN or ScAlN is used as the piezoelectric material. Benefits of the platform will be presented via a variety application examples such as a resonator exhibiting quartz-like performance, a phase sensitive gyro sensor, and a MEMS mirror for automotive LIDAR application. Benefits of using piezoelectric transduction will be addressed in each case.



A photograph of a piezo actuated in-plane tuning fork resonator fabricated using the piezo-on-C-SOI platform.

Microfluidics for High-Pressure Analyses

Martin Andersson, Lena Klintberg, Karolina Svensson, Simon Södergren,
Javier Cruz, and Klas Hjort
Uppsala University, Microsystems Technology Division

When using appropriate materials and microfabrication techniques, the small dimensions and mechanical stability of microstructured devices allow for processes at high pressures without loss in safety. The largest area of applications has been demonstrated in chemistry, where extraction, synthesis and analyses often excel at high densities and high temperatures. These two parameters are accessible through high pressures. Capillary chemistry has been used since long but, just like in low-pressure applications, there are several advantages in using microfluidic platforms for control of reactions, catalysis, mixing and separation. For example, planar isothermal set-ups, large local variations in geometries, dense form factors, small dead volumes and precisely positioned microstructures.

In analytical systems, we are studying high-pressure components and microsystems for sampling, sample preparation, analyses and fractionation. We will present what drives our research and development: Our experimental set-up with high-pressure pumps, high-speed camera, sensors, valves, piston-chambers, backpressure regulators, cooling table, *etc*. How we have built capability in pumping and valving by the use of stainless steel and paraffin actuation. How we are making high pressure silicon-glass and glass-glass chips with integrated electrical thin film sensors, using printed circuit boards to ease handling of the chips and integrating modules. A set of relevant publications are listed below.

[1] M. Andersson, I. Rodriguez-Meizoso, C. Turner, K. Hjort, and L. Klintberg, Dynamic pH determination at high pressure of aqueous additive mixtures in contact with dense CO_2, J. Supercrit. Fluids (accepted Febr 2018).
[2] J. Cruz, S. Hooshmand, T. Graells, M. Andersson, J. Malmström, Z.G. Wu, and K. Hjort, J. Micromech. Microeng. 27, 084001 (2017).
[3] M. Andersson, K. Hjort, and L. Klintberg, Fracture strength of glass chips for high-pressure microfluidics, J. Micromech. Microeng. 26, 095009 (2016).
[4] Andersson, K. Hjort, and L. Klintberg, Fracture strength of glass chips for high-pressure microfluidics, J. Micromech. Microeng. 26, 095009 (2016).
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[9] R. Bodén, K. Hjort, J.-Å. Schweitz, and U. Simu, Metallic micropump for high-pressure microfluidics, J. Micromech. Microeng. 18 (2008) 115009 (7pp). [

Session 2

Monday 14th

11:15 - 12:15

THz MEMS - Micromachining enabling new solutions at millimeter and submillimeter frequencies

Joachim Oberhammer

KTH Royal Institute of Technology, EECS-MST

Silicon micromachining is mainly known from being fabrication technology of MEMS switches for planar circuits, which have demonstrated excellent RF performance[1], and already found their way as commercial products, for instance into mobile phones for tuning antenna matching circuits[2]. However, micromachining allows even for creating three-dimensional geometries which enables new, high-performance RF/microwave/THz device and system concepts. Silicon is the preferred material for micromachining, since silicon micromachining processes are highly advanced and robust, it allows for fabricating micrometer-sized features and high-aspect ratio geometries with a height-to-feature-size ratio of over 110:1, and since silicon machining is a highly parallel batch fabrication technology where many thousands of devices can be fabricated simultaneously on silicon wafers with high product uniformity and high yield[3]. Silicon-micromachining is an excellent fabrication technology for microwave filters, in particular above 100 GHz, due to small and accurate feature definition and unparalleled surface roughness achieving very low losses.

This paper first gives an overview of the world-wide state of the art in silicon micromachining for applications in the frequency range from 100 GHz to 2.9 THz, including recent work from leading players such as NASA-Jet Propulsion Laboratory and Northrup Grumman, both of which have demonstrated micromachined filters up to 1 THz.

KTH has a long track record in exploring silicon micromachining for passive and reconfigurable microwave devices and circuits, including and in particular filters. The second part of the talk gives an overview of recent achievements.

KTH has developed an ultra-low loss micromachined-waveguide technology, which achieves 0.008 dB/mm loss in the 110-170 GHz band[11], and 0.02 dB/mm losses in the 220-330 GHz frequency band[4]. These very low losses allow to create cavity resonators with measured unloaded Q-factors of 1600 in the 110-170 GHz band, and of 800 in the 220-330 GHz band, which enables very low-loss filters even for small fractional bandwidth.

As filter demonstrators, the following recent results will be shown: (1) a 4-pole and 2-transmission zero 1.85% fractional bandwidth filter at 270 GHz, with only 1.5 dB insertion loss and 18 dB return loss (cavity Q-factors of 750-800). Since KTH's simulation models take fabrication imperfection into account in the design phase, excellent agreement between the simulations and the measurements can be presented[5]; (2) a 6-pole 141-148 GHz bandpass filter for telecommunication-link applications, with insertion loss as low as 0.4 dB and return loss better than 20 dB [11]; (3) a design study showing that these high Q-factors enable so sharp filters that the sub-spectral lines of the 183 GHz water line for earth observation can be resolved.

As further demonstrators for this low-loss micromachined waveguide technology, the following very recent devices will be shown: (1) a micromachined, full-band 3-dB coupler at 220-330 GHz with only 3.2 dB insertion loss and high directivity[6]; (2) a low loss power divider/coupler technology[7]; (3) integrated micromachined absorbers and attenuators; (3) a full-band turn-style orthogonal mode transducer at 220-330 GHz with insertion loss of <0.5 dB and cross-polarization isolation >50 dB, which is the first implementation of this type of microwave component above 110 GHz in any technology[12].

Furthermore, KTH has also been working on integrating MEMS (micro-electromechanical systems) actuators into its micromachined waveguides, enabling high-performance reconfigurable circuits. As the key component, a micromachined waveguide switch will be presented, which achieved 0.3 dB insertion loss and isolation of 40 dB at 50-75 GHz, despite being just 30 µm thick[8]. An embodiment of this switch technology has achieved 18-25 dB isolation and 2.5 dB insertion loss at 10-times higher frequencies, in the 500-750 GHz band[9]. The latest embodiment of this switch technology comprises a 140-220 GHz switch with better than 0.6 dB insertion loss and better than 50 dB isolation over the whole band[13]. Such switches achieve basically the same performance as bulky, heavy rotary waveguide switches, but are of sub-mm size and can switch in the micro-second range, thus being ideal for compact, low-weight reconfigurable circuits for space-borne applications. Furthermore, a 3.3-bit phase-shifter integrated in a micromachined waveguide, operating at 500-600 GHz, in a collaboration with NASA-JPL will be shown[10].

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[5] Oleksandr Glubokov, Xinghai Zhao, Bernhard Beuerle, James Campion, Umer Shah, and Joachim Oberhammer, "Micromachined Multilayer Bandpass Filter at 270 GHz Using Dual-Mode Circular Cavities," Procs. IEEE International Microwave Symposium 2017, Honolulu, HI, USA, June 4-9, 2017.

[6] Jan Svedin, Robert Malmqvist, Bernhard Beuerle, Umer Shah, and Joachim Oberhammer, "A 230-300 GHz low-loss micromachined waveguide hybrid coupler," Procs IEEE/EuMA European Microwave Conference 2017, Nuremberg, Germany, 8-13 October, 2017.

[7] Robert Malmqvist, Andreas Gustafsson, Jan Svedin, Bernhard Beuerle, Umer Shah, and Joachim Oberhammer, "A 220-325 GHz low-loss micromachined waveguide power divider," Procs IEEE Asia-Pacific Microwave Conference 2017, Kuala Lumpur, Malaysia, Nov. 13-16, 2017.

[8] Zargham Baghchehsaraei and Joachim Oberhammer, "Parameter Analysis of Millimeter-Wave Waveguide Switch Based on a MEMS-Reconfigurable Surface," IEEE Transactions on Microwave Theory and Techniques, vol. 61, no. 12, Dec. 2013.

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[10] U. Shah, E. Decrossas, C. Jung-Kubiak, T. Reck, G. Chattopadhyay, I. Mehdi, and J. Oberhammer, "Submillimeter-Wave 3.3 bit RF MEMS Phase Shifter Integrated in Micromachined Waveguide," IEEE Trans. on Terhaertz Science and Technology, vol. 6, no. 5, pp. 706-715, 2016.

[11] Adrian Gomez, Umer Shah, Joachim Oberhammer, "Wideband 220 – 330GHz Turnstile OMT Enabled by Silicon Micromachining, " accepted for presentation at IEEE International Microwave Symposium 2018.

[12] James Campion et al., "An Ultra Low-Loss Silicon-Micromachined Waveguide Filter for D-Band Telecommunication Applications ," accepted for presentation at IEEE International Microwave Symposium 2018.

[13] submitted for publication.

Session 3

Monday 14th

14:30 - 15:15

Session 3A

Monday 14th

15:30 - 16:30

Micromachined D-Band Multi-layer Gap Waveguide Slot Antenna Array for Line of Sight (LOS) MIMO Systems

S. Farjana[1], A.U.Zaman[2], S.Rahiminejad[1,3], J. Hansson[4],T. Eriksson[2], S.Haasl[5], T. Emanuelsson[6], J. Hansryd[7], Yinggang Li[7], P. Enoksson[1]

[1]Chalmers University of Technology, Department of Microtechnology and Nanoscience
[2]Chalmers University of Technology, Department of Electrical Engineering
[3]Nasa Jet Propulsion Laboratory, USA
[4]MerceneLabs AB
[5]RISE Acreo
[6]GapWaves AB
[7]Ericsson Research AB

With the development of future 5G networks where each user will have more than one Gb/s data connectivity, data traffic will grow enormously (~ 50 Gb/s) at the base stations and high speed back-hauling will play a very critical role for network performance. Today's microwave backhaul link will not be able to handle this enormous data traffic. To make this possible, research work has now started on the long term use of frequencies beyond 100 GHz, targeting the support of 5G evolution towards 2020[1]. In our study, we focus on very low loss antenna elements consisting of several metal coated layers. Manufacturing of waveguide slot array antennas requires high precision, and good electrical contact between separate joining parts (which is a problem at high frequencies due to the small dimensions)[2]. This paper presents a micromachined based 140 GHz planar antenna array based on gap waveguide technology.

The fabrication process has been optimized for a LOS MIMO antenna operating at 140 GHz. The antenna consists of three layers: the slot layer, the groove gap cavity layer and the feed network layer. Each layer is polymer based and has its own fabrication process. The slot layer is completely made out of Au coated SU8, while the groove gap cavity layer and the feed network layers are fabricated by injection molding. SU8 on Si masters are made, and are then used to make PDMS molds. The PDMS mold is paired with a milled Al piece. The Al pieces are used to define thewaveguide opening in the feed network layer and the coupling slots in the groove gap cavity layer. The molds are then injected with the polymer OSTE322. The OSTE322 pieces are UV exposed, released and then hard baked. The cured pieces are then covered with gold.

We have measured the S_{11} of the micromachined gap waveguide antenna by using a Key sight PNA and D-band extender modules. The simulated S_{11} for the complete 16×16 element antenna array is well below -14dB level over the band of interest from 130-150GHz. However, the measured S_{11} is 6dB higher compared to the simulation. This higher S_{11} level in measured case can be attributed to the fabrication inaccuracies observed after the first trial of fabrication.

References

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Nanofibrillated and bacterial celluloses as renewable piezoelectric sensor materials

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Cellulose based nanomaterials, generally known as nanocellulose, are interesting renewable biomaterial which has potential applications for example in material science, electronics and biomedical engineering and diagnostics[1]. Cellulose has a strong ability to form light-weight, highly porous, entangled networks makes nanocellulose suitable as substrate or membrane material for various applications, for example as a material for in supercapacitors in different ways[2,3,4].

The piezoelectricity of wood was proposed already in 1950's[5], but only slightly studied since. Here, we report the experimental evidence of significant piezoelectric activity of different type nanocellulose films. We have studied both wood-based cellulose nanofibril (CNF) films[6] and bacterial nanocellulose (BC) films[7] (see Figure 1), as well as composite of chitosan and cellulose nanocrystals (CNC)[8]. Our results suggest that nanocellulose is a potential bio-based piezoelectric sensor material.

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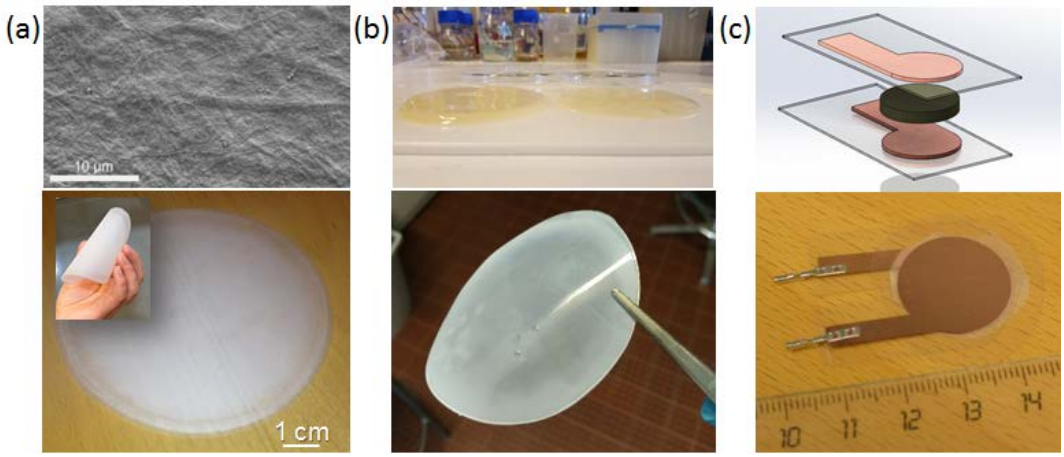

(a) wood based nanocellulose film, (b) bacterial nanocellulose film, (c) piezoelectric sensor.

PillarHall LHAR structure for Thin Film Conformality Measurements

M. Utriainen[1], V. Korpelainen[2], O. M. E. Ylivaara[1], Feng Gao[1], M. Ylilammi[1] and R. L. Puurunen[3]

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The downscaling of future semiconductor devices with increasing 3D character leads to increasing demand of highly conformal thin films. Similarly, conformal deposition enables new opportunities in microelectromechanical systems (MEMS), photonics, and other material science applications. Although, conformality is a core value proposition of Atomic Layer Deposition (ALD) and related thin film processing methods, it is challenging to measure and quantify, while standardized measurement methods do not exist.

A potential approach to circumvent the challenge is a MEMS-based all-silicon lateral high aspect ratio (LHAR) test structure, PillarHall® developed at VTT [1-3]. The test chip is compatible for CMOS process lines and suitable for wide temperature range. PillarHall® Prototype 3B LHAR test structure consists of a lateral gap of typically 500 nm (optionally, 100 to 2000 nm) in height under a polysilicon silicon membrane, supported by silicon pillars. One test chip consists of multiple LHAR structures, where the gap length varies from 1 to 5000 µm, giving aspect ratios (length vs height) for the typical ~500 nm gap of 2:1 to 10 000:1. Silicon pillars provide dimensional accuracy by stabilizing membrane roof. The pillars and additional distance indicator lines provide internal length scale for visual examination. PillarHall® Test Chips are available at VTT for applications and research cooperation. The test chips have been employed with good success in ALD, conformality metrology for baseline and figure-of-merits as well as comparative studies with vertical AR structures. Future opportunities are e.g in process optimization and control & monitoring.

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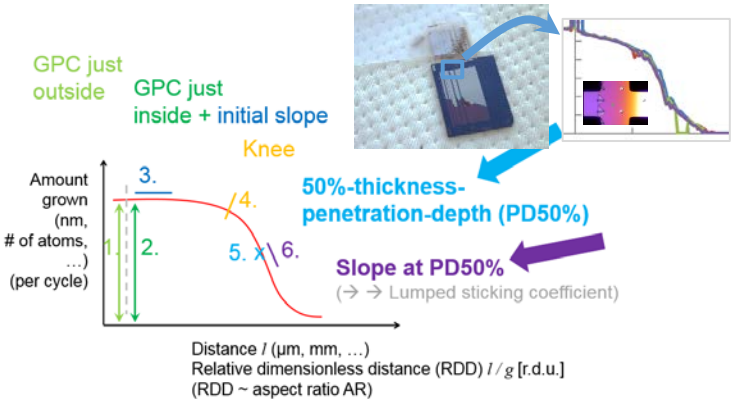


Characterizing conformality of the deposited film from the LHAR3B test structure. After removal of the silicon roof membrane, the conventional surface analysis tools can be employed to give access to the new parameter space from the trench wall.

Patternability of quasi-mono silicon beyond the photovoltaic industry

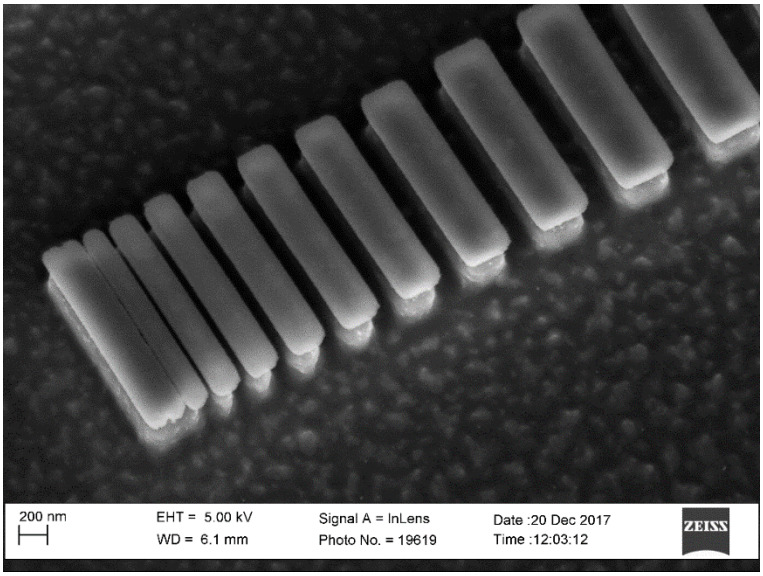
Zhengjun Liu[1], Nikolai Chekurov[2], Ville Vähänissi[1], Ilkka Tittonen[1], Hele Savin[1]

[1]Aalto University, Department of Electronics and Nanoengineering
[2]Oxford Instruments Technologies Oy

Seed assisted casting methods in the substrate production have been utilized for wafer production by photovoltaic (PV) industry. A new type of seed-assist-casted wafers, called quasi-mono silicon (QM-Si), combine the most crucial benefits of the single crystalline (sc-) and multicrystalline silicon (mc-Si). An optimal QM-Si process offers the high quality of sc-Si and low cost of mc-Si. Since QM-Si has already been successfully applied in solar cell fabrication and the large majority of a QM-Si ingot is in single crystalline form, we expect that QM-Si has great promise beyond the PV industry as well.

The applicability of the micro- and nano patterning methods and the resulting pattern quality directly determine the properties of the final devices. Currently QM-Si substrates are available for photovoltaic purposes with non-polished surface making accurate patterning impossible for conventional lithography methods such as photolithography, nanoimprint lithography and electron beam lithography. Focused ion beam (FIB) lithography provides an innovative method enabling rapid and accurate patterning of the corrugated QM-Si wafer surface. The Ga^+ FIB implantation into silicon reduces the etch rate of the implanted region and as a result, the gallium-doped silicon can serve as a mask for silicon etching in a variety of conditions.

Here we demonstrated the patternability of QM-Si wafers by achieving a submicron resolution in a silicon line array fabricated by FIB lithography and deep reactive ion etching (DRIE). We also studied the etching profile of QM-Si in an alkaline solution and the results presented similar crystal plane-dependent anisotropic features as in conventional single crystalline silicon indicating a high degree of crystal regularity also in QM-Si. Thus, it is safe to say, that QM-Si could have high potential also outside photovoltaics.



SEM image of the silicon line array fabricated on the QM-Si substrate with FIB lithography and DRIE.

Session 3B

Monday 14th

15:30 - 16:30

High pressure inertial focusing; integration in parallel and series

F. Javier Cruz, Klas Hjort

Uppsala University, Microsystems Technology Division

Inertial focusing is a phenomenon where particles are forced to migrate inside microchannels. With adequate conditions, microparticles align at equilibrium positions that depend on their size and geometry, enabling their separation and concentration at very high throughputs and recovery. The forces in play are extremely size dependent; *i.e.* the lift force (which normally plays the major role) relates to the size of the particle to the power of four ($F_L \propto a^4$). Therefore, to succeed in the alignment when targeting small particles, one must tailor the microchannel dimensions, its geometry and flow rate to compensate for the size. The smaller the particle targeted, the more pressure is needed; we used tens of bars and showed alignment of 1 µm particles in a spiral microchannel with the proper dimensions[1]. Others have shown it to work for 1 µm particles in a horse-shoe design at high pressure too[2].

In this abstract we present the results obtained in a chip with horse-shoe design that integrates five units in parallel (multiplying the though-put) and one in series (multiplying the concentration factor), Fig 1. Once the sample passes the parallel units, the concentrated outlets are recombined and go through the series unit where they are re-aligned and fractionated once more. In order to recombine the outlets we went out of plane; the channels were on both sides of a silicon wafer.

We built this system in silicon and glass to handle the high pressure. Especial attention was paid to the hydraulic resistance of the outlets; the particles should be centered in the outlet of interest to maximize the recovery.

[1] J. Cruz, S. Hooshmand, T. Graells, M. Andersson, J. Malmström, Z.G. Wu, and K. Hjort, J. Micromech. Microeng. 27, 084001 (2017).

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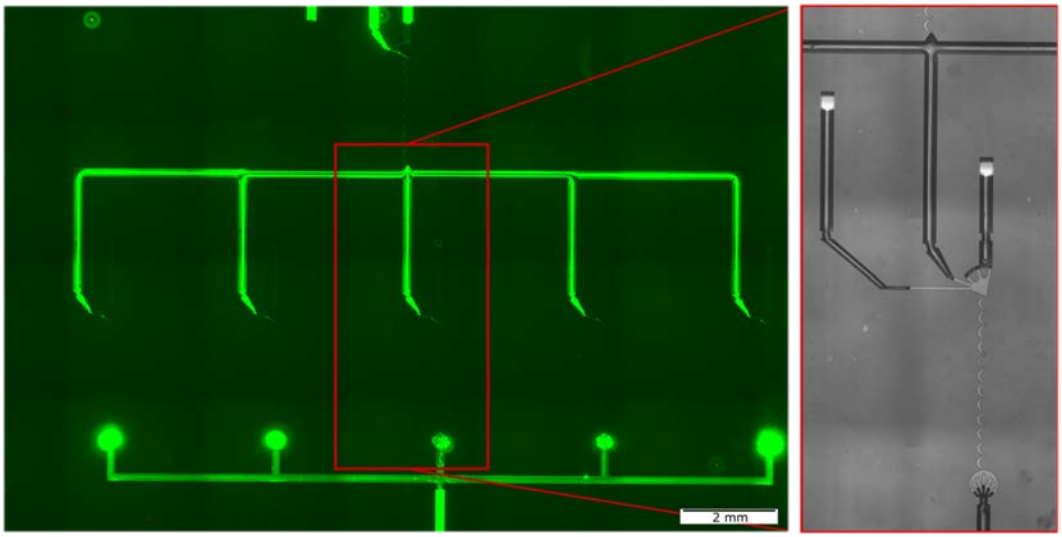

Left: Microfluidic chip with five units in parallel and one coupled in series concentrating 1 µm fluorescent particles. The recovery was 97% at a concentration factor of 35 with at a throughput of 200 µl/min and a pressure drop of 60 bar. Right: Single unit. It consists of a shallow horse shoe channel with deep and wide interconnects.

Carbon Microfactory – Microfluidics for Sorting Carbon Nanotubes

Ján Borovský[1], Mika Pettersson[2], Andreas Johansson[1,2]

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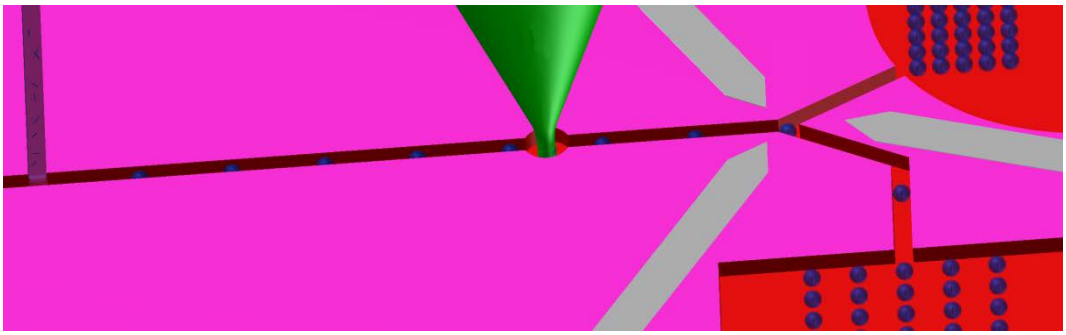
[2]Department of Chemistry, Nanoscience Center, University of Jyväskylä, P.O. Box 35, FIN-40014 University of Jyväskylä, Finland

Wide utilization of single-walled carbon nanotubes (SWCNTs) was forecasted already long time ago. Their unique electronic properties offer a possible way for further downsizing in transistor based technology[1] as well as new solutions in electronics, sensors, displays, etc. Unfortunately, the advent of SWCNT-based technologies is strongly impeded by the lack of knowledge in preparation of nanotube ensembles with identical properties[2].

Here we present a novel approach amongst currently known protocols for sorting uniform fractions of SWCNTs from synthesized blend. The aqueous dispersion of individualized SWCNTs forms droplets in a continuous oil phase. The droplets in femtoliter scale are tailored for single SWCNT spectroscopy, while full-glass microfluidic system provides outstanding chemical stability and spectroscopic environment.

The droplet-based microfluidics brings the possibility of single SWCNT manipulation within a microfluidic chip as they are confined in stable droplets. These droplets undergo spectroscopic characterization, defining the nanotube inside. The droplets are then sorted in dielectrophoretic valves based on automated decision algorithms. In this way, we aim for obtaining very pure single-type SWCNTs.

[1] Nougaret, L. *et al.*, Appl. Phys. Lett. 94, 243505 (2009), doi: 10.1063/1.3155212
[2] Hersam, M. C., Nat. Nanotech. 3, 387 - 394 (2008), doi: 10.1038/nnano.2008.135



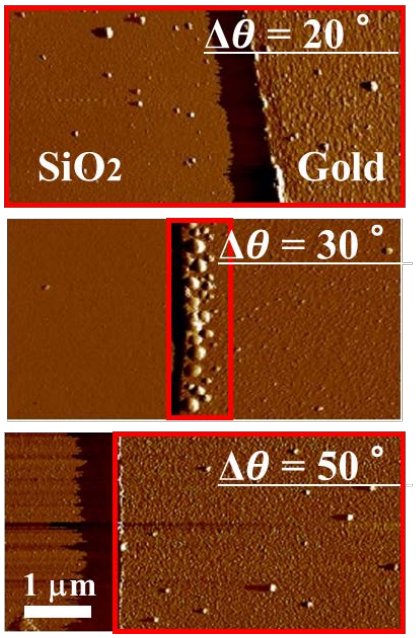
A layout of the microfluidic system.

Generation of Interfacial Nanobubbles Controlled by Surface Wettability

Hideaki Teshima[1,2], Takashi Nishiyama[3], Yasuyuki Takata[2,4], Koji Takahashi[1,2]

[1]Kyushu University, Department of Aeronautics and Astronautics
[2]Kyushu University, Institute for Carbon-Neutral Energy Research (WPI-I2CNER)
[3]Fukuoka University, Department of Mechanical Engineering
[4]Kyushu University, Department of Mechanical Engineering

Interfacial nanobubbles are attracting attention because of their application in engineering fields, including reduction of surface drag on liquid flow. In this study, we fabricated three hydrophilic-hydrophobic (SiO_2-Gold) hybrid surfaces by using physical vapor deposition and oxygen plasma treatment and investigated how surface wettability influences on nanobubble generation. The interfacial nanobubbles were generated on the hybrid surfaces by using solvent-exchange method which utilizes the difference in air solubility between ethanol and water. The hybrid surfaces were characterized by the difference between the macroscopic water contact angles of adjacent surfaces (Δθ). It was found that the location of generated nanobubbles greatly varies depending on the magnitude of Δθ. The nanobubbles were generated on the entire hybrid surface with low Δθ (20°), whereas they were only on the hydrophobic side of the hybrid surface with high Δθ (50°). Interestingly, when Δθ is intermediate (30°), the nanobubbles were localized on the hydrophobic surface in the vicinity of the boundary of the two surfaces. We suppose that the difference in wettability between adjacent surfaces influences on local dissolved gas concentration in water and changes the location of nanobubbles. Our results lead to a new technique that enables us to control the nanobubble generation.



Interfacial nanobubbles generated around the boundary of hydrophilic-hydrophobic hybrid surfaces. Red squares show the location of nanobubble generation.

Session 4

Monday 14th

17:00 - 18:30

3D printing soft microfluidics for mini-organs

Niels B. Larsen[1], Rujing Zhang[1], Milan Wesseler[1], Esben K.U. Larsen[1], Kristoffer Almdal[1]

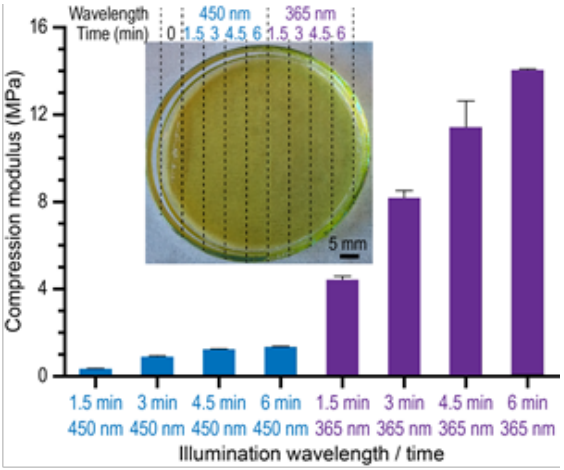
[1]Technical University of Denmark, Department of Micro- and Nanotechnology

Cells organized in 3D in human organs rely on a well-defined microenvironment in terms of shape, chemistry, mechanics, and additionally require adequate oxygen and nutrition supply via oxygenated medium perfusion through 3D microchannel systems. 3D printing of hydrogels is being explored to enable such advanced cell culture under tissue like conditions due to the high oxygen and nutrient permeability of hydrogels and their inherent softness[1].

This presentation will introduce the state-of-the-art in high-resolution single- and multi-material 3D printing of soft polymer materials, with attention to the cell-compatibility of different materials and processing types. Light-guided 3D printing, in particular stereolithography, is a promising class of methods for high-resolution shaping of both stiff and compliant materials. However, no reported material and method can vary the stiffness broadly within a printed object without complex transfers between multiple baths with different chemical precursors for each layer printed, leading to slow print speeds, complex printing systems, and limited spatial resolution.

We have met this challenge by combining spectrally independent radical-initiated photopolymerization of poly(ethylene glycol)-diacrylate monomers (compliant) and cation-initiated polymerization of epoxy monomers (stiff)[2]. The local compression moduli of the resulting polymer material can be varied in the range from roughly 100 kPa to 10 MPa by illuminating at two distinct wavelengths (365 nm and 450 nm) for defined times (see figure). Through development of a unique multi-color stereolithographic exposure system, we have demonstrated 3D printing of fully connected acrylate- and epoxy-based materials to form mechanically robust microperfusion systems.

[1] R. Zhang, N.B. Larsen, Lab Chip 17, 4273-4282 (2017).
[2] E.K.U. Larsen, N.B. Larsen, K. Almdal, J. Polym. Sci. Part B Polym. Phys. 54, 1195-1201 (2016).



Compression modulus across a Ø60 mm hydrogel disk (insert) after exposure of an acrylate / epoxy monomer mixture to 365 nm or 450 nm light for different times.

Production of hyaluronic acid-acrylamide microgels as potential cell culture scaffolds

Searle, S. S.[1], Porras, A. M.[2], Barbe, L.[2], Shi, L.[3], Hannah P. [3], Dieter, T.[1], and Tenje, M.[2]

[1] Dept. of Biomedical Engineering, Faculty of Engineering, National University of Singapore, Singapore.
[2] Dept. of Engineering Sciences, Science for Life Laboratory, Uppsala University, Sweden
[3] Dept. of Chemistry, Uppsala University, Sweden.

Hyaluronic acid (HA) derived hydrogels give support and structure for cultured cells in 3D environments that better mimic in vivo conditions [1]. Adequate diffusion of oxygen and nutrients however, is generally limited to a depth of 200 µm in bulk hydrogels [2], limiting their applicability to larger size constructs. Through droplet-based microfluidics we produced monodisperse HA-derived microgel droplets. Hyaluronic acid acrylamide (HA-am) was synthesized by partially modifying high molecular weight sodium hyaluronan with a N-(2-aminoethyl)acrylamide linker to a 20% degree.

Gel droplets were produced in a PDMS microfluidic device designed in a flow focusing geometry. In this setup polystyrene beads were added to simulate cell-encapsulation into a matrix that would better reflect in vivo conditions. The hydrogel precursor mixtures were prepared with 2% solution of HA-am and a photoinitiator with the addition of polystyrene beads (10µm in diameter) at a concentration of 10 million beads per milliliter. A fluorinated oil (Novec 7500, 3M) with 0.5% surfactant (PicoSurf 1) was used as the continuous phase. Highly monodisperse droplets of 151 µm in average diameter were produced and later polymerized by exposing to a long-wave UV light source (365 nm).

We demonstrate that photocrosslinkable hydrogel droplets can be produced from HA-am. These microgels could enable the diffusion of nutrients and metabolites, while maintaining a size in which encapsulating sufficient cells to allow cell-cell interactions and proliferation would be possible.

[1] J. A. Burdick and G. D. Prestwich, Adv. Mater., 2011, 23, 41–56.
[2] H. Huang, Y. Yu, Y. Hu, X. He, O. Berk Usta and M. L. Yarmush, Lab Chip, 2017, 17, 1913–1932.

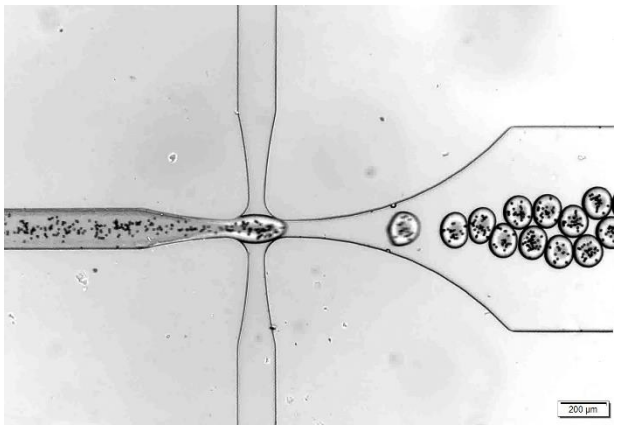


Figure 1: Microfluidic production of HA-am droplets with 10 µm sized polystyrene beads. Scale bars correspond to 200 µm.

Integrated transparent electrodes in an organs-on-chip system

Sofia Johansson[1], Ana María Porras[1], Sean Searle[2], Laurent Barbe[1], Maria Tenje[1]

[1]Uppsala University, Dept. Engineering Sciences, Science for Life Laboratory
[2]National University of Singapore, Dept. Biomedical Engineering

Many emerging organs-on-chip technologies target improved possibilities to control and monitor biological barriers[1]. An established, non-invasive and label-free method to characterize barrier tightness, in both conventional Transwell systems and in microfluidic organs-on-chip systems, is trans-endothelial/epithelial electrical resistance (TEER) measurements[2]. Preferably, integrated electrodes should be placed as close as possible to the cell culture area. To prevent such electrodes from obstructing the microscope light path, we now demonstrate the possibility to use Indium Tin Oxide (ITO) as a transparent TEER electrode material in microfluidic organ-on-chip systems.

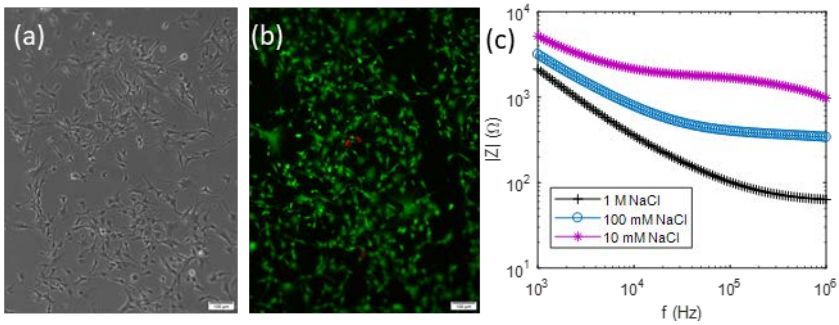
ITO is well known for solar cell and screen applications, and has been successfully used in different cells culture systems, including very briefly tested in an organs-on-chip system[3].

The ITO on glass substrate used in this work has a sheet resistance of $R_{sq} \approx 4$ Ω/square and a transparency of 89% in the visual spectra. The suitability of the material in terms of transparency and biocompatibility was evaluated by culturing bEnd.3 endothelial cells on the substrates and optical image the cells. As seen in the figure below, the cells are clearly visible through the ITO coated glass both without and with fluorescent live/dead staining. The large amount of live cells (in green) demonstrates the biocompatibility of the material.

A microfluidic chip was fabricated by sandwiching a porous polyester membrane between two glass slides covered with ITO and a patterned adhesive film (t = 130 µm). The adhesive film forms microfluidic channels on both sides of the membrane with an intersecting flow cell area of 1x1 mm^2.

The chip performance was evaluated using NaCl solution. The obtained impedance correlates well with the conductivity of the liquid in the flow cell in the relevant frequency range. At low frequencies the electrode-liquid contact impedance dominates. The typical desired resolution for TEER is about 1 Ω-cm^2, which corresponds to 100 Ω for the given flow cell area. The resolution of our system is well above this.

[1] R. Booth *et. al.*, Lab on a Chip 12, 1784-1792 (2012)
[2] M. Odijk *et. al.*, Lab on a Chip 15, 745-752 (2015)
[3] F. R. Walter *et. al.*, Sensors Actuators B Chem. 222, 1209–1219 (2016)



Cells grown on ITO coated glass depicted using (a) phase contrast microscopy and (b) fluorescent live/dead staining. (c) Chip impedance for different NaCl concentrations.

Fabrication of multifunctional nanoparticles by microfluidics for drug delivery and biomedical applications

Hélder A. Santos

Drug Research Program, Division of Pharmaceutical Chemistry and Technology
Faculty of Pharmacy, University of Helsinki, FI-00014 Helsinki, Finland
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In this work, prominent biomaterials, such as nanocomposites mades of nanoporous silicon (pSi) nanomaterials and polymeric structures are presented and discussed as potential platforms for the individualization of medical intervention. These nanocomposites are promising advanced drug delivery technologies for biomedical applications. Examples on how these nanocomposites can be prepared using microfluidics and how they can be used to enhance the bioavailability of drug/peptide molecules, demonstrating their cytocompatibility, *in vivo* biocompatibility, intracellular targeting in cancer cells (Fig. 1), and theranostic applications, will also be presented and demonstrated.[1–10] Applications for cancer and diabetes diseases of the developed nanocomposites will be discussed and elucidated.

The recent cutting-edge advances on pSi nanomaterials is anticipated to overcome some of the therapeutic window and clinical applicability of many drug/peptide molecules and can also act as innovative theranostic platform and tool for the clinic in the future.

[1] H. Zhang, […], H. A. Santos. Adv. Mater. 26, 4497-4503 (2015).
[2] F. Araújo, […], H. A. Santos. ACS Nano. 9, 8291-8302 (2015).
[3] F. Kong, […], H. A. Santos, M. Hai, D. A. Weitz. Adv. Funct. Mater. 25, 3330-3340 (2015).
[4] Liu D. […], H. A. Santos. Adv. Mater. 27, 2298-2304, (2015).
[5] Liu D. […], H. A. Santos. Biomaterials. 39, 249-259, (2015).
[6] F. Kong, […], H. A. Santos, M. Hai. Adv. Mater. 28, 10195-10203 (2016).
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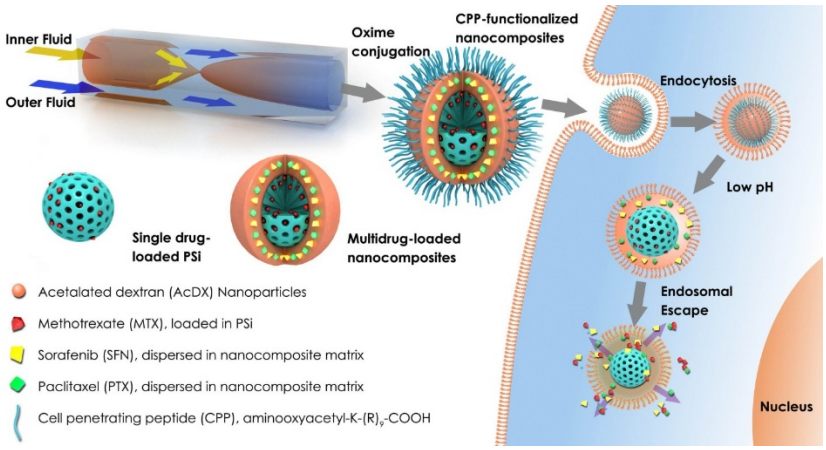


Fig. 1. Intracellular targeting of pSi-modified nanoparticles prepared by the microfluidics technology for cancer therapy.[5]

Session 5

Tuesday 15th

09:00 - 10:00

Introducing acoustophoresis to droplet microfluidics for particle manipulation

Maria Tenje[1]

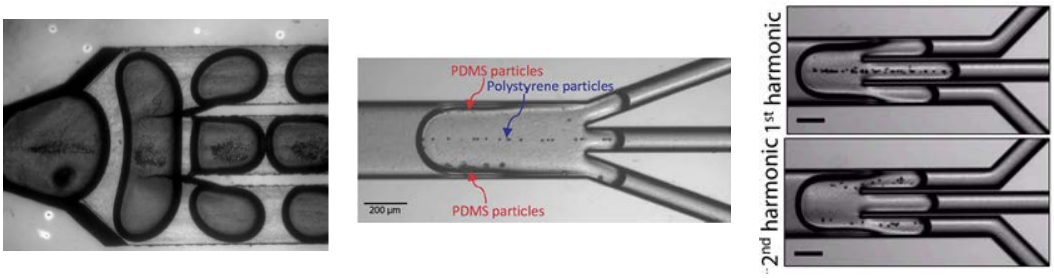
[1]Uppsala University, Science for Life Laboratory, Department Engineering Sciences

Droplet microfluidics has emerged as a powerful technology for fast and sensitive analytical analysis on-chip. Typically, water-in-oil droplets are generated where one major application of the technology is to use the droplets as individual reaction chambers for bead- and cell-based assays. During the last few years, acoustic particle manipulation (acoustophoresis) has been used to focus, concentrate, and separate particles in various one-phase microfluidic systems[1], and recently, acoustics has also been implemented in two-phase systems to sort whole droplets[2].

In this work, I will present show how acoustic forces can be integrated with droplet microfluidic systems as a method to manipulate particles encapsulated in the droplets[3]. I will also show that the method can be used for separation of two particle species with different acoustic properties originally encapsulated in the same droplet in a continuous two-phase system[4]. Finally, a demonstration on how this technology can be used as a fluidic switch in a droplet microfluidic circuit will be given[5].

Our research has shown that integrated acoustics opens up for many new and interesting applications in droplet microfluidics. Compared with other particle manipulation methods, acoustophoresis has the advantage of being label-free and generic as the method does not require the particles to magnetic or charged.

[1] T. Laurell, F. Petersson, and A. Nilsson, *Chem Soc Rev,* vol. 36, pp. 492-506, Mar 2007.
[2] I. Leibacher, P. Reichert, and J. Dual, *Lab Chip,* vol. 15, pp. 2896-2905, 2015.
[3] A. Fornell, J. Nilsson, L. Jonsson, P. K. Periyannan Rajeswari, H. N. Joensson, and M. Tenje, *Anal Chem,* vol. 87, pp. 10521-6, Oct 20 2015.
[4] A. Fornell, K. Cushing, J. Nilsson, and M. Tenje, *Applied Physics Letters,* vol. 112, p. 063701, 2018.
[5] A. Fornell, M. Ohlin, F. Garofalo, J. Nilsson, and M. Tenje, *Biomicrofluidics,* vol. 11, 2017.



Integrated acoustics can be used to manipulate particles inside droplets (left), separate particles of different acoustic properties (centre) and to serve as a fluidic switch (right).

Magnetic microactuators

Kari Ullakko[1], Andrey Saren[1], Denys Musiienko[1], Alexei Sozinov[1], Benedek Poor[2], Päivi Saavalainen[2]

[1]Lappeenranta University of Technology, LUT Material Physics

[2]University of Helsinki, Research Programs Unit, Immunobiology

Active microfluidics requires micropumps or microvalves. We developed an integratable, wireless micropump[1] made from the magnetic shape memory (MSM) alloy Ni–Mn–Ga [2]. An external magnetic field generates a shape change in the MSM material, which drives the fluid in a similar fashion as a peristaltic pump. Thus, the pump does not need electrical contacts and avoids the mechanical parts found in traditional pumping technologies, decreasing the complexity of the micropump. With a discrete pumping resolution of 1–100 nL per pumping cycle, which is further scalable, and a pumping pressure reaching 10 bar, the MSM micropump is capable of accurately delivering the fluids needed for microfluidic devices. The MSM micropump is self-priming, pumping both liquid and gas, and demonstrates repeatable performance across a range of pumping frequencies. Furthermore, it operates simultaneously as both a valve and reversible micropump, offering superior possibilities compared to existing technologies within the flow rate range of 0–2000 µL/min. Due to its simplicity, this technology can be scaled down easily, which lends itself for future integration into lab-on-a-chips and microreactors for life science and chemistry applications. Figure 1 shows a stand-alone pump and a rendered isometric and cross-sectional view of a plausible scenario that the MSM micropump could be integrated into a lab-on-chip device. The MSM pumps were also used for droplet formation in a lab-on-chip as presented by Benedek Poor in this workshop.

We will also report on micro grippers made from Ni-Mn-Ga using Xe plasma source focused ion beam milling technology[3]. Our results demonstrate the feasibility of manufacturing of micrometer-sized magnetic shape memory actuators and devices for biomedical applications.

[1] A. Saren, A. R. Smith, K. Ullakko, Microfluidics and nanofluidics, (2018), published online 16 March 2018.

[2] K. Ullakko, J. K. Huang, C. Kantner, R. C. Ohandley, V. V. Kokorin, Applied Physics Letters 69 (1996) 1966

[3] Denys Musiienko, Ladislav Straka, Ladislav Klimsa, Andrey Saren, Alexei Sozinov, Oleg Heczko and Kari Ullakko, Scripta Materialia, in press, 2018

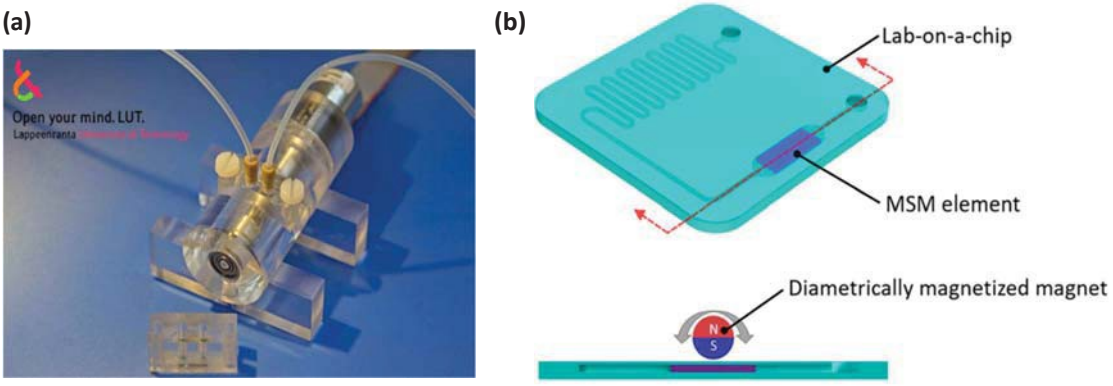


Fig. 1. (a) An MSM micropump. (b) An isometric and cross section rendering of integrating the MSM micropump into a lab-on-chip.

Session 6

Tuesday 15th

13:15 - 15:15

Thin-film thermoelectric devices for energy harvesting and material parameter extraction

Kirsi Tappura[1], Kaarle Jaakkola[1], Taneli Juntunen[2], Ilkka Tittonen[2], Riina Ritasalo[3]

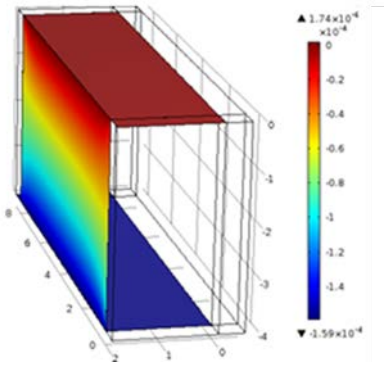
[1]VTT Technical Research Centre of Finland Ltd., Finland
[2]Aalto University, Department of Electronics and Nanoengineering, Espoo, Finland
[3]Picosun Oy, Espoo, Finland

A major barrier for a wider use of thermoelectric devices for energy harvesting is their low efficiency, which tends lead to a high cost per converted power. The ability to use non-toxic and abundant materials has also become increasingly important in the recent years and enhanced the interest towards improving the thermoelectric properties of metal oxides. Tin-doped indium oxide (ITO) is one of the most commonly used transparent conductive oxides due to its high electrical conductivity and high transparency. However, aluminum-doped zinc oxide (AZO) provides an environmentally friendly alternative that is more abundant, has better thermoelectric properties and lower cost.

In this work, we present selected results of our thermoelectric device development based on AZO aiming at flexible thin-film TEG applications. Thermodynamic modelling and performance simulations are conducted for selected designs in order to estimate the available thermal gradients, the performance of the thermoelectric elements and the power available from the thermoelectric modules consisting of various geometries and configurations[1]. In addition to the electrical properties, the heat transfer mechanisms over the modules are studied. In addition to the conventional material characterizations, the potential of the materials is also evaluated by constructing experimental test devices of the thin-films and building corresponding simulation models of the test devices.

By combining the experimental and theoretical approaches through device evaluations, the optimization of the thin-film materials and device designs can be performed in parallel for constructing a large-area thermoelectric module for thermal energy harvesting applicable in various environments without elaborated heat sinks. The ultimate goal of the project is to build a distributed sensor network integrating large-area thin-film thermoelectric devices and sensors for multifunctional smart windows and flexible high impact volume applications.

[1] K. Tappura, Renewable Energy 120, 78–87 (2018).



An example of a potential difference generated by a temperature gradient over a thin-film thermoelectric device.

Functional Plasma Micro-Nanotextured Microfluidic Devices

Katerina Tsougeni[1], Athina Kastania[1], Kosmas Ellinas[1], Angeliki Tserepi[1], Evangelos Gogolides[1]

[1]Institute of Nanoscience and Nanotechnology, NCSR "Demokritos", Aghia Paraskevi, 15341, Greece

Plasma micro-nanotexturing can create micro-nanotopography and simultaneously chemically modify polymeric or polymer coated surfaces. Structures in the form of cones, columns, or fibers random or quasi ordered are developed using plasma micro-nanotexturing. We can tune the wettability of such surfaces and produce surfaces that are water, ice, oil, and microorganism repellent (i.e. superaphiphobic, anti-icing, antifouling). Additionally, we can produce hydrophilic surfaces with increased biomolecule attraction and binding (increased biomolecule immobilization up to 5x). The method is generic and can be applied in several polymers (i.e. COP, PMMA, PEEK, PDMS).

The fabrication of microanalytical devices with minimum feature size in the micrometer range is of great importance in many fields of analytical science, where a small quantity of sample is available, enhanced resolution and sensitivity in separation and detection is needed and increased functional integration is desired[1,2]. We can accomplish this, by applying our technology in microfluidics and we can produce functional microfluidics with optimized performance in analytical and bioanalytical applications. The devices we have already developed using this method are: a) DNA purification device[3], b) bacteria capture and lysis device[4], c) microfluidics with predesigned adhesion of proteins and cells or combination of the two functionalities (and antifouling) on a single microchannel[5-7].

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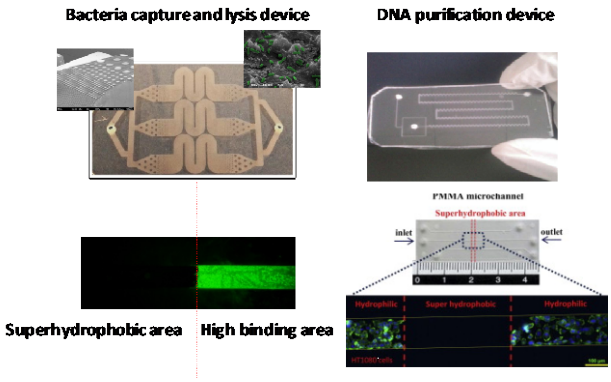

Images of the functional plasma micro-nanotextured microfluidic prototypes

Cost effective potentiostat design for large dynamic range measurements

Juhani Virtanen[1], Sampo Tuukkanen[1]

[1]BioMediTech Institute and Faculty of Biomedical Sciences and Engineering, Tampere University of Technology (TUT), P.O. Box 692, FI-33101 Tampere, Finland

A potentiostat is a measurement device which has wide variety application areas such as electrochemical measurements, electrical component and phenomena characterisation and biomeasurements. Commercial potentiostats can be expensive and require large storage space. Moreover they may not be portable. There has been several attempts to overcome this challenge by publishing open source potentiostat designs such as CheapStat[1], EmStat[2], ioRodeoStat[3] and Ardustat[4]. Additionally the development customized measurement setups with the above mentioned potentiostats may not be simple.

The aim of this study is to develop a cheap yet high performance portable open source based potentiostat utilising the Arduino[5] development platform (ref). Moreover the operation and analysis was build on open source Octave software platform and enables easy access to large number of mathermatical libraries. This potentiostat is mainly targeted for biomedical potentiostatic measurements which require a wide dynamic measurement range, even as high as over 100 dB over a single measurement range. However, applications such as supercapacitors[6] could be studied with the presented device.

In this study the high dynamic range was obtained by utilizing a logarithmic amplifier in the potentiostat implementation. The operable current and voltage ranges were from less than 1nA to 10mA while the applied voltages could be varied between -2.5V and 2.5V in 1mV steps. The performance of this implementation was verified against a IviumStat (Ivium Technologies B.V., Nethelands) commercial potentiostat.

The cost of the components for the potentiostat design reported here is less than 10 euros, and it is combined with an Arduino UNO board which costs far less than 30 euros. Performance of the potentiostat was found to be able to reliably measure smaller than 1nA currents and the accuracy of the measurements was acceptable when compared to the IviumStat.

[1] Rowe, Aaron A., et al. "CheapStat: An open-source,“do-it-yourself” potentiostat for analytical and educational applications." *PloS one* 6.9 (2011): e23783.
[2] Emstat, PalmSens BV, The Netherlands.
[3] IoRodeoStat, IoRodeo corporation.
[4] Harnett, Cindy. "Open source hardware for instrumentation and measurement." *IEEE Instrumentation & Measurement Magazine* 14.3 (2011).
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M-shaped Piezoelectric Microenergy Harvester for Enhanced Stress Distribution

Agin Vyas[1], Henrik Staaf[1], Elof Köhler[1], Cristina Rusu[2] Peter Enoksson[1]

[1]Chalmers University of Technology, Micro and Nano Systems Group, MC2
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Piezoelectric energy harvesters are a potential solution to creating a wireless sensor based platform for Internet-of-Things (IoT). They can generate microwatts of power by converting ambient vibrations to electrical energy. These devices, however, suffer from narrow power peaks at their specific resonant frequencies. Therefore, novel mechanisms for their bandwidth broadening are required.

Studies by Staaf et al.[1,2] focused on stress distribution patterns and the linear dependence of bandwidth on coupled resonance at frequencies near the natural excitations and demonstrated a broad bandwidth. Based on these findings, this abstract presents the proof-of-concept of the work in micromachined, 5 mm x 4 mm, vibrational energy harvesters. The designed devices target the extension of stress distribution by using coupled cantilevers in a two-degree-of-freedom (2-DOF) system. When the middle beam (Fig. 1(a)) has a natural frequency similar to the resonant frequency of the side-beam structure, it enhances the latter's vibrational mode. Hence, a larger stress is observed throughout the beam area. Similarly, at non-resonating frequencies, the presence of such an effect provides more stressed areas for the piezoelectric material.

Three devices, M-shape, M-long, and M-big are designed and simulated in COMSOL. Figure 1(b) shows the simulated stress values obtained from the three devices and compares them to a single cantilever of their length. A nearly constant shaped curve is achieved in M-long and M-big, and an enhanced stress pattern is generated in M-shape. They are fabricated using standard MEMS processing techniques on SOI wafer. An SEM image of the fabricated M-long device is shown in Figure 1(a). The structures will be wirebonded at RISE, Acreo AB, then tested and analyzed by using a Laser Doppler vibrometer with mechanical shaker and vacuum chamber.

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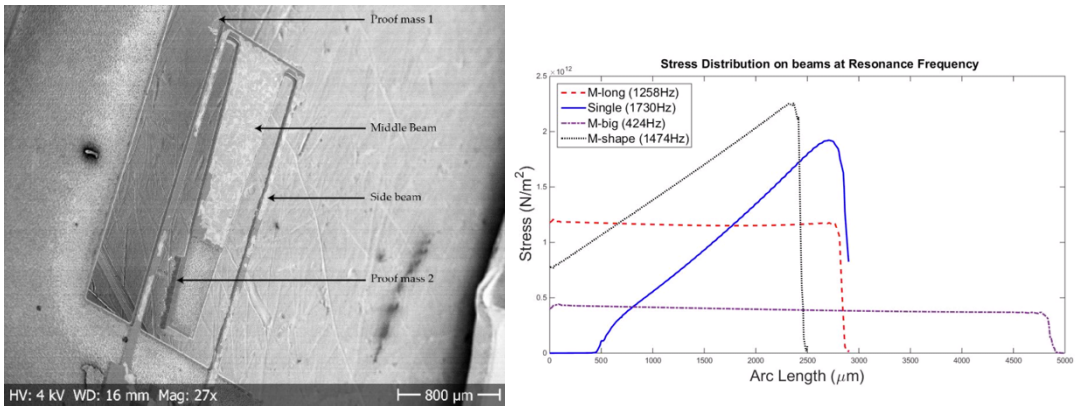

(a) (b)

Figure 1: (a) SEM image of the M-long microenergy harvester. (b) Stress distribution simulation results for the fabricated devices compared to a single cantilever.

Low resistance metal-MoS_2 nano-contact: realization and evaluation

Xinying Shi[1], Sergei Posysaev[1], Marko Huttula[1], Olga Miroshnichenko[1], Zhongjia Huang[2], Gang Wang[2], Sami Saukko[3], Matti Alatalo[1], Wei Cao[1]

[1]University of Oulu, Nano and Molecular Systems Research Unit
[2]Anhui Polytechnic University, School of Mechanical and Automotive Engineering
[3]University of Oulu, Center of Microscopy and Nanotechnology

As an emerging alternative to conventional semiconductors, molybdenum disulfide (MoS_2), a typical inorganic layered crystal, has attracted enormous attention due to its excellent mobility, high on/off current ratio and tunable band structure. Various methods of tailoring its properties have been achieved theoretically and experimentally[1,2]. However, there is still lack of understanding of the contact with a metal electrode. The presence of Schottky barrier is accompanied with the formation metal-semiconductor (M/S) contact, leading to a high electrical resistance and a nonlinear current-voltage (*I-V*) behavior. Thus, realizing a low resistance M/S contact and exploring physical mechanisms beyond the electrical property are demanded.

Here we present a nanofabrication strategy to join Ni to MoS_2, and evaluate the electrical behaviors via physical determinations. The synthesis involves chloroauric acid as a nano-glue, and is benefited under an ultrasonic circumstance[3]. Ni and MoS_2 are joined by either Au nanocrystals or a ternary MoS_2-Au-Ni alloy, as shown in Fig. 1a. Due to limitation of traditional *I-V* tests for FET devices, conductive-AFM is employed to measure the *I-V* property. Figure 1b demonstrates a significant resistivity drop of such contact compared to a direct MoS_2-Ni contact. Such electrical performance is revealed through first-principles calculations. In Fig. 1c, an optimized structural model proves the stability of such contact type, and the charge density difference shows Au atoms attract Ni and MoS_2 from both sides. The charge transfer between Ni and S atoms leads to effective bonding, lowering the barrier and reducing the resistivity.

The reported synthesis and characterization methods provide general routes to fabricate and evaluate a nano-scale M/S contact, and the theoretical computation helps to understand the contact mechanism and offers possibilities of tuning the contact performance.

[1] X. Shi, Z. Huang, M. Huttula, T. Li, S. Li, X. Wang, Y. Luo, M. Zhang, W. Cao. Crystals 8, 24 (2018).
[2] W. Cao, V. Pankratov, M. Huttula, X. Shi, S. Saukko, Z. Huang, M. Zhang. Mater. Chem. Phys. 158, 89-95 (2015).
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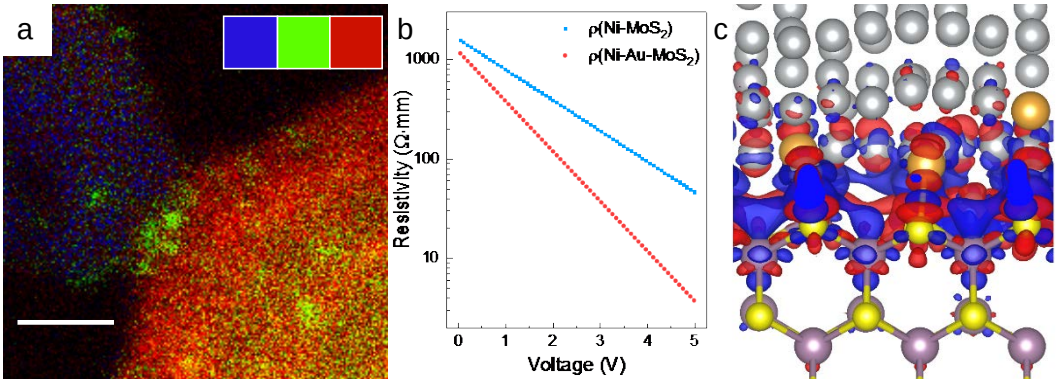

Figure 1. (a) TEM-EDS map of a MoS_2-Au-Ni contact interface. (b) Contact resistivity of MoS_2-Au-Ni and MoS_2-Ni. (c) Geometric structure and charge transfer of the contact.

Minimally invasive pressure sensor catheter

Anu Kärkkäinen[1], David Gomes Martins[1], Jaakko Saarilahti[1], Feng Gao[1], Jukka Kyynäräinen[1]

[1]VTT Technical Research Ctr. of Finland Ltd., Espoo, Finland

One of the latest minimally invasive technologies used in diagnostic and therapeutic intervention in the Cardiovascular diseases (CVD) is catheter-based pressure sensors for fractional flow reserve (FFR) [1]. We report a system for FFR including capacitive pressure sensor, ASIC, and integration to flexible substrate. The novelty presented in this work is based on two innovations: (1) VTT surface micromachined process used in fabrication of the ultra thin and narrow pressure sensor element and (2) mounting of the pressure sensor on the catheter sidewall instead of the guide wire enabling thus to use standard guide wires[2]. We have also developed interface electronics and testing platforms for the sensor subassembly. Results of the work are presented in the figure below.

This work was done in the frame of the ENIAC "INCITE" project No.621278 and partially financed by the ENIAC JU and TEKES the Finnish Funding Agency for Technology and Innovation. We will also acknowledge our project partners Murata Electronics Ltd, Afore Ltd, Tyndall and Creganna Ltd.

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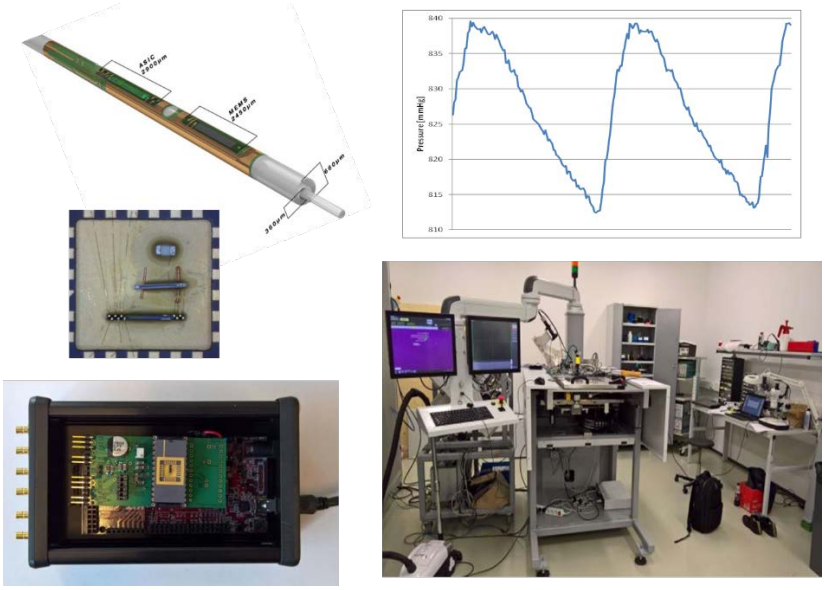
[2] Ultrathin MEMS pressure sensor and readout ASIC (2017), Kärkkäinen, Anu; Saarilahti, Jaakko; Kyynäräinen, Jukka; Kuisma, Heikki, 30th Anniversary Eurosensors Conference, EUROSENSORS 2017, 4 - 7 September 2016, Budapest, Hungary Procedia Engineering. Elsevier. Vol. 168 (2016), 76-79.



Left up illustration of FFR catheter, MEMS and ASIC mounted on the side wall, left middle MEMS and pressure sensor chips mounted on ceramics substrate for calibration, left down interface electronics. Right up measurement results of pressure pulse generated by Afore wafer level measurement euipment presented in figure below (photo courtecy of Afore).

Session 7

Tuesday 15th

15:30 - 17:15

Millimeter wave integration concepts based on micromachining

Pekka Pursula[1]

[1]VTT Technical Research Centre of Finland

The interest in high millimeter wave band and THz frequency band has increased in the recent years, as MMIC technologies have developed up to 1 THz. This frequency band could provide the bandwidth for ever-growing wireless data traffic. For imaging, the THz band enables reasonable apertures with some material penetration to facilitate security imaging for contraband detection.

The micromachined system integration technologies enable systems with smaller footprint and better performance than state-of-the-art technologies, such as LTCC, or CNC machined split block systems. The presentation considers the pros and cons of micro-optical structures, dielectric and metallic waveguides. Micro-optical approach enables big arrays of detectors, but waveguides provide a flexibility to include passives and several active components per channel.

Electrowetting: a flexible tool for manipulating fluids from lab-on-a-chip to optofluidics and heat transfer

Frieder Mugele

Physics of Complex Fluids, MESA+ Institute for Nanotechnology, University of Twente, Enschede (The Netherlands)

Electrowetting (EW) is one of the most versatile tools to manipulate drops on the sub-millimeter length scale. It provides active control over the energy landscape experienced by liquids at interfaces for a broad range of applications including drop-based microfluidics, adaptive optics, and display technology. After a brief review of basic physical concepts of electrowetting, I will illustrate the capabilities of electrowetting with examples of switchable superhydrophobic surfaces and enhanced drop sliding on inclined plains that enable a detailed control of drop condensation patterns from supercooled vapor for enhanced heat transfer. Moreover, I will discuss are series of recent experiments on adaptive optofluidic lenses that allow not only for varying the focal length but also for a detailed control of optical aberrations and general wavefront shaping.

Poster presentation abstracts

Fabrication of high-resolution dry film photoresist bridges over trenches

Samuel Rantataro[1], Anand Tatikonda[1], Ville Jokinen[1], Sami Franssila[1]

[1]Aalto University, Department of Chemistry and Materials Science

Fabrication of high-resolution dry film resist bridges over open trenches was investigated by using ADEX (DJ MicroLaminates), a negative i-line (365 nm) resist. Whereas spin coating would result in flooding of the photoresist into trenches and therefore require complicated process design, using dry film photoresist is a very simple method.

A single side polished silicon wafer was used as a support substrate. The bridges (Figure 1) were fabricated by using a 10 µm thick ADEX sheet, a conventional office laminator, a hot plate, and a mask aligner. A plastic photomask with 10 µm lines with 10 µm spaces was used. Resist was developed prior to applying the next layer. The mask was rotated 90° between consecutive layers resulting in a multilayer mesh (logpile) structure.

To prevent sagging of the photoresist, processing parameters of the upper layers were altered slightly. Lamination and baking temperatures were kept under glass-transition temperature, and the post exposure bake (PEB) temperature profile was ramped. Whereas the first resist layer was laminated in 70 °C and an adhesion improvement bake (AIB) was done in 70 °C for 2 min, the subsequent layers were laminated in 27 °C and the AIB was done in 29 °C for 3 min. Exposure time in 30mW/cm^2 illumination was increased from 4,4 s to 4,8 s to compensate for the decrease of crosslinking due to lower PEB temperature.

The adhesion and resolution of the photoresist lines were good, and the resist did not show sagging effect with optimized processing parameters. With these results in mind, the application of dry film photoresist instead of conventional spin coating resist provides intriguing possibilities for simple production of flat free-hanging structures regardless of the underlying topography.

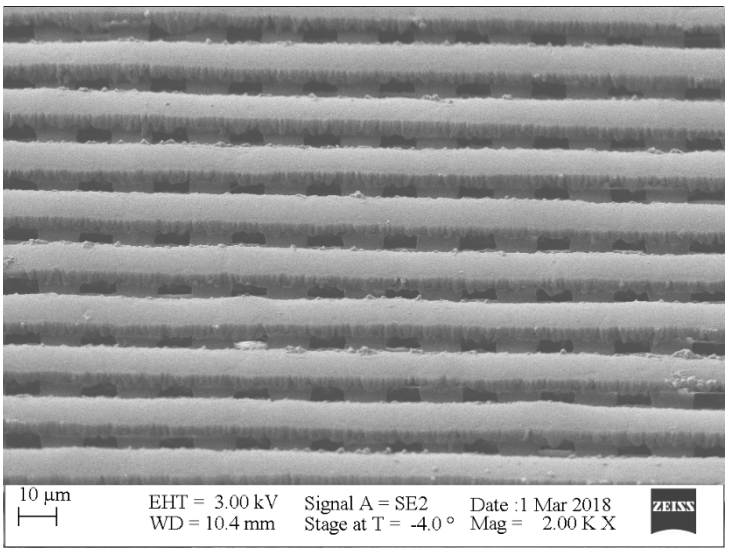


Figure 1. Scanning electron microscope (SEM) image of the dry film photoresist bridges over open trenches. The underlying lines are on the second layer.

Conductive Superhydrophobic Elastomer/Metal Hybrid Materials

Sasha Hoshian[1*], Sami Franssila[1]

[1]Aalto University, Department of Chemistry and Materials Science

Multifunctional biomimetic materials are gaining more interest both in research and in industry[1]. For example, electrically conductive superhydrophobic surfaces can be used for self-cleaning water-resistant wearable electronics. Recently, we invented a fabrication process to produce extremely durable and self-healable ceramic-elastomeric superhydrophobic material[2].

A scalable fabrication process to produce electrically conductive superhydrophobic surfaces is now introduced. The process is based on electroless copper (Cu) plating of a sacrificial aluminum (Al) substrate. The copper layer is transferred onto a curable hydrophobic elastomer such as polydimethylsiloxane (PDMS). A short wet etching of Al surface was done prior to Cu plating to produce hierarchical micro and nanostructures which are necessary for superhydrophobic surfaces. The Al etching process took 5 minutes in 3M HCl followed by water rinsing and drying. A thin plastic cover on the backside of the Al substrate protected the sample from unnecessary backside etching. Electroless Cu plating was carried out on a 2 cm×2 cm etched Al substrate in a copper sulfate electrolyte solution for 1 hour followed by water rinsing and drying. Next, 2 mm PDMS layer was cured on the Cu plated sample at 60 °C for 2 hours. Then the Al substrate was sacrificially etched in a 12M HCl solution after removal of the backside cover. The Cu film was transferred to PDMS while the hierarchical geometry was preserved during the sacrificial etching process. Figure 1a-d show schematic of the fabrication process with corresponding scanning electron microscopy (SEM) images. The resulting hybrid PDMS/Cu material was conductive and superhydrophobic with advancing contact angle 163° and receding 161° and 5° rolling angle. No low surface energy coating was needed for the material to exhibit superhydrophobicity.

[1] S. Li, J. Huang, Z. Chen, G. Chen and Y. Lai, *J. Mater. Chem. A*, 5, 31-55 (2017)
[2] S. Hoshian, V. Jokinen and S. Franssila, *Soft Matter*, 12, 6526-6535 (2016)

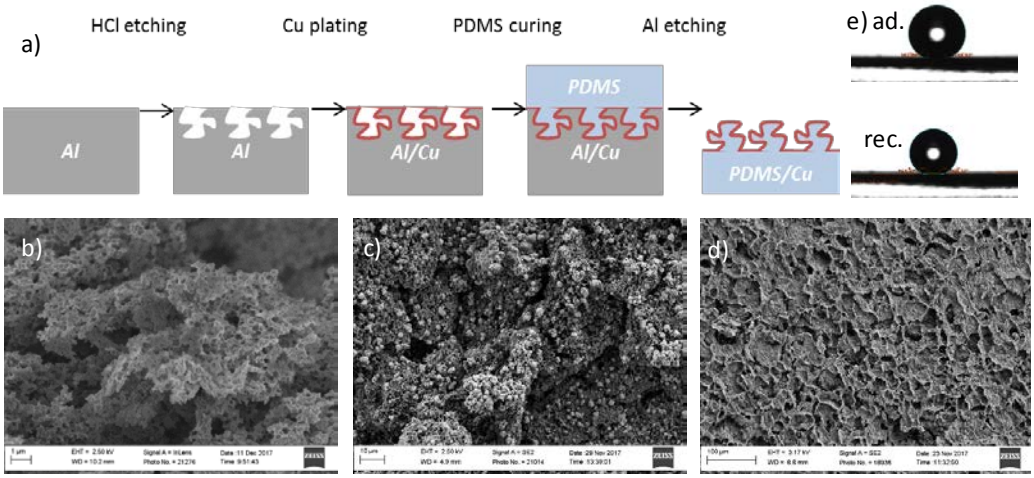


Figure 1, a) Schematic of the fabrication process followed by SEM micrograph of b) HCl etched Al substrate, c) Cu plated Al substrate, d) superhydrophobic PDMS/Cu replica with e) advancing and receding contact angles.

Biofunctionalization of thiol-ene microfluidic devices

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[1]University of Helsinki, Faculty of Pharmacy, Division of Pharmaceutical Chemistry and Technology
[2]Aalto University, Department of Chemistry and Materials Science, School of Chemical Engineering

Thiol-enes are promising materials for rapid prototyping of microfluidic devices based on the click-chemistry between thiol and allyl (-ene) monomers[1,2]. The ratio of thiol or allyl functional groups on the surface can be altered by using off-stoichiometric ratios of the monomers so as to allow further biofunctionalizations, particularly *via* the free surface thiols (-SH)[3]. Biotin-avidin complex formation is the strongest non-covalent interaction (Kd = 10^{-15}M) known with very rapid reaction kinetics. Once formed, the biotin-avidin bond is unaffected by pH, temperature, organic solvents or other denaturing agents, and thus, widely applied to protein-ligand binding.

In this work, we carried out a parametric study to optimize the surface chemistry of thiol-enes and the reaction conditions for their biotinylation with biotin-PEG_4-alkyne followed by subsequent biofunctionalization with fluorescent tagged streptavidin (Alexa Fluor 488)[2,3]. The fluorescence signal (ex 488 nm/em 500-700 nm) of the immobilized streptavidin was quantified with a photomultiplier tube attached to the Zeiss Axioscope A1 microscope. The functionalization tests were carried out using a micropillar array (Figure 1A, 1B) in order to increase the total surface area of the assay so as to maximize the binding capacity.

As expected, the amount of free surface thiols increased the amount of the covalently bound biotin and thus the amount of streptavidin (Figure 1C). However, significant fluorescence signal was also gained when using stoichiometric and allyl-rich thiol-ene surfaces suggesting that also these compositions yield free surface thiols, although less than thiol-rich compositions. In addition to the polymer composition, the biotin-PEG_4-alkyne concentration during biotinylation was shown to affect the amount of bound streptavidin. The success of the functionalization process could also be observed as a clear change in the water contact angle from 62±4° (native surface) to 25±2° (modified surface after streptavidin binding) (Figure 1D).

[1] C. F. Carlborg et al, Lab Chip. 11, 3136-3147 (2011).
[2] T. Sikanen et al, J Micromech. Microeng. 23, 037002 (7pp) (2013).
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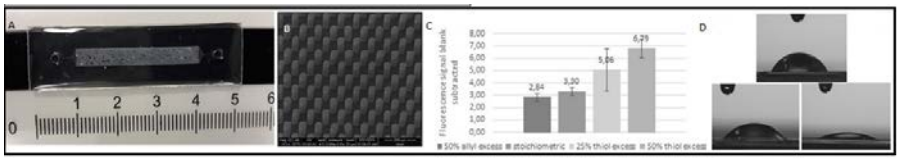

Figure 1. A) Photograph of a micropillar chip. B) Scanning electron micrograph of the micropillar array. C) Fluorescence of Streptavidin on biotinylated thiol-ene chip. D) Photographs of water contact angle on native, biotinylated, and Streptavidin coated surface.

Thiol-ene -based on-chip toxicity assays for chemical toxicity screening

Iiro Kiiski[1], Päivi Järvinen[1], Sari Tähkä[1], Päivi Tammela[1], Ville Jokinen[2], Tiina Sikanen[1]

[1]University of Helsinki, Faculty of Pharmacy
[2]Aalto University, Department of Chemistry and Materials Science

The number of chemicals on the market is constantly increasing which places a burden on current toxicity screening methodology. Microfluidic assays offer several advantages over conventional cell-based in vitro assays, such as creation of spatial and temporal variations into the assay set-ups. Embryonic mouse fibroblasts are the recommended standard for acute toxicity screening assays by the European Union Reference Laboratory[1]. However, polydimethylsiloxane (PDMS), the most commonly used polymer in microfluidic applications, is not well suited for culturing mouse fibroblasts because of limited cell adhesion and spreading[2]. In this work, we developed an on-chip mouse fibroblast assay for acute toxicity screening and showed that thiol-ene polymers offer a feasible alternative to PDMS in cell-based microfluidic applications.

Acute toxicity of thiol and allyl monomers was studied by growing BALB/3T3 cells in the presence of monomers dissolved in cell culture medium and on cured surfaces with different monomer ratios. The monomers slightly reduced the fibroblast viability in a dose-dependent manner, but no toxic effects were observed on cured surfaces, which suggests negligible monomer leaching from cured thiol-enes.

For an on-chip toxicity assay, thiol-rich (50 mol-% excess of thiol groups) thiol-ene channels (30 mm × 2 mm, length × width) were fabricated. BALB/3T3 cells were seeded into the channel and continuous flow of culture medium was maintained with a syringe pump. The feasibility of the chips for chemical toxicity screening was studied with a cytotoxic drug, paclitaxel.

The cells were shown to maintain their viability for over 24h and the morphology of fibroblasts grown on thiol-ene surfaces was similar to that of cells grown on polystyrene. Compared with well plate technology, the chip-approach facilitates more complex assay set-ups, e.g. temporal variations in terms of chronic exposure. Moreover, low autofluorescence and optical transparency of thiol-enes enables high quality optical detection even in the UV-range.

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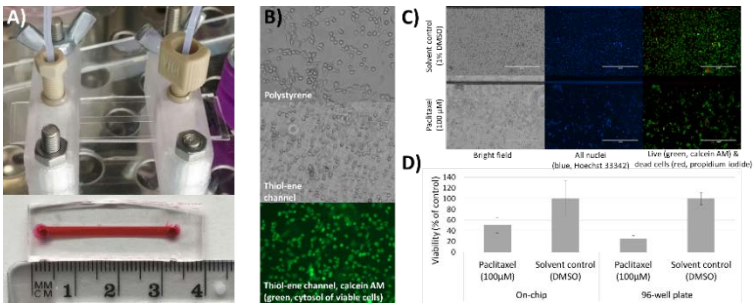
[2] L. Liu et al., Biomed. Microdevices 12, 505-511 (2010).



(A) Photograph of the thiol-ene chip with fluidic connectors. (B) Morphology of fibroblasts growing on a polystyrene well plate and thiol-ene chip surfaces. (C) Micrographs of stained fibroblasts inside a thiol-ene channel after 24h incubation with and without 100 µM paclitaxel. (D) Relative viability of cells exposed to 100 µM paclitaxel for 24h on-chip and on a microtiter well plate.

Electrochemical capacitors as AC line filters for miniaturized systems

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[1]Chalmers University of Technology, Department of Microtechnology and Nanoscience

With the establishment of the internet of things (IoT) and the rapid development of advanced microsystems, there is a growing demand to develop electrochemical capacitors (ECs) to replace bulky aluminum electrolytic capacitors on circuit boards for AC line filtering, and as a storage component in energy autonomous systems. For this purpose, ECs must be capable of handling sufficiently high signal frequencies, display low leakage current as well as maintaining an adequate capacitance. Here, we demonstrate ECs based on a mechanically flexible graphite / vertically aligned carbon nanotubes (graphite/VACNTs) hybrid material. The ECs employing a potassium hydroxide electrolyte exhibit a phase angle of -84.82° and an areal capacitance of 1.38 mF cm^{-2} at 120 Hz, which is among the highest value for carbon based high frequency ECs reported so far. The device also has an excellent stability (99.8% capacitance retention over 30000 cycles) and a low self-discharge rate. Additionally, the performance as a storage EC for miniaturized systems is evaluated, and a gel electrolyte was applied as a demonstration to reduce self-discharge and thus achieve capacitive behavior at µA current.

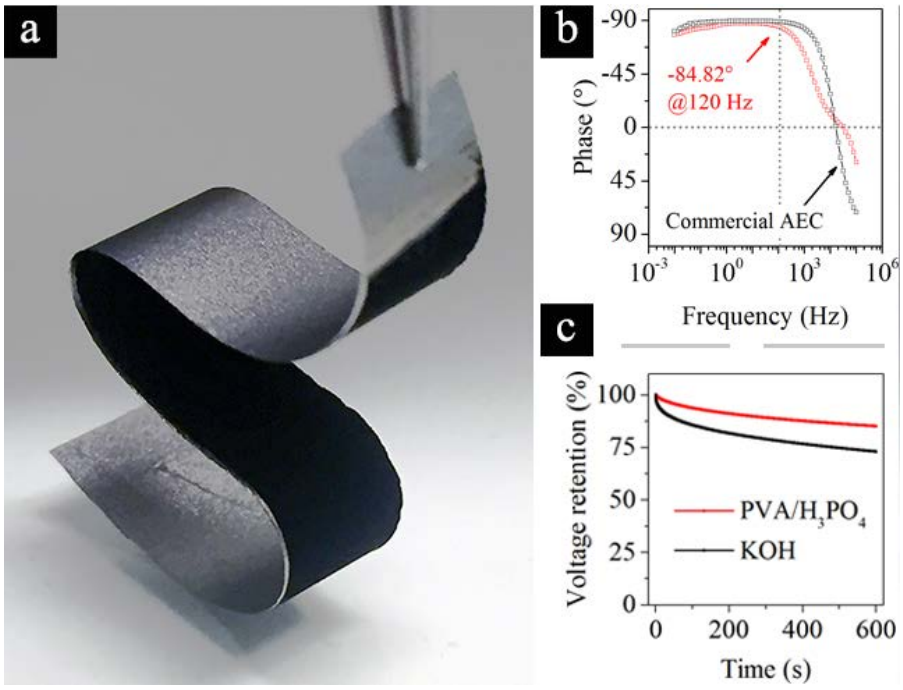

Fig. a – Picture of graphite/VACNTs hybrid material; b – Phase angle vs. frequency with a KOH electrolyte; c – Self-discharge with PVA/H_3PO_4 and KOH electrolytes.

Screen-printed curvature sensors for soft robots

Anastasia Koivikko[1], Ehsan Sadeghian Raei[1], Mahmoud Mosallaei[2], Matti Mäntysalo[2], Veikko Sariola[1]

[1]Tampere University of Technology, Faculty of Biomedical Sciences and Engineering
[2]Tampere University of Technology, Laboratory of Electronics and Communications Engineering

Castable elastomers have been used to fabricate soft robotic devices and it has been shown that the technique scales well from prototyping to mass manufacturing. However, similarly scalable techniques for integrating strain or curvature sensors into such devices are still lacking. In this poster, we will summarize our recent progress[1,2] towards integrating screen-printed silver-ink curvature sensors into soft robotic devices.

The curvature sensors are fabricated onto elastomer substrates in a single screen-printing step and then integrated into soft pneumatic actuators. We have characterized the resistance-curvature relationship of the sensors, which allows the curvature of the actuators to be estimated from the sensor measurements. Hysteresis was observed, which does limit the absolute accuracy of the sensors. However, temperature characterizations showed that the sensor measurements are not significantly affected by temperature fluctuations during normal operation. Dynamic experiments showed that the system bandwidth is limited by the actuators, rather than the sensors. We experimentally validated that these sensors can be used to detect whether the motion of an actuator has been blocked, clearing the way towards simple-to-fabricate soft robots that react to their surroundings. Finally, we demonstrate a three-fingered soft robotic gripper with integrated sensors. We conclude that screen-printing is a promising way to integrate curvature sensors into soft robots.

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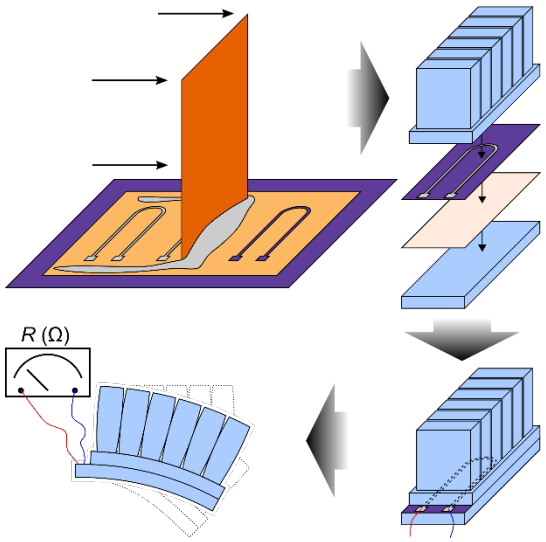
[2] A. Koivikko et al. *Sensors*, 18 (1), 223-230 (2018).



Screen-printing curvature sensors for soft robotic devices. After screen-printing, the sensors are integrated into soft pneumatic actuators. Measuring the resistance of the screen-printed sensors gives the curvature of the soft actuator.

Digital microfluidic enzyme reactor with integrated low-cost printed microheater

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Digital microfluidics (DMF) based on electrowetting-on-dielectric has become a very potential technique for performing (bio)chemical analysis in situ in small-volume-droplets (typically ~ 1 µL)[1]. The feasibility of DMF for a variety of enzyme assays and cell culturing and analysis has been shown but only very few studies have addressed the possibilities of local and precise heating of DMF devices with help of integrated heater elements. In this work, we report a simple, low-cost and mask-less fabrication of thin-film microheaters using an ink-jet printer for localized heating of the DMF chip.

The meandering microheater covered an area of 4×4 mm^2 (i.e., area of four driving electrodes) and it was printed on a transparent sheet with conductive silver ink. After sintering at 100 °C, the heater was assembled to the DMF bottom plate with help of a glass slide and tape (Figure 1a). The relationship between the power applied to the heater and the increase in temperature (ΔT) observed on the DMF chip was recorded (Figure 1b) and the percentage loss of the sample volume due to evaporation was determined (Figure 1c). In all DMF experiments, the actuation of sample droplets were carried out using a DropBot[2] automation system.

For the first time, porous polymer monoliths were used to immobilize enzymes on a DMF device. The thiol-rich monoliths with uniform porosity and large surface to volume ratio (Figure 1d) were functionalized with streptavidin and then with biotinylated recombinant CYP1A1 supersomes. Ethoxyresorufin-O-deethylase (EROD) assay was used for the determination of CYP1A1 activity and the fluorescence emission of the metabolite resorufin was measured on-chip by placing the DMF chip inside a well plate reader. Higher metabolite production rate was achieved with the heated positive control (at ~37 °C) when compared to the controls with no enzyme, no substrate (ethoxyresorufin), no co-substrate (NADPH) and no heating (Figure 1d).

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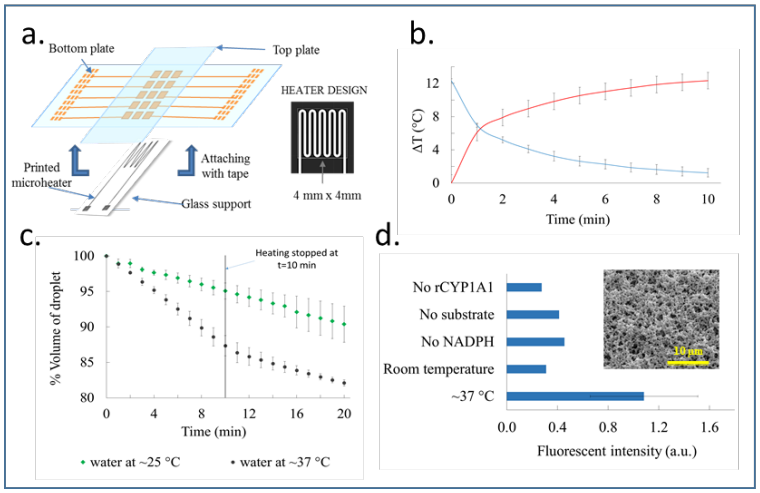

Figure 1: a. DMF device and microheater, b. Heater characterization, c. Determination of evaporation loss, and d. Metabolite production and SEM image of monolith

Thiol-ene-based, replicated, high-aspect ratio micropillar arrays as immobilized chymotrypsin reactors

Sari Tähkä[1], Riccardo Provenzani[1], Gustav Boije af Gennäs[1], Jari Yli-Kauhaluoma[1], Ville Jokinen[2], Tiina Sikanen[1]

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Thiol-enes are versatile microfabrication materials due to their simple non-cleanroom replication method and tunable mechanical properties and surface chemistry.[1] The use of off-stoichiometric monomer ratios in the bulk polymer results in free functional groups on the surface for further biofunctionalization. Off-stoichiometric thiol-enes have been used in e.g. microfluidic separations[2], biosensing[3] and as immobilized enzyme microreactors (IMERs)[4].

In this work, we present a non-cleanroom replication of high aspect ratio micropillar arrays and the feasibility of these for chymotrypsin (CHT) immobilization via thiol-gold chemistry (Figure 1A-B). The thiol-rich thiol-ene surface is first functionalized with gold nanoparticles which are then used to bind chymotrypsin (reduced). The thiol-ene chips are prepared by mixing commercially available thiol and allyl monomers, and the mixture is cast against a poly(dimethylsiloxane) (PDMS) mold and cured under UV.

The effects of thiol monomer type and the UV exposure dose on physico-chemical properties of the cured thiol-ene micropillar arrays were determined by comparing their solvent compatibility and the number of free surface thiols available for functionalization. Tetrafunctional thiol monomer was shown to provide better solvent stability and stiffness than trifunctional thiol. The number of free surface thiols was not affected by the type of the thiol monomer as long as the molar excess of the functional groups remained the same. Instead, the UV curing time (crosslinking degree) had an effect on the number of free surface thiols (Figure 1C). The efficiency of enzyme immobilization via thiol-gold chemistry was monitored by fluorescence monitoring of the CHT catalyzed hydrolysis of resorufin acetate to resorufin.

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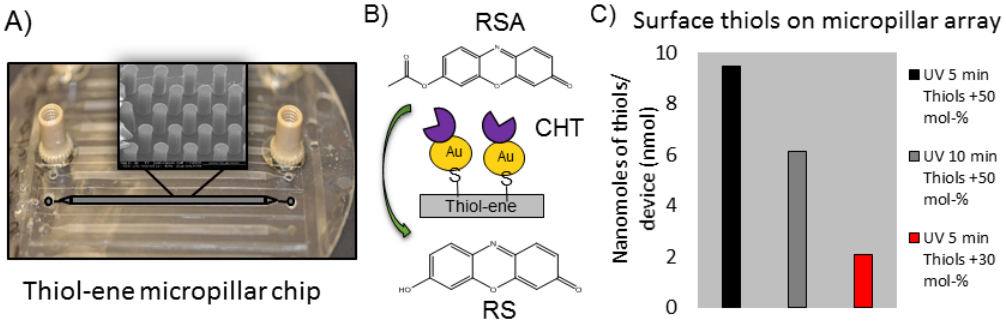

Figure 1. A) Thiol-ene micropillar chip, B) schematic of CHT immobilization on thiol-ene *via* gold nanoparticles and CHT catalyzed hydrolysis reaction of resorufin acetate (RSA) to resorufin (RS) and C) The effects of UV curing time and the molar excess of thiol monomer in the bulk on the number of free surface thiols.

Electrical contacts in SOI MEMS using aerosol jet printing

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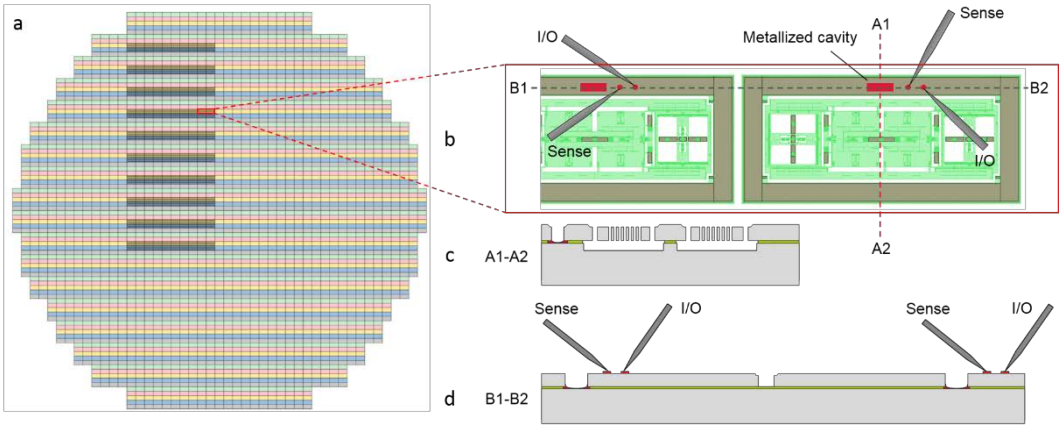
[1]Tampere University of Technology, Department of Electronics and Communications Engineering
[2]Murata Electronics Oy

This research work, introduces an additive method to make electrical contacts in SOI MEMS devices with aerosol jet printing. Small grooves were etched to the frame of MEMS accelerometer in the same step with the active structure release. Aluminum ink was jetted to the trenches in wafer-level to bridge the device layer to the handle wafer with the minimum amount of material. After subsequent annealing, ohmic contacts between p-type device layer and p-type handle silicon were verified by I–V measurements. The via resistance less than 4 Ω per via is measured. The method demonstrated in this paper provides simple and low-cost approach for SOI handle contact where additional packaging of wafer process steps can be avoided.



Schematic of (a) whole device layer with metallized frames highlighted, (b) 4-point resistance measurement setup from top view, (c) vertical x-sectional view over device frame and (d) horizontal x-sectional view over two adjacent device frames used for electrical measurement.

Capillary Isoelectric Focusing on 3D Printed Methacrylate Microchips

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University of Helsinki, Faculty of Pharmacy

3D printing is an emerging polymer processing method in industry and consumer use, but also feasible for fabrication of microfluidic devices. Low-cost stereolithography (SL) printers currently provide the best feature resolution vs. cost-efficiency ratio, while maintaining large print volume. In this work, a commercial SL printer (Form 2) was harnessed for 3D printing of electrokinetically actuated separation devices combined with integrated membranes for sample filtering, which is often needed before analysis of proteins from for example cell lysates. This necessitated development of a new bonding method for 3D printed parts (Figure 1A), which also allowed better feature resolution than 3D printing of embedded channels (Figure 1B).

The bonding of two 3D printed parts together was facilitated by the thin layer of the resin, which remained on the surface after printing and cleaning if postprocessing (UV curing) was not performed. For bonding, the aligned parts were compressed together, baked at 75 °C for 20 min, and the stack was exposed to 405 nm light while still compressed to finalize the bonding. The relatively high surface roughness of the 3D printed parts was shown to result in moderate transparency and optical clarity of the devices and thus a custom surface polishing method was also developed to facilitate optical detection of the separation channel through the 3D printed layers (Figure 1C).

Figure 1D shows a separation of myoglobin and cytochrome c by isoelectric focusing (110 V/cm) in a 3D printed and bonded channel in the presence of 2% ampholytes of pH 3-10 with hydrochloric acid as anolyte in the anode inlet and sodium hydroxide as catholyte in the cathode inlet.

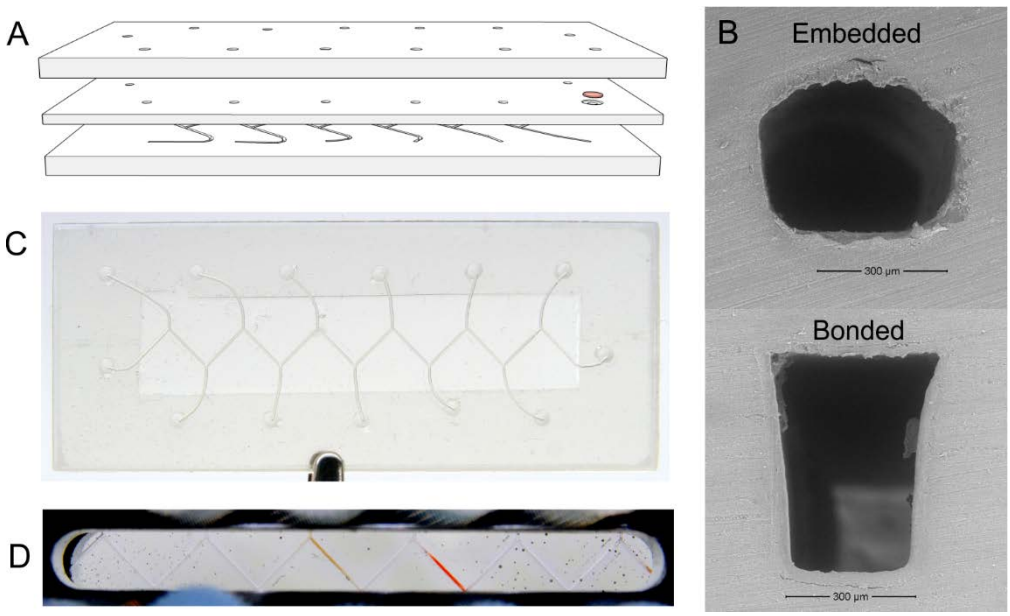

Figure 1. (A) Schematic view of the device layers, (B) SEM images of cross-cut 3D printed channels, (C) polished device, and (D) isoelectric focusing of myoglobin and cytochrome c in a zigzag shaped 3D printed channel.

Integrated microfluidic filter structures for cell-cell communication studies

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[1]Aalto University, Department of Chemistry and Materials Science

Introduction In synthetic biology, one of the main challenges in studying the cell-cell communication at colonial level has been to provide a physical barrier with chemical permeability to allow and track transport of distinct signaling molecules necessary for communication, while maintaining colonial physical separation for prolonged experimental times. In this work, a method for fabricating and integrating filtering membrane module into the microfluidics chip for communication studies have been developed.

Experimental The PDMS-glass microfluidics design used in this study is depicted in figure 1ab. It is comprised of two main parallel channels with independent access ports. Cells are captured hydrodynamically in side traps and growth phase will follow. When two different cells types are loaded into adjacent traps from opposite channels, the communication will commence and can be followed via fluorescent signal.

Selected membrane materials are biocompatible and photoactive hydrogels including PolyEthylene Glycol –Diacrylate (PEG-DA) and 2-hydroxyethyl methacrylate-co-ethylene dimethacrylate (HEMA-EDMA). After loading the gel solutions into the chip, UV lithography is utilized to pattern gel structures inside microfluidic cavities. The UV exposure is performed in clean room mask aligner from cover slip side. After exposure, uncrosslinked species are washed away using a syringe pump. In order to increase the adhesion and stability of the membranes, a silanization step (3-(Trichlorosilyl) Propyl Methacrylate, with 1 hour of RT incubation right after plasma bonding of chips) was added prior to the gel injection.

Results The primary filtering efficiency tests have been successfully performed with 2 µm PS microbeads and are shown in figure 1b. The bacterial communication tests are currently under development. In comparison with other methods of nanofilter fabrication such as direct 3D printing in channels with two photon polymerization technology with submicron resolution, our method renders faster and more cost effective prototyping cycles.

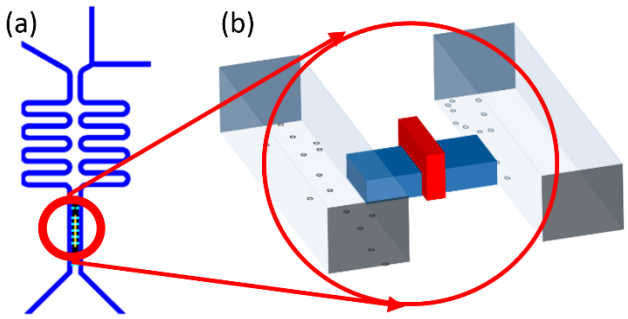

Figure 2 – Microfluidic circuit design for communication studies, (a) overall design large supply channels, (b) shallow trap areas (dark blue) and filter (red).

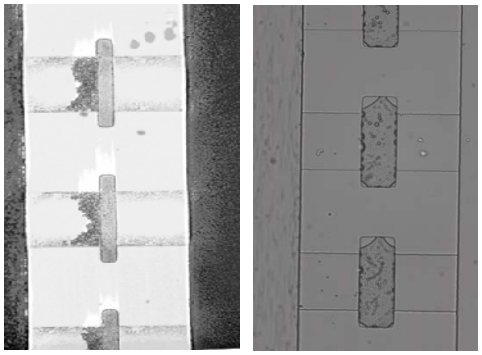

Figure 1 – Optical micrograph of filter membranes. Flow of 0.2µl/min and 2 µm PS microbeads simulating E. coli cells. Left: PEG-DA: right HEMA-EDMA

Taking ceramic microcomponents to higher temperatures

Erika Åkerfeldt[1], Lena Klintberg[1], Peter Sturesson[1,2], Greger Thornell[1]

[1]Ångström Space Technology Centre, Division of Microsystems Technology, Department of Engineering Sciences, Uppsala University, Uppsala, Sweden
[2]Department of Military Sciences, Swedish Defence University, Stockholm, Sweden

Introduction: Because of thermal gradients and transients, microcomponents made of High-Temperature Co-fired Ceramics (HTCC) usually fail at temperatures far below what the materials can withstand *per se*. For example, cracking temperatures of only 679°C or lower have been reported from dry tests of HTCC microthrusters[1,2]. The purpose of the present work is to investigate how resistance to thermal fracture in HTCC components can be increased by improving the component design, aiming for microthruster applications.

Experimentals: Simplified microsystems, see figure, containing a cavity and screen-printed platinum heater elements, were investigated with respect to chip and cavity geometries (circular or square), heater placement (central or peripheral) and addition of embedded platinum layers, using an experiment with two-level full factorial design. The resistance to thermal fracture was tested by rapid resistive heating of the components using the integrated heaters, with simultaneous IR camera monitoring of the components' surface temperature. The temperature was increased in steps, with cooling to room temperature prior to every increment, until component failure.

Results and discussion: Maximum surface temperatures at failure varying between 665 and 1361°C were attained. A peripheral placement of the heater increased the failure temperature with 228°C compared to central placement, as it causes more uniform heating of the component, which reduces thermal stresses. Addition of platinum layers was also seen to improve thermal endurance, although not as much as the heater location. Varying chip and cavity geometries did not cause any significant change.

Conclusions: Optimizing the design, HTCC components withstanding rapid heating up to 1361°C were achieved. Peripheral placement of the integrated heater element and addition of embedded platinum layers improved resistance to thermal fracture, whereas chip and cavity geometries did not affect thermal endurance.

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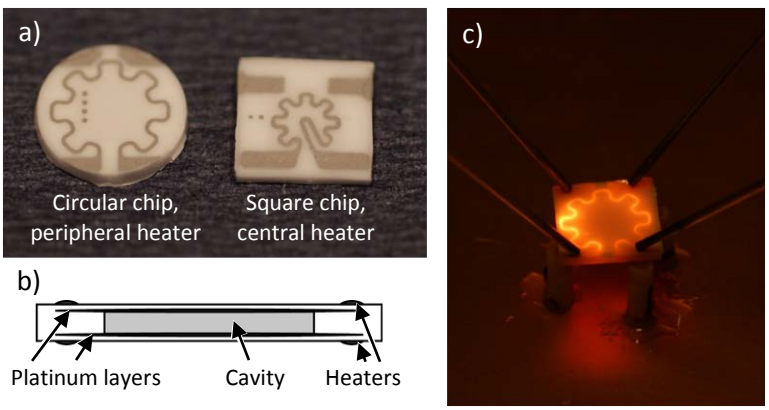

a) sample examples. b) cross-section, side view. c) heater glowing during operation.

Minihypoxy - Portable alternative for cell culture in controlled oxygen environment

Kaisa Tornberg[1], Joose Kreutzer[1], Krista Rantanen[1], Olli Tanhuanpää[1], Olli Metsälä[2], Heidi Högel[2], Panu Jaakkola[2] and Pasi Kallio[1]

[1]Tampere University of Technology, BioMediTech Institute and Faculty of Biomedical Sciences and Engineering

[2] University of Turku, Department of Medical Biochemistry and Genetics Institute of Biomedicine

Standard cell culture experiments consider parameters such as chemical composition of the culture medium, pH and temperature but these experiments are carried out in ambient laboratory air with 21 % level of oxygen. This value is considerably different from values found in human body which are shifting in the range of 2 – 9 %[1]. Normal incubators can maintain only pH and temperature, but for controlling oxygen concentration, there are specially designed heavy stationary workstations available in the market. These hypoxia workstations are developed to model environment where tissue oxygen partial pressure is below normal values. These systems require huge investment and running costs are high. Furthermore, their fixed position in laboratory limit experiment possibilities. For example, microscopy and radiation treatment under controlled oxygen environment are still difficult to perform. For mimicking better human body conditions, laboratories should be able culture cells in physiologically relevant environment considering also oxygen concentration with versatile analysis possibilities. We have developed a portable mini incubator, where cells are cultured in low oxygen partial pressure while maintaining constant pH and temperature.

Battery operated portable platform include an integrated heating element and O_2/CO_2 containing gas mixture tank to maintain oxygen, temperature and pH inside six individual culture chambers. Each culture chamber is supplied with low flow rate (5 ml/min) of non-humidified gas to maintain the gas concentration environment. The oxygen conditions in the chamber was studied with non-invasive optical oxygen sensor method[2] by using gas mixtures with different oxygen levels (0 %, 1 %, 5 % and 10 %) and maintaining temperature at 37 °C. Furthermore, hypoxic conditions have been demonstrated with living cells with standard protein assay for common hypoxia marker protein HIF-1a[3].

Measured data shows dynamical behavior of the system with different oxygen levels as gas flow is connected and after disconnection. These results combined with cell culture experiment demonstrates that Minihypoxy is capable of creating hypoxic conditions equal to commercial hypoxia stations and can maintain these conditions reasonable period of time even after gas flow is disconnected. This device provides more versatile analysis possibilities in hypoxia by its portability and it is suitable for prolonged experiments. With this device, laboratories can control oxygen concentration in their cell cultivation studies without heavy monetary investments and limitations caused by stationary equipment.

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Cell stretching device for high-resolution fluorescent imaging

Joose Kreutzer[1], Marlitt Viehrig[1], Rolle Rahikainen[2], Antti-Juhana Mäki[1], Vesa Hytönen[2], Pasi Kallio[1]

[1]Tampere University of Technology, BioMediTech Institute and Faculty of Biomedical Sciences and Engineering
[2]University of Tampere, Protein Dynamics group, BioMediTech

Here, we demonstrate the functionality and usability of a compact electro-pneumatic cell stretching device that enables high resolution live-cell confocal fluorescent imaging during the stretching. Earlier, we have shown that this technology enables long-term cell culture and continuous stretching of multiple parallel devices inside the incubator[1]. However, to extend the usability of the technology we demonstrate the capability of the device for live-cell fluorescent confocal imaging during the mechanical stimulation. This would be a beneficial tool for various applications in cellular mechanobiology. The advantage of the device is that it enables real time observation of cells with an inverted microscope without any loading post or oil lubricants behind the stretchable membrane that would affect the image quality. For demonstration, we provide image based analysis of dynamic change of the cell body and the nucleus area and actin fiber orientation during the mechanical stimulation. Additionally, we present the characteristics of the device utilizing computational simulations and experimental validation.

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Bone Cement Embedded in a Microfluidic Device

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INTRODUCTION: Calcium phosphate cements (CPCs) have a great potential in the treatment of bone disorders due to their excellent biocompatibility. Although CPCs are promising when implanted in vivo, there is poor correlation between in vitro and in vivo studies. This could be because most conventional in vitro systems lack a 3D architecture, or dynamic conditions (i.e. a continuous refreshment stream). The aim of this work is to embed CPCs into a microfluidic system and evaluate ion and protein exchange at different flow rates.

METHODS: α-tricalcium phosphate (α-TCP) was prepared by mixing calcium hydrogen phosphate ($CaHPO_4$) and calcium carbonate ($CaCO_3$) at a 2:1 M ratio and heating in a furnace at 1400°C for 6h, followed by quenching in air. α-TCP was milled and 2% w/w hydroxyapatite was added to the powder. The CPC was prepared by mixing the powder with 2.5% w/v disodium hydrogen phosphate (Na_2HPO_4) at a liquid-to-powder ratio of 0.65 mlg^{-1}. CPC paste was casted into a 2 mm deep pocket within a polydimethylsiloxane (PDMS, Sylgard 184, Dow Corning) mold, the latter cured at 60°C for 2h. CPCs were set by immersing them in 0.9% w/v sodium chloride (NaCl) at 37°C for 5 days. Subsequently, another piece of PDMS (cured at 60°C for 2h) comprising a 100 μm deep channel was bonded on top, thus embedding the CPC.

Minimum Essential Media (MEM, 1 ml, Phenol Red Free, Gibco), supplemented with 10 $mgml^{-1}$ Bovine Serum Albumin (BSA), was flowed through the channel at low (2 $\mu lmin^{-1}$), medium (8 $\mu lmin^{-1}$) and high (14 $\mu lmin^{-1}$) flow rates. MEM (1 ml) was also exposed to CPC (ø = 15 mm, h = 1 mm) at static conditions (0 $\mu lmin^{-1}$) for 24h. Stock MEM was taken as a control. The change in BSA concentration ([BSA]) in each MEM sample was quantified via the BCA Protein Assay Kit (Pierce). In addition, the changes in calcium and phosphate concentration ([Ca], [P]) in each MEM sample were determined through Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES).

RESULTS & CONCLUSIONS: CPC was successfully embedded in a PDMS microfluidic system (Fig. 1A). At static conditions (0 $\mu lmin^{-1}$), [Ca] and [BSA] in MEM decreased by 39% and 33% respectively, due to adsorption by CPC; in contrast, [P] increased by 79% as it leached out of the CPC (Fig. 1B). The higher the flow rate, the closer the [Ca], [P] and [BSA] were to levels in stock MEM. We expect that osteoblast viability will be increased when grown in embedded CPC systems under dynamic conditions as compared to static-based systems due to increased stability in media composition.

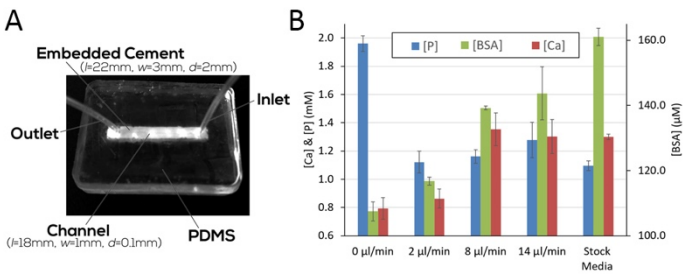

Figure 1. (A) Cement embedded in PDMS. (B) Ca, P and BSA concentrations in media as a result of different flow rates through the CPC-PDMS channel.

Towards microfluidic scent synthesizer and integrated e-nose technology

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[2]New York University, Department of Chemical and Biomolecular Engineering
[3]University of Tampere, Faculty of Communication Sciences

Olfactory sense is affecting human performance and behaviour[1,2]. In order to study how different scents and their intensities affect humans, scent production needs to be highly controllable. In this work, we demonstrate a proof of concept scent synthesizer for producing scents and a sensor array, which can measure output scent produced by the device.

The main part of the synthesizer is a 3D printed evaporation chamber. It is composed of two glass chips, which have two microchannels each filled with scent liquid. At the end of these microchannels, 100 nm thick joule heated titanium tracks were used for evaporating the scent liquids. The synthesizer also contains a pump and a proportional valve to produce and control carrier gas flow which is used for providing the evaporated scent to the user. A pressure controller is used to control the pressure for the selected scent liquid, to fill the micro channel. The entire system is controlled with an Arduino 101 microcontroller and custom-made circuit boards.

The developed sensor array is placed in another chamber. Sensors are based on a conducting polymer[3]. In this study, doped polyaniline (PANI) works as a sensing material via conductivity changes caused by the produced scents. Ion mobility spectrometer (IMS) was used as a reference measurement.

With benzyl acetate, we have demonstrated that the scent synthesizer is able to produce different concentration levels simply by changing the current through the heater. The study shows that IMS measurements can be used to evaluate odors synthesized by the device. The PANI coated sensor array is able to detect the scents but the induced changes in conductivity seem irreversible. The main challenge related to this evaporation method is the design of the channels. Too small cross-section leads easily to a clogged channel. On the other hand, too large cross-section causes leakages.

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Drop-casting of PDMS lenses to improve the fluorescence detection sensitivity and resolution of microfluidic cell assays

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University of Helsinki, Faculty of Pharmacy

Microfluidic cell assays are sometimes setting challenges to the use of conventional optics, such as fluorescence microscopy. In cell assays, oxygen permeable materials, such poly (dimethylsiloxne) (PDMS), are typically the preferred chip fabrication materials. However, the good oxygen permeability often comes at the cost of high elasticity, which necessitates the use of relatively thick top layers. This however complicates high-resolution imaging of the cell layer due to the short working distance of the objectives with high magnification number (focusing to the cell layer is complicated). In this study, we demonstrate the use of drop-casted PDMS lenses in order to improve the resolution of cell imaging when using small magnification number objectives. At the same time, also the detection sensitivity is improved thanks to the focusing of the excitation beam by the PDMS lens.

The PDMS lenses were prepared by drop-casting of the monomer solution (elastomer:curing agent, 9:1, w/w) on a microscope slide preheated to 150 ˚C. BALB 3T3 fibroblasts were grown in a microchannel, under flow rate 0.7 ul/min for 24 hours and then stained with Hoechst, CalceinAM and propidium iodide (PI). The fluorescence imaging was carried out with EVOS FL microscope and the quantification of the signal with Varioskan LUX microplate reader.

Due to the hydrophobicity and temperature-dependent curing rate of PDMS, the drop applied on a heated microscope slide cures instantly and produces a convex lens with smooth and optically clear surface (Figure 1A). Owing to the simplicity of drop-casting, these lenses can be easily and reproducibly made in any regular laboratory (Figure 1B). The resolution of cell imaging was significantly improved (Figure 1C) and the fluorescence gain of the stained fibroblasts was increased by 2-3-fold with the PDMS lens, when compared to the gain without the lens (Figure 1D).

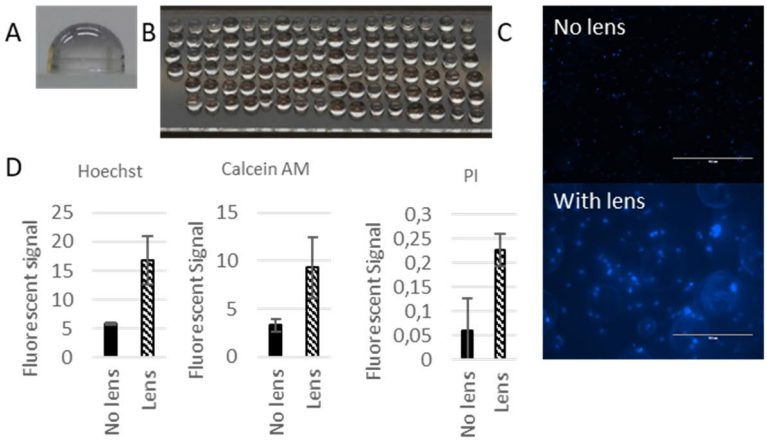


Figure 1. A) Side profile of a PDMS lens. B) One hundred reproducibly made PDMS lenses. C) Fluorescence microscope images of Hoechst stained fibroblasts D) Fluorescence gain measured with Varioskan LUX of Hoechst (ex 355 nm/em 460 nm) for nuclei, CalceinAM (ex 488 nm/em 515 nm) for live cells and PI (ex 530 nm/em 620nm) for dead cells, with and without PDMS lens.

Pyrolytic carbon 3D structures

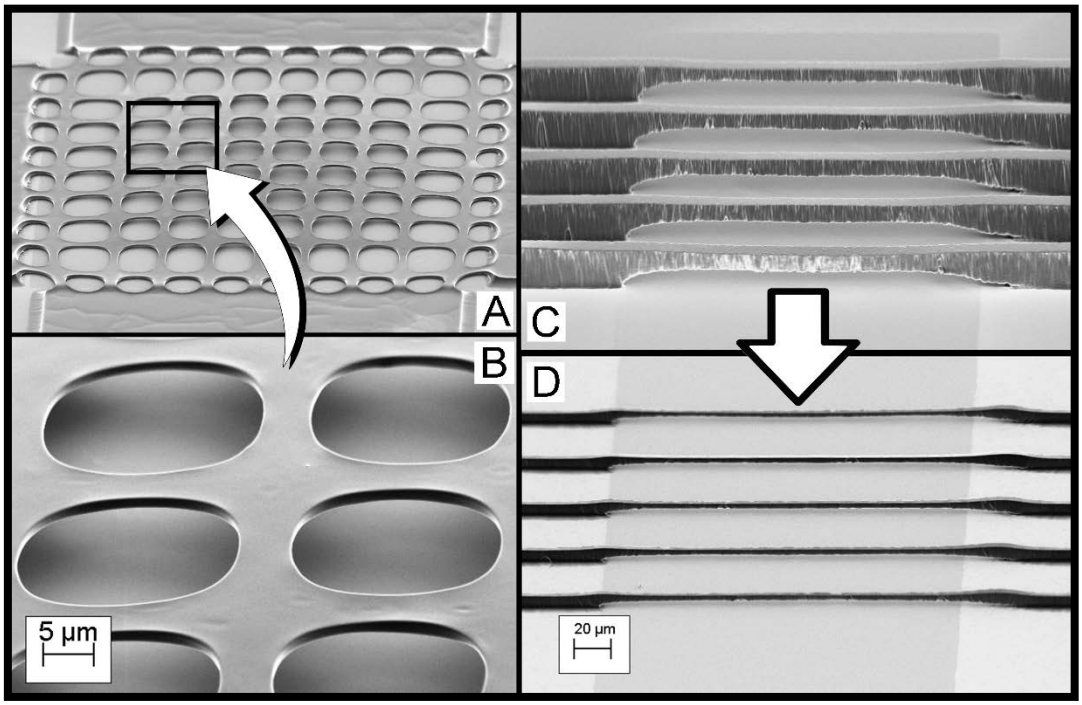
Joonas J. Heikkinen[1], Janez Kosir[1], Ville Jokinen[1], Sami Franssila[1]

[1]Aalto University, Department of Chemistry and Materials Science

The aim of the research is to fabricate demanding 3D carbon structures with different geometries. The material under study is SU-8 derived pyrolytic carbon (PyC). PyC is fabricated from epoxy-based SU-8 photoactive resist through pyrolysis process, resulting in all-carbon material with varying shapes.

Pyrolytic carbon can be fabricated in multiple ways, but most of the methods provide only planar coatings. By using photoresist SU-8 as a base material, it is possible to acquire more complex layers and structures than with other methods. SU-8 can be patterned with photolithography, and after pyrolysis, all patterned structures are preserved. Fabrication of complex 3D structures with overhangs and elevated layers require detailed process planning and optimized parameters. In this research, we will present a simple sacrificial process to fabricate PyC 3D structures in different sizes. The process utilizes conventional lithography methods, but demands understanding of material properties and compatibility.

The studied structures include pillars, mushrooms, cantilevers, bridges (Figure C and D), and membranes (Figure A and B). Besides different shapes and structures, also PyC characteristics were studied. We pyrolysed SU-8 in several temperatures and measured physical, chemical, and electrical properties. In conclusion we mapped all the fabrication parameters affecting different properties. Our results can help other researchers to choose correct PyC material for specific applications.



A) Pyrolysed carbon membrane B) Close-up of the elevated membrane
C) SU-8 bridges before pyrolysis D) Same bridges after pyrolysis process

Fabrication of Concave Microwells via Single Step lithography of Organically Modified Ceramics

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Microwells are extensively used for cell trapping in a range of applications from single cell monitoring[1] to 3D spheroid growth[2]. In this paper we present fabrication of concave microwells out of inorganic-organic hybrid polymer (Ormocomp) by using single step lithography. The inherent residual layer formation of Ormocomp has been shown to cause the rounded cross-section shape of microfluidic channels upon controlled over exposure in proximity mode[3].

Various microwell diameters (30µm -200µm) of Ormocomp (130µm layer thickness) and two different UV exposure dose (13.3 and 47.5 mJ/cm²) were compared in this study. The microwells were characterized by profilometery and scanning electron microscopy (SEM). We concluded that it is possible to control the residual layer thickness, and thus achieve concave microwells of desired size, by tuning the UV exposure dose (Figure 1). Similar effect was also reached by altering the distance of the proximity gap (to the photomask) or the thickness of the Ormocomp layer.

In all, the good control over the microwell size and shape will allow exploitation of this technique to a range of applications including single cell monitoring (small microwells) or culturing of 3D cell spheroids (larger microwells).

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[2] C. Kim et al, ''On-chip anticancer drug test of regular tumor spheroids formed in microwells by a distributive microchannel network'' Lab on Chip, 2012, 12, 4135–4142.
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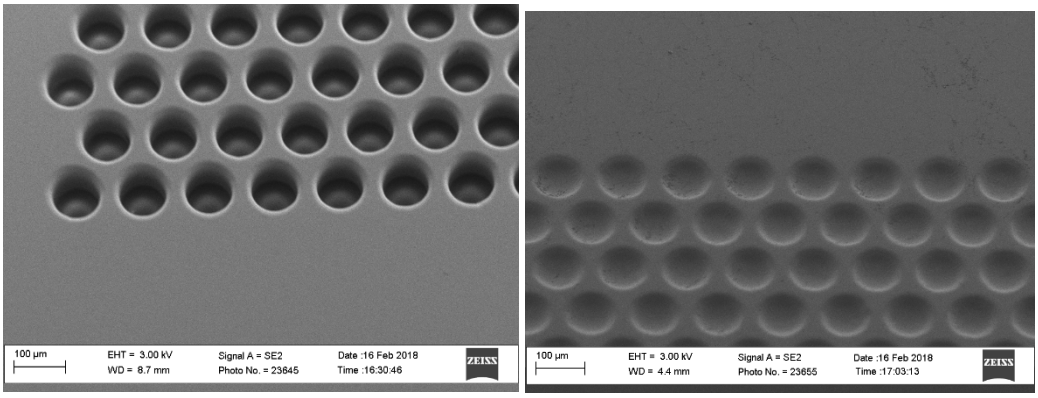

(a) (b)

Figure 1: Microwells with 100 µm diameter and thickness of 130µm with proximity gap of 450 µm with two different UV exposures doses a) UV exposure dose 13.3 mJ/cm^2 b) UV exposure dose 47.5 mJ/cm^2

Coulometric nano thickness gauge

Grigory Yakopov

Special Astrophysical Observatory of the Russian Academy of Sciences

Controlled anodic oxidation can be used in the measurements of thickness of thin-film nanostructures.

A working prototype of the device is presented, the principle of operation of which is that a studied sample containing a thin film structure is subjected to an electric current in an electrolytic cell formed by a substrate (anode) and a probe (cathode) containing a platinum electrode. The thickness of the coating is determined by analyzing the dependence of the voltage growth rate on time during anodic oxidation in the direct current mode. At the same time, the oxidation rate in the electrolyte under the influence of electric current varies for different metals, requiring a careful calibration before each measurement cycle.

Coulometric nano thickness gauge contains a two-electrode electrolytic cell connected to a source of high stability current, an electrolyte source and a device that records the voltage variations in the electrode circuit of the electrolytic cell. The electrolyte source is equipped with a node for its precise dosing, and a two-electrode electrolytic cell consisting of a platinum cathode and an anode, which is a layered metal coating of the sample under investigation, containing a capacitive feedback unit formed by the metal coating of the studied region and a platinum cathode, the data from which allow the formation of a drop of an optimal shape with the help of a device for receiving and processing the data. The device features a personal computer, input-output boards and the corresponding software, which also allows analyzing the dependence of the voltage growth rate on time during the anode oxidation in the direct current mode to determine the thicknesses and the boundaries of the layered structure in nanometers.

The thickness of metal coatings is carried out as follows. The sample is fixed by means of the vacuum fixation unit. With the help of the micrometric drive of the table, the test portion of the sample is advanced to the platinum cathode of a two-electrode electrolytic cell. Using a precision electrolyte dosing unit which is equipped with capacitive feedback, we form an optimal shape of the electrolyte drop, which completely covers the area under investigation, not touching the adjacent ones. This is done by measuring the capacitance of the capacitor formed by the metal coating of the test section of the sample and the platinum cathode. This is a subsequent comparison with the calibration values. The precision electrolyte dosing unit, based on the data obtained by comparing the current capacitance value with the calibration one, adds or lowers the required volume of the electrolyte. Further, between the platinum cathode and the test sample, which performs the anode function, a difference of electric potential is fed from the high stability current source.

The data on the potential difference is digitized in real time and then analyzed on the PC by means of the appropriate software. The dependence of the voltage growth rate on time during the anode oxidation in the constant current mode is analyzed and converted into the value of film thickness in nanometers.

The application of the device will ensure the measurement of the nanocoating thickness in real time and increase its estimation accuracy.

Direct laser writing of a three-dimensional filter system for microfluidic applications

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In a microfluidic Lab-on-Chip (LOC)[1] system, micro-filters are widely used for different functionalities such as sorting, mixing and trapping, due to the simplicity of the approach. However, there are challenges in the traditional fabrication processes, such as how to control the filter shape[2], the pore size[2], and the post-fabrication sealing[3], which limit the usage of micro-filters for many applications. We report here our recent success in integrating a three-dimensional (3D) meshed filter with sub-micrometer-sized periodical pores directly into a sealed microfluidic chip, by using two-photon polymerization (2PP) 3D direct laser writing techniques[5] with a liquid resist.

We demonstrate here a filter system consisting of 20 layers of mesh shaped structures with a line width under 200 nm and a designed pore size about 500 nm x 500 nm, as shown in Figures (a) and (b). The system is fabricated and embedded directly into a pre-made polydimethylsiloxane (PDMS) microfluidic chip sealed by a 150 µm thick glass slide. This type of filter can be used to separate bacteria cells like E.coli, while allowing nutrition or biochemicals to freely pass or communicate through the filter. Therefore, is perfect for applications like quorum sensing[4], as shown in Figure (c) and (d).

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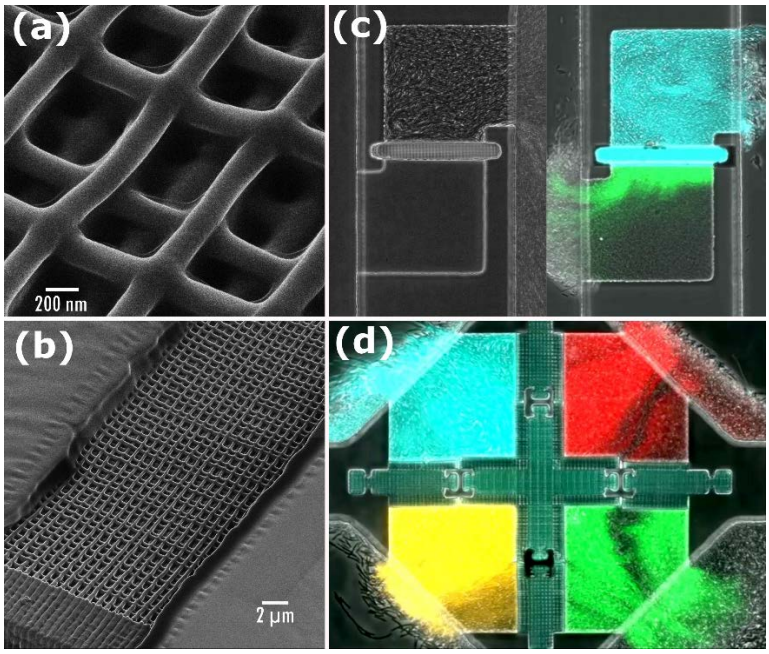

Modeling *in vitro* cell culture microenvironments

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[1]Tampere University of Technology, BioMediTech Institute and Faculty of Biomedical Sciences and Engineering

Culturing cells *in vitro* is one of the most used method in many biomedical and biochemical engineering fields. Optimal environment is essential for human cell cultures. To mimic normal human body conditions *in vitro*, cells should be cultured in a biomimetic and controlled environment. Several environmental parameters, such as, temperature, nutrient delivery, oxygen (O_2) and carbon dioxide (CO_2) (used to control medium pH), are required to be maintained in a physiologically relevant level. Furthermore, cell morphology, orientation, and fate of differentiated stem cells can be affected by mechanical stimulation.

Modeling allows us to study environmental changes and mechanical stimulation in a cell level, thus improve microscale cell culture systems. Here we summarize the modeling work related to the microscale cell culture system currently under development. The system does not only provide physiologically relevant cell culture conditions *in vitro* but can also regulate the microenvironment and the functions of cells.

Models of passive delivery of nutrient and drug molecules using gravity-driven flow were used to study for example drug distribution[1-3]. Developed temperature estimation model[4] provided a method to control indirectly cell culture temperature. It has been used in temperature-dependent cell study to regulate the beating rate of cardiomyocytes cell cultures[5]. Developed finite element model (FEM) has been used to study and optimize gas transport and liquid pH inside the culturing device[6]. Finally, a FEM model was used to characterize the developed stretching device[7]. To conclude, developed models have improved the understanding of cell culture microenvironments and have helped to improve *in vitro* cell culture systems.

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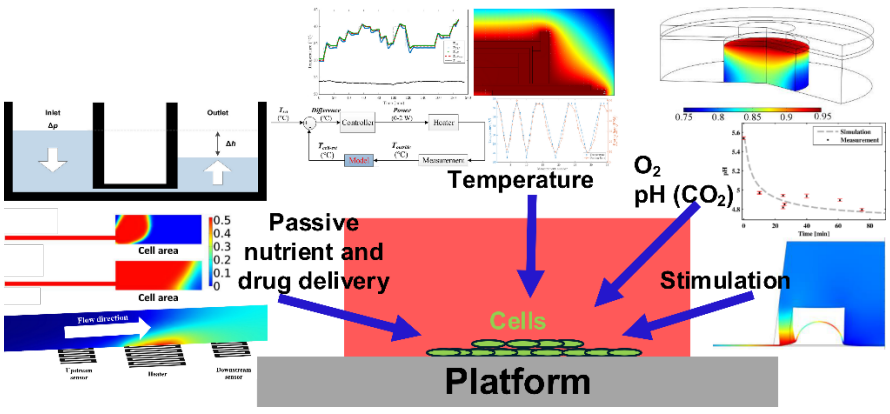

Figure 1. Modeling *in vitro* cell culture environment.

Properties of ScAlN thin films sputtered from Al targets with embedded Sc ingots

Stefan Mertin[1], Andrey Shchepetov[1], Tuomas Pensala[1]

[1]VTT Technical Research Centre of Finland

Scandium aluminium nitride (ScAlN) thin films gained much attention within the last years due to their largely enhanced piezoelectric response compared to aluminium nitride (AlN).[1] Furthermore, ScAlN films with more than 30% Sc possess not only a large piezoelectric response, but also a low dielectric constant compared to traditional strong piezoelectrics such as PZT, which makes them interesting for e.g. microacoustic RF filters,[2] energy-harvesting devices,[3] piezo-driven gyroscopes, and MEMS mirrors. For the latter, VTT's PiezoMEMS process provides a robust application platform.

Both, AlN and ScAlN are compatible with well-established IC processing methods forming the backbone of a reliable Process Design Kit (PDK) and offer a greater variety of in-plane and out-of-plane actuation and sense modes than electrostatic designs. Because of the higher coupling forces achieved with AlN, the piezo-driven components can be much smaller than electrostatically driven components, and ScAlN offers even further improvement. In this contribution, we present material properties and characteristics of 30% Sc films deposited by reactive magnetron sputtering from Al target with embedded Sc ingots. The achieved films are very promising and comparable to other deposition techniques, such as magnetron co-sputtering, or sputtering from AlSc alloy targets.

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3D nano-sized filters enable controlled interactions between microbial populations

Christopher Jonkergouw[1], Zhouran Geng[2], Ekaterina Osmekhina[1], Farzin Jahangiri[3], Sami Franssila[3], Ilari Maasilta[2] and Markus B. Linder[1]

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The engineering of microbial systems increasingly strives to achieve a co-existence and co-functioning of different populations. By creating interactions between populations, one can utilize combinations of populations each having specialized functions such as regulation or sharing of metabolic burden. Inspiration is drawn from naturally occurring multicellular networks such as the microbiota[1] and the plant root rhizosphere[2] where the complexity and diversity of functions performed by the community far surpasses the capabilities of any individual.

Here we present a system based a combination of microfluidics and two-photon (2PP) 3D laser writing[3] that enables growth of physically separated bacterial populations physically, but with continuous communication over long periods of time. The filter is fabricated inside a polydimethylsiloxane (PDMS) microfluidic chip. The coupling of individual populations, standardized interaction and context-independent function lay the foundation for the construction of increasingly complex community-wide dynamic genetic regulatory mechanisms.

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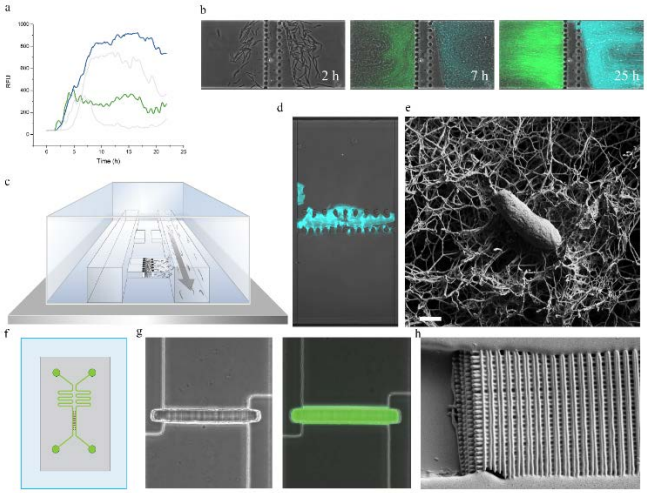

a) Fluorescence expression between independent cellular populations. b) Phase contrast and Fluorescence images of communication over long time periods. c) Schematic of the microfluididc device. d) Confocal images of cellulose filters stained with Calcofluor White. e) Scanning Electron images of entangled cellulose fibers and an E. coli cell. f) Overview of the chip layout. g) Phase contrast and fluorescent images of a two-photon printed filter. h) SEM image of the two photon printed filter.

Droplet microfluidics driven by magnetic shape memory micropumps

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[1]University of Helsinki, Research Programs Unit, Immunobiology
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Droplet microfluidics is a powerful tool for generation of high throughput nano/picoliter reaction chambers. It has been recently applied also in single cell genomics field for co-encapsulation of cells, lysis buffer and microbeads that bind and tag the released RNA within water-in-oil droplets. The currently available devices with syringe pump or pressure control systems lack, however, the desired higher precision of bead-cell co-encapsulation.

In this work, we have tested the performance of magnetic shape memory (MSM) technology-based micropumps[1] in droplet microfluidics. The MSM micropump technology provides superior microfluidic actuation and flow control characteristics to other alternatives enabling the creation and manipulation of droplets with higher accuracy. With only few seconds of flow stabilization time from priming and less than average 0.4 μL/min (or 1.6% of the measured value) flow rate fluctuations, the MSM pumps have proven to be superior in their characteristics to currently available solenoid valve controlled pressure pump systems.

MSM pump technology shows great potential to develop novel microfluidic chips and devices with alternate droplet generation, merging and manipulation functionalities, thus enabling precise cell selection and higher co-encapsulation rates. Our micropump unit (see the figure below) could be also easily integrated to other existing droplet chip designs that currently rely on pumps with significantly weaker characteristics. Therefore replacing those with MSM micropumps could result in a better flow control and higher precision in their functionality.

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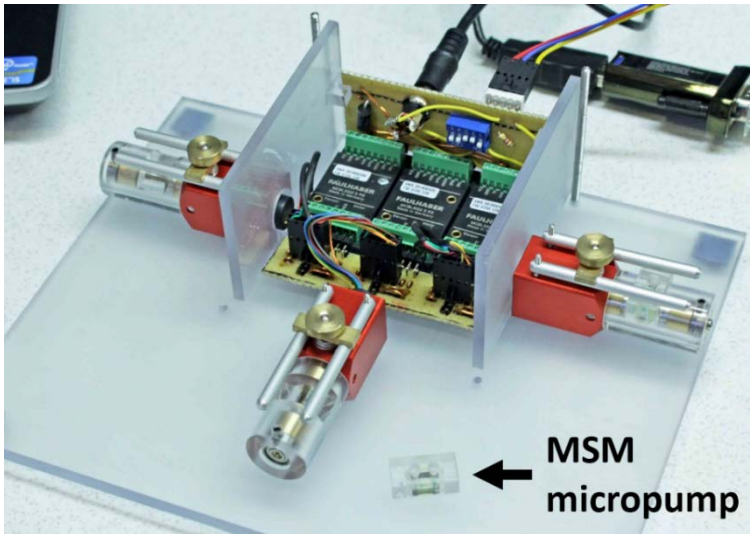

Photo image of the PC-controlled micropump system. The system includes three driving units operating three MSM micropumps. One MSM micropump is shown apart.

Roll-to-roll Manufacturing of Microfluidic Immunoassay Chips

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VTT, Technical Research Centre of Finland, Oulu, Finland

Rapid diagnostic devices commonly apply immunoassays for the detection of biomarkers and disease causing microbes. Such a device should be affordable, disposable, easy-to-use and sensitive. To meet these demands, we have developed a manufacturing process for the fabrication of fully-integrated, microfluidic immunoassay chips (Fig.1).

The manufacturing process described here relies on roll-to-roll printing techniques. VTT has unique printing pilot lines which were applied in this work[1]. The process steps were:

1) R2R hot embossing of microfluidics on cyclic olefin copolymer (COC) substrate
2) R2R Die-cutting of vias
3) R2R Dispensing of antibodies
4) R2R Solvent lamination of fluidics with COC cover
5) R2R hybrid assembly of blood filtration membranes and blisters for actuation

High-volume fabrication of hundreds on devices per day enables low-cost manufacturing costs of disposable devices. Integration of functional elements allows add-just-a-sample type analysis within 10 minutes. With this device, we demonstrated detection of 0.25 µg/ml of C-reactive protein (inflammation marker) from whole blood.

[1] http://www.vttresearch.com/services/smart-industry/printed-and-hybrid-manufacturing-services/pilot-manufacturing-services-and-infrastructure

Fig.1. R2R manufactured microfluidic immunoassay chips

Vibration stimulator for live cell imaging

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[2]University of Tampere, BioMediTech Institute and the Faculty of Medicine and Life Sciences

Mechanical environment directs multiple biological cell functions, e.g. division and signaling, altering tissue development and disease formation. Cell mechanobiology is under intensive research, but currently there are available only limited tools for this. Our aim was to develop a system, which enables to stimulate a sample *in vitro* with dynamic mechanical stimulation and to study fast cell responses of live cells with high-resolution light microscopy.

We designed the stimulator system to fit on a commercial microscope unit (Zeiss LSM 780 LSCM, Carl Zeiss Microscopy GmbH), on which a commercial speaker (Partco Oy) moves 3D-printed sample vehicle (i.materialise) and produces horizontal high frequency (HF) vibration stimulation, which parameters are set with the user interface (LabVIEW 2012 SP1, National Instruments) (Figure 1). The stimulator performance (at range 30-200 Hz) was tested as the accelerometer-measured maximum vibration magnitudes ($\boldsymbol{G}_{peak}$) combined with imaging of the real-time movement of sample line (Au-printed, 63 x water). Usability for live cell imaging was tested with epithelial cells (MDCKII, Emerald-Occludin) plated on collagen I coated - cover slips that were assembled inside a coverslip cell chamber (Aireka Cells, Aireka Scientific Co. Ltd). A modified cover was tightened on top of the chamber for CO_2 exchange (Figure 1). Cellular morphology responses to the HF vibration (0.5 $\boldsymbol{G}_{peak}$; 30 Hz, 60 Hz; 4-80 min) was inspected from reflection (Occludin, λ=488 nm) and transmission images (Z-stack).

At the applicable stimulation range (0.1 $\boldsymbol{G}_{peak} \leq \boldsymbol{G}_{peak}$; 30-100 Hz, 150 Hz) the horizontal HF vibration was accurately produced, but at other frequencies the vibration magnitude declined with respect to other movement. Our stimulator enabled us to observe live cell responses to the HF vibration stimulation, although there occurred a modest sample displacement in the xy-axis after the first stimulation period especially at 30 Hz frequency and a change in the z-focus after every stimulation period. Our initial findings suggest that the epithelial cells tolerate well the HF vibration stimulation and the stimulation leaves their morphology unchanged.

Our designed stimulator is a user-friendly tool for mechanotransduction research. It enables to study real-time mechanobiology -related processes in live cells to the HF vibration stimulation both with label-free and fluorescence imaging.

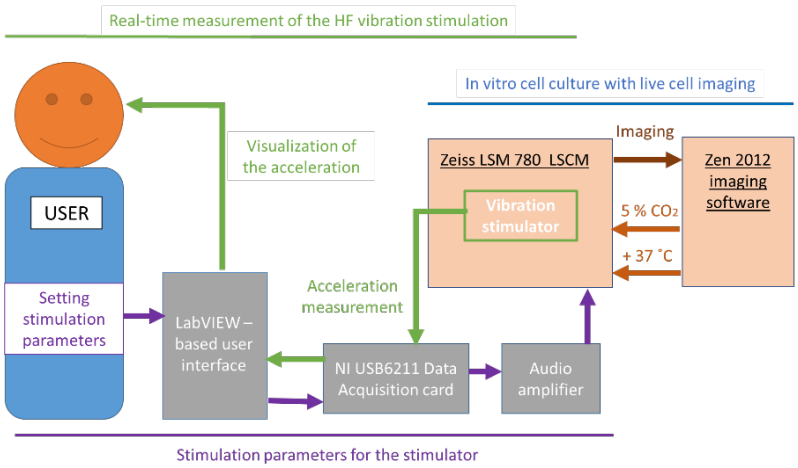

Figure 1. A schematic image of the working principle of the HF vibration stimulator.

Well-plate compatible direct hydrogel patterning for spheroid formation

Anand Tatikonda, Ville P. Jokinen, Sami Franssila

Aalto University, Department of Chemistry and Materials Science

Hydrogels are ideal engineering materials to simulate in vivo conditions as they have a large tunable range of physical properties, like stiffness and topological aspects, and interesting biochemical properties[1]. Conventionally patterned hydrogels are peeled/stripped and placed in a cell culture vessel for cell interaction studies that is tedious and time consuming. We show a method that enables hydrogel patterning directly into multi-well plate format for cell interaction studies and spheroid formation.

We achieve this by attaching a patterned PDMS master (1-2 mm thick) to a 3D printed solid cylinder, which has dimensions matching the targeted well plate format and a pre-defined height based on the hydrogel volume needed in the well plate (Fig Left). For patterning, we pour warm dissolved agarose solution into the well plate and simply close the PDMS+3D printed cylinder attached to the lid before it cools to room temperature.

We have cultured H9C2 cells on flat and patterned hydrogel in the well plates. Cells cultured on patterned hydrogels (well sizes ranging from 50µm to 1000 µm) behave quite uniquely compared with cells on flat unpatterned hydrogel. As agarose does not have active protein absorption sites, cells cultured on agarose hydrogel tend to form spheroids. On patterned surfaces, cells form small clusters, and the cluster size depends largely on the pattern size and scales relatively to the well diameter (Figure Right). On unpatterned hydrogel surface, the size of the spheroid is not well defined and there is a large variance in the spheroid sizes.

The greatest advantage of our technique is that we can vary the hydrogel stiffness (by changing the agarose concentration) and the pattern of the hydrogel (by changing the PDMS master) at the same time, which is hard to achieve by any other technique[2]. Our methodology can be adapted to any commercial and existing cell culture multi-well plates, or any cell culture vessel, because of versatility and accuracy of 3D printing.

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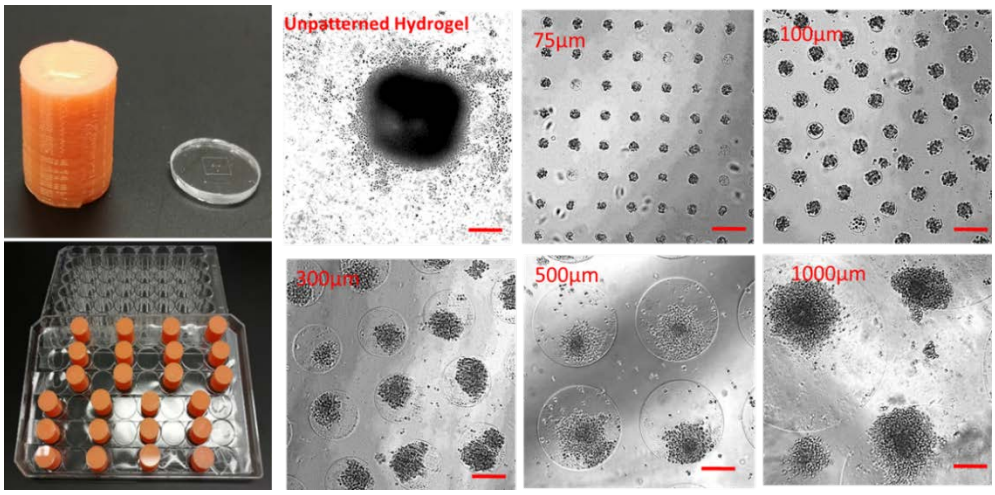

Schematic showing A) 3D printed cylinder and along with PDMS master attached to the lid of the multi well plate. B) Shows spheroid size strongly depends on the diameter of the patterned well and it relatively scales with patterned well diameter. Scale bar 200µm.