Microtechnology Department

Head: Gábor BATTISTIG, Ph.D.

Research Staff

- István BÁRSONY, Member of HAS
- László DÓZSA, Ph.D.
- Csaba DÜCSŐ, Ph.D.
- Péter FÜRJES, Ph.D.
- Zoltán HAJNAL, Ph.D.
- Zoltán LÁBADI, Ph.D.
- György MOLNÁR, Ph.D.
- Anita PONGRÁCZ, Ph.D.
- Vilmos RAKOVICS, Ph.D.
- Zsolt ZOLNAI, Ph.D.
- Andrea Edit PAP, Ph.D.
- Antalné ÁDÁM, M.Sc. (part time)
- Albert KARACS, M.Sc. (part time)
- Ákos NEMCSICS, Ph.D. (part time)
- Gábor PETŐ, D.Sc. Prof. Emeritus
- Béla SZENTPÁLI, Ph.D. (part time)
- Éva VÁZSONYI, M.Sc. (part time)

Ph.D. students / Diploma workers

- Zsófia BAJI, Ph.D. student
- Ferenc BIRÓ, Ph.D.student
- Zoltán FEKETE, Ph.D. student
- Tamás KÁRPÁTI, Ph.D. student
- Gergely MÁRTON, Ph.D.student
- Gergely HUSZKA (PPKE ITK) B.Sc. diploma w.
- Ferenc TOLNER (BME VIK) B.Sc. diploma w.
- Tamás PARDY (PPKE ITK) M.Sc. diploma w.

Technical Staff

- János FERENCZ, engineer
- Róbert HODOVÁN, engineer
- Csaba LÁZÁR, engineer
- András LŐRINCZ, engineer
- Ákos MAJOROS, engineer
- István RÉTI, engineer
- Erika TUNYOGI, engineer
- Katalin VERESNÉ-VÖRÖS, engineer
- Imre SZABÓ, engineer, dr. Univ. (part time)

- György ALTMANN, technician
- Gabriella BIRÓ, technician
- Sándor CSARNAI, technician
- Tibor CSARNAI, technician
- Magdolna ERŐS, technician
- Attila NAGY, technician
- Károlyné PÁJER, technician
- Csilla ARIAS-SOTONÉ FARAGÓ, technician
- Magda VARGA, technician

The main task of the Microtechnology Department is the research, development and system integration of physical, chemical/biochemical sensors and systems:

- Micro- electromechanical systems (MEMS) and MEMS related technologies, with special emphasis on development 3D microstructures;
- Development and functional testing of different MEMS based gas, chemical, 3D force, thermal, biology related sensors and sensor systems;
- Development of micro- and nanofluidic components and systems;
- Development and applications of near IR light emitting diodes and detectors;

Fundamental research on:

- Sensing principles;
- Novel materials and nanostructures;
- Novel 3D fabrication techniques;
- Ion-solid interaction for supporting MEMS development.

Device and material characterizations widely used in our projects:

- Ion beam analysis methods;
- IR and Raman scattering;
- Scanning Microprobes;
- Optical and Electron Microscopy, SEM, TEM, EDX;
- Spectroscopic Ellipsometry;
- Electrical characterisations;
- Microfluidic and biofunctional characterisation.

The Microtechnology Department of MFA runs the 300m^2 clean lab (Class 100-10000) with the complete Si-CMOS technology together with a mask shop, unique in Hungary. The technology base of the clean lab has been further improved in the recent years. The facility allows us to prepare layers, structures and devices on 3" and 4" Si and glass wafers with 1-micrometer line-width.

Main technologies available in the Microtechnology lab also for our partners and customers:

- High temperature annealing, diffusion and oxidation;
- Rapid Thermal Treatment;
- Low Pressure Chemical Vapor Deposition of poly-Si, SiO_2 and Si_3N_4 layers;
- Low Temperature Chemical Vapor Deposition;
- Ion implantation;
- Thin film depositions – Electron beam evaporation, DC and RF Sputtering;
- Atomic Layer Deposition;
- Deep Reactive Ion Etching;

- Photolithography with back-side alignment and Nanoimprinting;
- Wafer Bonding;
- Wet chemical treatments;
- Electro-chemical porous Silicon formation;
- Molecular Beam Epitaxy of III-V compound semiconductors;
- Mask design, laser pattern generator and laser writer;
- Polymer (PDMS, SU8, Polyimide) structuring by photolithography and micromoulding techniques;
- Materials and structural characterizations;
- Electrical and functional characterizations.

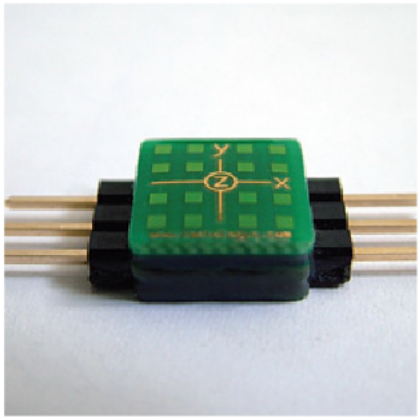
For detailed information please visit us at our web-site or contact through E-mail:
dragon@mfa ttk hu, http://www mems hu/

MEMS (BIOMEMS) devices

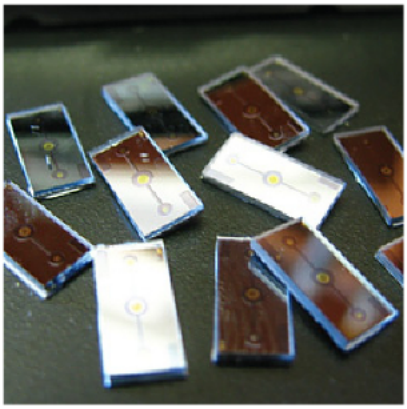
Pellistor type gas sensor module

- **Pellistor type gas sensors** for multi-parallel flammable gas detection
- **Taguchi type gas sensors**
- **Microbolometers**
- **Thermopiles** for temperature monitoring
- **Thermopile antennas** for detection THz range radiation
- **Surface Acoustic Wave (SAW) filters**

- **Capacitive pressure sensors**
- **Calorimetric flow sensors**
- **Vectorial force and tactile sensors** for automotive, robotic and medical applications



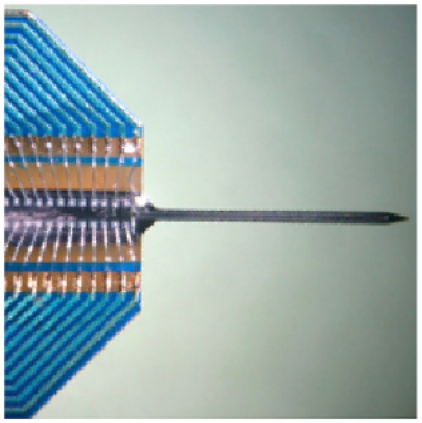
Vectorial force sensor



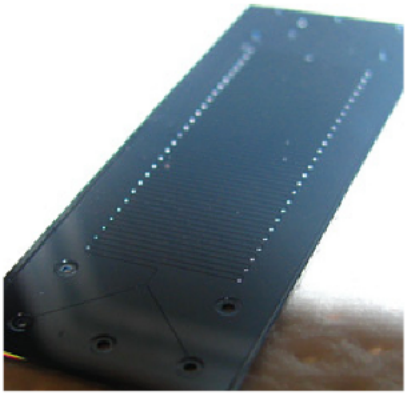
Nanopore biochemical sensors

- **Nanopore based biochemical sensors** for multi-parametric biomarker detection
- **Lab-on-a-Chip systems** for biomedical sample preparation

- **Cortical brain electrodes** for in-vivo monitoring local neural activity
- **Deep brain probes**with integrated drug delivery channels



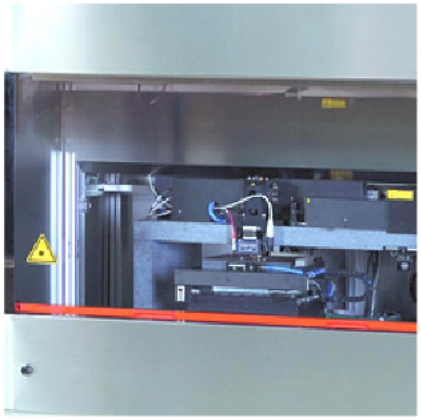
Cortical brain electrode



Microfluidic chip

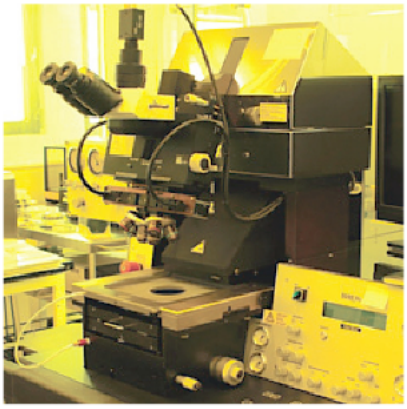
- **Micro and Nanofluidics**
  Design, modelling and fabrication micro- and nanofluidic components and systems in Silicon, glass and polymer materials for biomedical applications

Competences



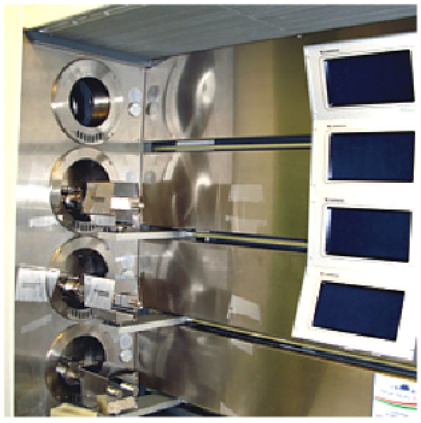
Mask Shop

- 1 µm resolution
- Laser Pattern Generator
- Chromium masks (4-7 inch)
- Direct wafer writing (3-6 inch)



Photolithography

- 1 µm resolution
- Substractive patterning
- Lift-off patterning
- High aspect ratio SU-8 photorezist
- Double side alignment
- Pre-bond wafer alignment



Thin film depositions - Chemical

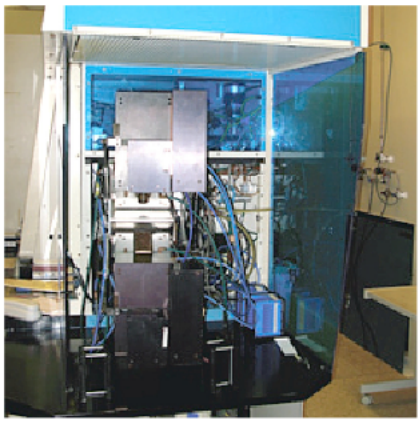
- Low Pressure Chemical Vapor Deposition on
- (poly-Si, Silicon-Nitride)
- Low Temperature Oxide
- Atmospheric CVD (SiOx, PSG)
- Atomic Layer Deposition (ZnO, Al_2O_3, TiO_2)

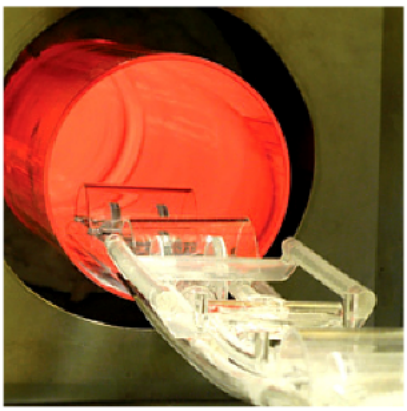
Thin film depositions – Physical

- Electron beam vacuum evaporation (Al, Au, Ti, Cr)
- DC magnetron and RF sputtering (AlSi, Pt, Ti, AlSiCu, FeNi, Si, TiN, TiO_2, W)

CMOS related technologies

- Ion implantation
  energy: 20-120 keV
  dose: 10^{12} - 10^{16} ion/cm^2
- Semiconductor doping
- Surface treatment (B, BF_2, P, Ne, Ar)



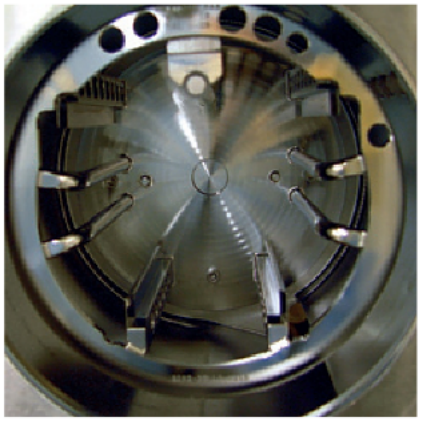


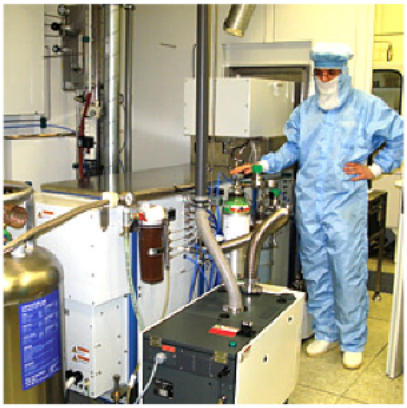
High temperature processes

- Max. 1150°C, N_2, O_2, Ar, N_2+H_2
- Thermal oxidation
- Dopant activation
- Drive-in diffusion
- Sintering contacts
- Rapid Thermal Annealing

Wet chemical processes

- Cleaning (standard CMOS)
- SiO_2, Si_3N_4, SiN_x, poly-Si, Al, Cr etching
- Sacrificial layer etching (SiO_2)
- Anisotropic alkaline etching of Si
- Electrochemical formation: porous Si, Al_2O_3
- Electrochemical Etch Stop of Si
- Sol-gel layers: TiO_2, SnO_2, SiO_2



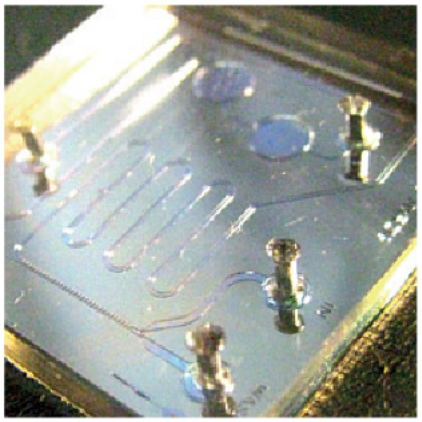


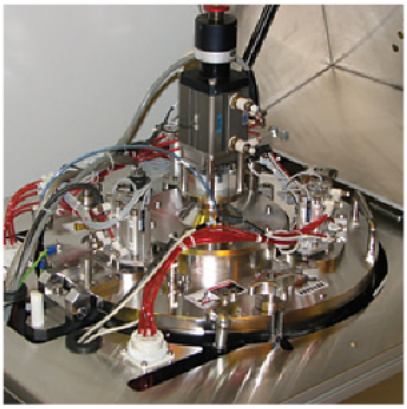
Dry chemical processes

- Plasma cleaning and treatments (O_2, Ar)
- Isotrop Silicon etching
- High Aspect Ratio Silicon etching
- ICP DRIE: Bosch, Cryo processes
- Dielectric (SiO_2, Si_3N_4, SiN_x) layer etching

Polymer technology

- PDMS micromoulding
- SU-8 photoresist (10-150 µm)
- Bonding
- Surface modification



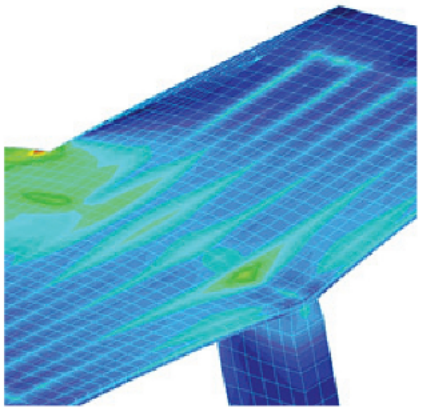


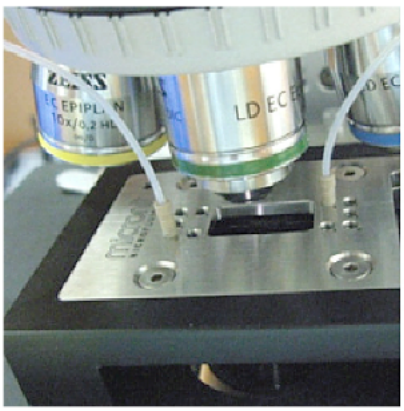
System integration – Packaging

- Wafer bonding: thermocompression, anodic and intermediate layer bonding
- Wafer dicing
- Wire bonding (Al, Au: 25 µm)
- Custom made special packaging

Simulation

- Technology and process simulation
- Monte-Carlo process simulation
- Device simulation
- Spice circuit modelling
- Finite Element Modelling: thermal, mechanical, electrical, fluid dynamics and coupled modeling





Characterisation

- Electrical characterisation
- Surface profiling
- SEM, TEM, AFM, EDS
- Functional tests: mechanical, chemical, biochemical, fluidical

From MEMS to BIOMEMS

The scientific orientation of the MEMS Laboratory of MTA TTK MFA has been significantly changed in the last period. Besides the developments in the field of silicon micromachining, reliable technology–knowledge and infrastructural background has been concentrated around the micro- and nanofluidical, bioanalytical and medical diagnostic research topics – based on several projects. The group – consisting of postdoc researchers, Ph.D. and gradual students – is able to efficiently support the scientific research of national and foreign partners, the development at industrial partners or the education in the partner universities well beyond its own scientific topics.

Motivation

The application of complex micro- and nanofabricated structures as sensing transducers becomes more important in the field of mechanical, chemical and biochemical sensors. As a result of novel and innovative biosensing principles new possibilities are being proposed in medical applications. These bioanalytical systems are expected to integrate the micro and nanoscale transducers with sample preparation microfluidic systems also composing Lab-on-a-Chip devices.
To fulfil the general requirements the microfluidic system must provide reliable sample transport, considering the final sensitivity of the diagnostic device. To make the sample preparation process more simple and comfortable from the point of the customers the integration of the main sample preparation steps in a microfluidic system is a clear demand. The aims:

- Development of reliable and robust micro- and nanofabrication technologies to realize structures.
- Revealing and establishing physical phenomena considering in the micro- and nanoscale systems, and utilizing them in novel bioanalitical, micro and nanofluidical devices.

Effects of the Focused Ion Beam parameters on nanopore milling in solid state membranes

(ENIAC JTI CAJAL4EU, OTKA NF69262, János Bolyai Fellowship)

P. Fürjes, Z. Fekete, L. Illés, A. L. Tóth, G. Battistig, and R. E. Gyurcsányi (BME)

This work describes a reliable nanofabrication technology of solid-state nanopore arrays. The geometric parameters of pores are achieved and optimized according to the requirements of bioanalytical applications regarding conformation and size of the characteristic proteins in clinical diagnostics. Different structural configurations and material compositions of the nanopore structures were developed and characterized according to the variable biofunctionalisation strategies. The geometry of the

fabricated pores were analysed as the statistical function of the focused ion beam milling parameters.
The chemically modified nanonopore based sensors can be applied to the detection of specific biomolecules through transport modulation determined by molecule binding in pores. In spite of the extraordinary sensitivity of the principle, reliability and reproducibility of nanoscale fabrication processes are not adequately elaborated so far.
The characterized test structures were fabricated by the combination of silicon micromachining and subsequent nanofabrication processes. The composition of supporting membrane materials was selected such that low-stress mechanical structures are achieved. Functional layers of the nanopores were altered in order to provide proper surfaces for the possible receptor immobilization techniques. Accordingly, nanopores were drilled in both non-passivated and perfluoro-alkyl passivated silicon-nitride and gold layers respectively (Fig. 1).

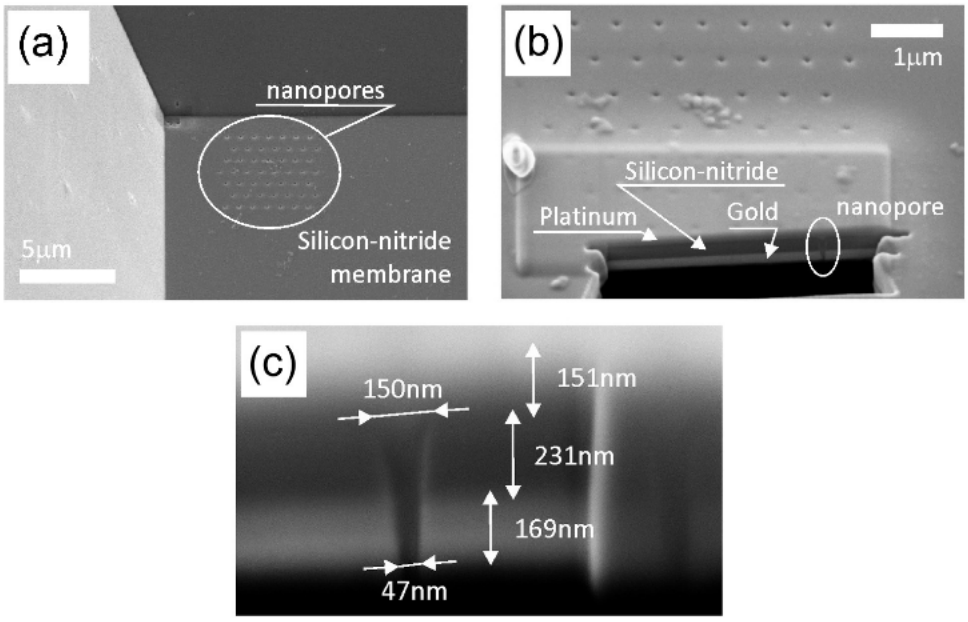


Figure 1. *(a): nanopore array fabricated in MEMS processed Silicon-nitride membrane. (b): the cross section of the membrane represents the layer structure, and (c): the nanopore geometry too.*

The multilayer membrane structures were developed by conventional MEMS technology including Low Pressure Chemical Vapour Deposition (LPCVD) of the supporting non-stoichiometric silicon-nitride (cca. 200nm thick), evaporation of titanium/gold layers (cca. 150nm thick) and anisotropic alkaline etching of silicon. The solid state nanopores were fabricated by Focused Ion Beam milling using accelerated Ga^+ ions applying different milling currents. The resulted nanopore membrane and geometry is demonstrated in the following Fig. 2.

The focused ion beam drilling process was characterized to establish a reliable fabrication technology regarding the accurate engineering of the pore geometry, particularly the pore diameter. The main issue was the tuning of the pore diameter by applying adequate fabrication parameters (milling time and ion current) in case of different material structures. The most interested membrane materials were the bare silicon-nitride and the gold covered Silicon-Nitride. To achieve the lower limit of the pore diameter 5pA and 10pA milling currents were applied. The measured average pore diameters plotted against the milling time in the case of different milling currents and membrane structures are shown in figure. Note, that the nanopore diameters could have significant uncertainty due to the nanoscale fabrication process influenced by the material behaviour and proper focusing of the ion beam. According to the previous experiments 5pA milling current were applied for 3 and 4 second to achieve the proposed pore geometry.

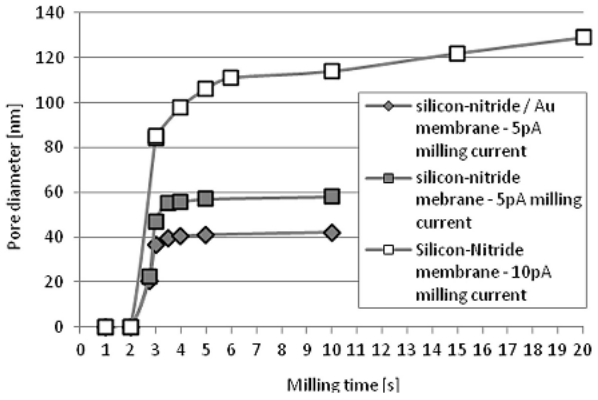


Figure 2. *The average pore diameter resulted by the ion milling of different layer structures as the function of the milling time applying 5 and 10pA ion current.*

Conclusions

The focused ion beam milling of micromachined membranes was characterized to establish reliable nanopore fabrication technology for nanoscale biosensing transducers. Bare and Gold covered Silicon-Nitride membranes were perforated by focused ion beam applying variable milling currents and times. The resulted pore geometries were analyzed to define optimal milling parameters, and statistical limits (as pore diameter accuracy) caused by the uncertainties of nanoscale processes such as beam convergence. The significant influence of the material composition was also clearly presented: the metallization of the dielectric membrane can improve the beam stability due to the reduced electrostatic fluctuations.

Integrated microfluidic environment for solid-state nanopore sensors

(ENIAC JTI CAJAL4EU, OTKA NF69262, János Bolyai Fellowship)

Z. Fekete, G. Huszka, A. Pongrácz, Gy. Jágerszki (BME), R. E. Gyurcsányi (BME), E. Vrouwe (Micronit), and P. Fürjes

The micro- and nanotechnology based biosensing principles open up new possibilities towards the development and realisation of robust, user-friendly and cost-effective in-vitro diagnostic platforms. Furthermore, label-free and multi-analyte detection is envisioned to allow more accuracy and higher throughput in clinical diagnostics. The bioanalytical systems are expected to integrate the nanoscale transducers with interface chemistry, and bio-receptors as well as the microfluidics, control software and hardware. The final goal of this work is to develop nanopore based multi-parametric biosensing platform, applicable for label-free detection of blood marker proteins of cardiovascular symptoms.

Combination of silicon micromachining and subsequent nanostructuring processes were applied to fabricate the transducer device. The fluidic vias, the channel system and the multilayer membrane structure were fabricated by MEMS technology including Low Pressure Chemical Vapour Deposition (LPCVD) of silicon-dioxide (SiO_2), non-stoichiometric silicon-nitride (SiN_x) layers, evaporation of titanium-dioxide and gold layers and multistep Deep Reactive Ion Etching (DRIE) of silicon substrate. The structural materials were extensively characterized by electrochemical impedance spectroscopy and fast chronoamperometry to provide a feedback on the electrical resistance of the mechanical multilayer being of crucial importance considering the electrochemical measurement method.

The realized silicon structure was anodically bonded to the glass microfluidics in wafer level. The final fluidic chips consisting nanopore membranes and vertical vias were mounted onto fluidic connection platform designed and realized by the Micronit Microfluidics (Fig. 1).

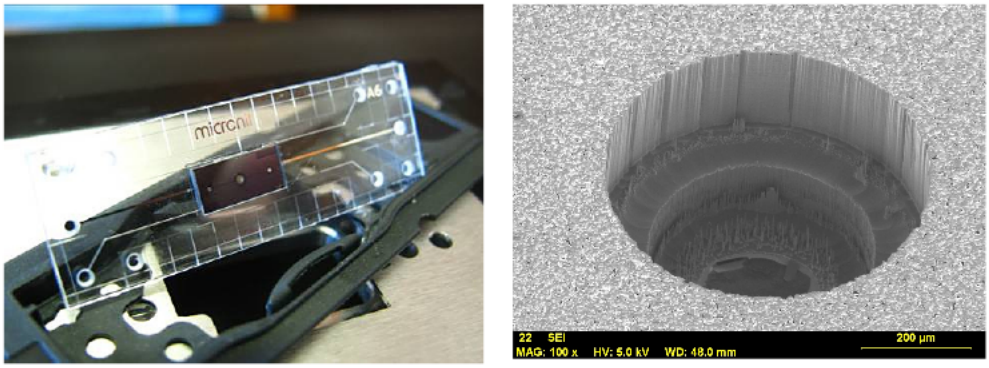


Figure 1. *The mounting realized microfluidic nanopore chips (left) with vertical fluidic vias (right) and the mounting onto the flow cell addressing the nanopores.*

The feasibility of the integrated microfluidics for nanopore sensing is characterized in terms of contingent shunting and proper sealing by impedance spectroscopy. Given the high resistance of the nanopore any leakage or shunting would prohibit the detection of specific changes of pore resistance. DC resistance of microfluidic channels and membrane without nanopores is measured (Fig. 2). The slight change in resistance of the membrane by increasing KCl electrolyte concentration suggests that 3D passivation of the microchip is necessary for improving sensitivity, however, channel resistance is clearly differs due to definite dependence on concentration. According to the preliminary measurements, the above microsystem is a good candidate for the detection of blood proteins in low concentration analytes.

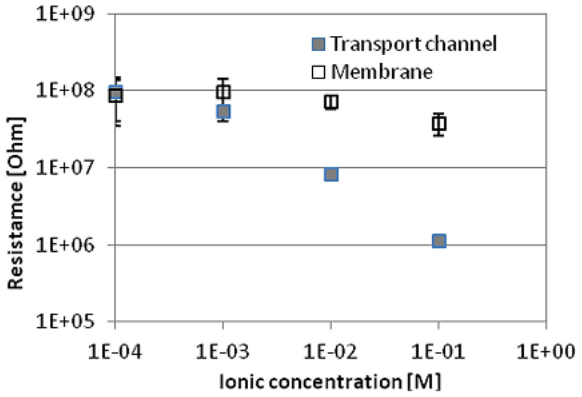


Figure 2. *Concentration vs DC resistance curve measured in the integrated transducer chip through the membrane and the transport microchannel.*

Conclusion

We described functional and design aspects of a silicon based solid-state microsystem consisting of fluidic interface, microfluidic components and nanoscale sensing transducers. The microfluidic system is proposed to cover the sample preparation (e.g. particle separation, mixing etc.) and precise transport, and facilitates the application of whole blood as well. In the further period of the development the main issue will be the proper 3D surface passivation of the whole microfluidic system, to achieve advanced and stabile chemical and electrical resistance of the channel surfaces.

Particle mixing by chaotic advection in polymer based microfluidic systems

(EU FP7 P3SENS, TÁMOP-4.2.1.B-11/2/KMR-2011-0002, TÁMOP-4.2.2/B-10/1-2010-0014 and János Bolyai Fellowship)

P. Fürjes, Z. Fekete, E. G. Holczer, E. Tóth, K. Iván (PPKE), and I. Bársony

The present work is intended to describe the functional aspects and working principles of special microfluidic structures applicable to dilute and transport real biologic sample (as whole blood) to the further functional parts of the sample preparation system or the sensing areas of biosensors. According to the preliminary expectations the fluidic layouts were designed consisting of advanced Herring-Bone type chaotic mixer systems and fabricated in PDMS polymer. The performance of the proposed mixer structures was characterized to optimise the main geometrical parameters of the microfluidic structures to support the design the final sample preparation system. The particle transport in the different mixer structures was visualized and analysed by numerical modelling to support the explanation of the experimental results and functional performance of the fluidic system.

The manipulation of fluids (e.g., biological samples as blood) in bioanalytical systems is a key issue in terms of the final applicability of these devices. According to the customers' requirement the developments aim to apply the simplest analyte at the inlet of the system as whole human blood in case of medical applications. In these novel analytical microsystems the sample manipulation is executed by complex micro-fluidic structures (Lab-on-a-Chip), integrating the main sample preparation tasks as dilution and mixing, blood plasma separation and precise transport also. To improve the performance of the proposed (Zweifach-Fung bifurcation effect based) blood plasma separation system the whole blood has to be diluted for an adequate haematocrite level, so diluting and mixing function has to be optimized also. The mixing possibilities are limited in microscale since turbulent flow cannot be built up due to the dominant viscosity. The chaotic advection could be an optimal mixing method in the case of the microfluidics considering stable and laminar flow in low Reynolds regime also.

Herring-Bone type chaotic mixers

"Herringbone" type chaotic mixer structures with various geometric parameters (Fig. 1) were characterized to reveal the motion trajectories and the mixing behaviour of the biological particles (fungi cells in this case) in the microfluidic systems. For revealing the hydrodynamic performance and behaviour of the different mixing structures the geometries parameters were varied as presented in figure (a: gap between the grooves, b: grove width, c: gap between the blocks, d: grove depth). The experimental microfluidic systems can be fabricated by Rapid Prototyping in PDMS, applying the SU-8 epoxy based negative photoresist as moulding replica developed

by a special multilayer technology. The figure also shows the fabricated SU-8 structure corresponding to the described "herringbone" structure.

The physical phenomena of the particle motions were characterized by mixing/interlocking fungi solution with phosphate buffered salt solution in the chaotic mixer structures. The particle traces were visualized by dark field microscopy (Fig. 2). The recorded light intensity scattered from the corpuscular particles can indicate the local concentration distribution of the fungi cells.

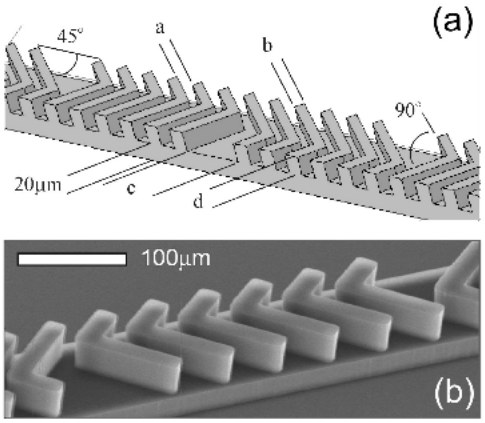


Figure 1. Schematic structure of the Herring-Bone type microfluidic mixer (a) with the varied geometric parameters, and the multilayer SU-8 molding master (b) for PDMS structuring of the real fluidic channel.

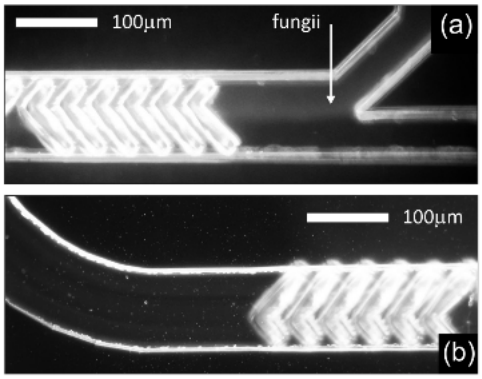


Figure 2. Particle traces in the Herring-Bone type chaotic mixer structure ((a): inlet, (b): outlet) recorded by dark field microscopy.

Fig. 3 presents the vertically integrated light intensity in the cross-sections of the "herringbone" type mixer channel at the inlet and the outlet planes referring the particle distribution.

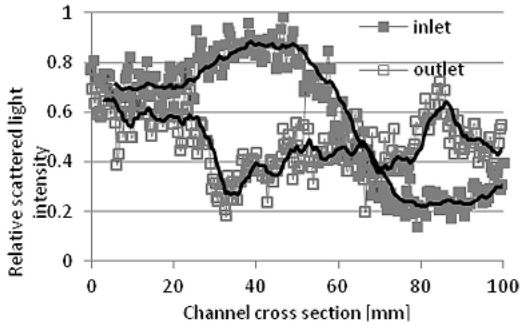


Figure 3. The relative light intensity scattered from the fungi cells referring the particle distribution in the cross section of the herringbone mixer structure (inlet and outlet planes).

The mixing process in the different microfluidic structures were analyzed and visualized by particle tracing calculated by Finite Element Modeling using COMSOL Multiphysics. The projection of the particle traces onto the plane perpendicular to the main flow direction is clearly present the mixing states evolving in the fluidic channel. The movement of the representative particles describes the mixing performance while passing through the structure.

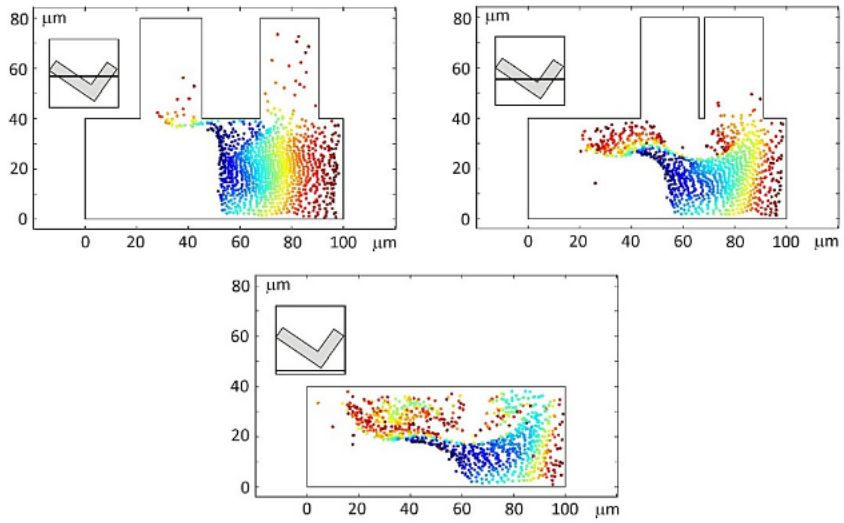


Figure 4. *The Poincare maps represent the particle mixing in the plane perpendicular to the channel direction evolving with the flow front.*

Conclusions

The mixing performance of Herring-Bone type chaotic mixers constructed with various geometric parameters were characterized by FEM modeling. The developing particle distribution in the microfluidic structures was visualized by Poincaré-maps considering the different geometries. The results of the simulations proved that for improving the performance of the mixer we should increase the depth, the number or the width of the grooves of the herringbone structure.

The results of the simulations were verified experimentally by recording the particle trajectories applying dark field microscopy. The experienced behavior of the Herring-Bone type mixer structures were in adequate accordance with the results of the simulations and the modeled trajectories of the individual particles could confirm the experimental results considering the main hydrodynamic effects as pressure gradients and shear forces.

Terahertz spatial light modulator with digital microfluidic array

(OTKA CNK77564 TERASTART)

P. Földesy (SZTAKI), Z. Fekete, T. Pardy, and D. Gergelyi

Generally, the terahertz (THz) spatial waveform modulators are able to control the transmission of an incident terahertz wave. Moreover, beam steering and focusing is also reachable by two-dimensional arrays of beam modulators. The monolithic integrated spatial modulators offer high modulation rate up to several megahertz, while usually limited to a certain resonant frequency or range with a limited switching value significantly less than 100%. Such modulators are the electrically driven terahertz metamaterial spatial modulators and reconfigurable metallic slits. Solid-state THz detector arrays are integrated in individual dies with a limited number of detectors per die due to the relatively long wavelength (0.1–3 mm). The spatially modulated illumination is a possibility to increase this spatial resolution in far field and near field cases (e.g. imaging using compressed sensing or resolution enhancement by structured light). Our proof of concept chip has been chosen from this field.

Droplet based modulation

We propose to utilize the high absorption of water for THz spatial modulation by means of programmable digital microfluidic droplet array. The water in liquid and vaporized form has high absorption coefficient with increasing value from 0.02THz to 30THz with several peaks. The droplet and electromagnetic wave interaction has been utilized in a different context as material analysis or dye laser frequency tuning architecture too. In the investigated sub-THz region this value varies in the range of 50-100 cm-1 with several peaks, which means that a few hundred μm water film constitutes almost total absorption. Our solution takes advantage of this phenomenon by using droplets to create “off” states in a controlled volume, thickness, shape, positioned in a regular rectangular grid. The platform of droplet positioning and movement is the droplet-based digital microfluidics. In digital microfluidics, discrete fluidic droplets are translated, mixed or stored on the surface of an array of electrodes coated with a hydrophobic insulator on within two such layers. The working principle of the droplet manipulation is the electrowetting on dielectric (EWOD). The common solution is to form two layers of hydrophobic substrates, in which the bottom plate is patterned by an array of controllable electrodes and the top plate is coated with grounding electrode. In our scheme, the top electrode must remain “transparent” to the THz radiation, hence a conductive electrode cannot be mounted. Such structure of single electrode plate is called co-planar structure with customized ground electrode system on the bottom plate only. Though the activation is higher than in the two conducting layer structure, the transparency is reached. The concept of modulation is presented in Fig. 1.

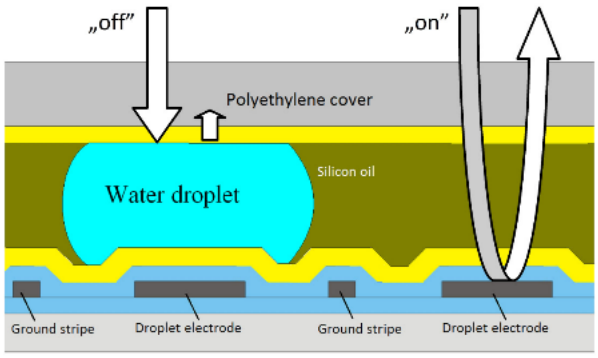


Figure 1. *Illustration of the modulation principle using highly absorptive water droplets and the cross-section of the coplanar microfluidic structure.*

The array was realized by silicon micromachining technology (Fig. 2). The initial substrate was <100> single-crystalline silicon wafer. On the bulk silicon, 1000nm thick thermally grown silicon-dioxide layer was applied. The electrode system was formed by lift-off technology. 300 nm thick aluminum film was deposited by e-beam evaporation and was patterned by conventional photolithography. The dielectric layer of the microfluidic chip is composed of silicon-dioxide and subsequently developed Teflon AF layer. 100 nm thick silicon dioxide was deposited by LPCVD process from silane and oxygen at a temperature of 435°C. Buffered HF removed the oxide from the electric contact pads. Finally, 500nm Teflon AF was spin-coated on the chip and dehydrated at 165°C on hot-plate to form a hydrophobic top layer. The top electrode of polyethylene is also covered with thick Teflon AF. The manufactured chip is shown in Fig. 3. The electrode pitch is 1700µm with 100µm gap, while ground lines in the gap are 20 µm. The droplet height was set in the experiments to 500µm. In spite of the fact, that the ground stripes are also covered by silicon-dioxide and hydrophobic layer (in contrast to co-planar structure, the chip enables very low voltage and stable operation (~60-70V, 10KHz).

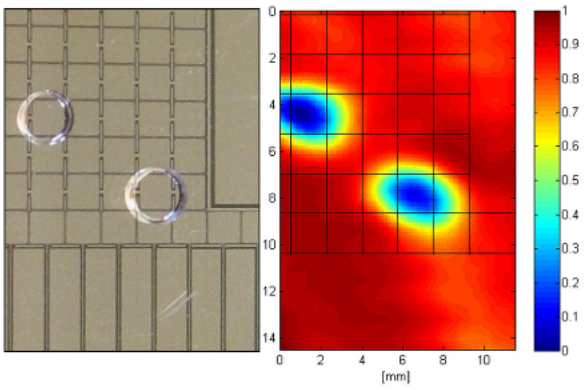


Figure 2. *Visual (left) and raster scan of two droplets in the array at 0.48 THz (λ = 620 µm) by focused irradiation (right) (spot size HWFM was 2.2 mm). The array pitch is 1700 µm, while the droplets had near 2 mm diameter.*

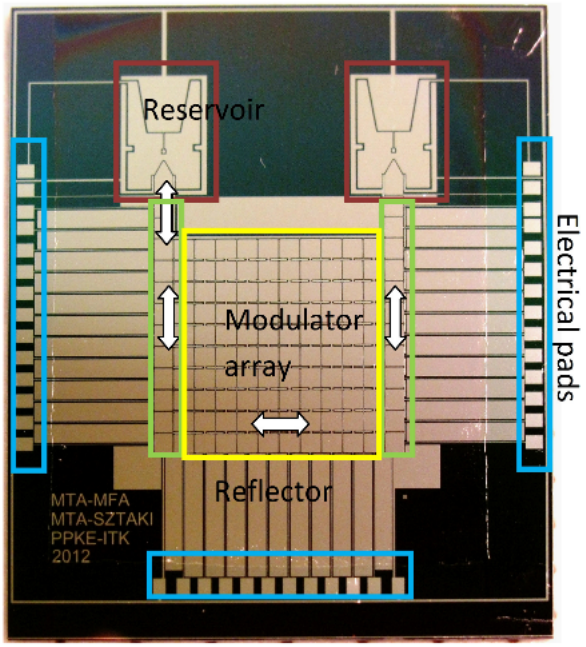


Figure 3. *10×10 pixel modulator digital microfluidic array.*

Results

The droplet translation architecture of the sample chip is designed for compressed sensing imaging applications. This imaging method is based on consequent randomly patterned illumination. First, one of the reservoirs is filled and closed and the vertical chain is driven to form a 1D droplet sequence. Next, the modulator array is used to move the shifted droplets horizontally towards the opposite side. These two steps are repeated, and the array is filled with changing sparse and orthogonal patterns (the fill factor is less than 1/9th in order to avoid droplet collision). The vertical chain of the other side is utilized to collect the droplets and store in the reservoir. Later on the direction of flow is changed to backward direction. A continuous wave VDI sub-THz source provides illumination in a quasi-optical setup. The sensor is a complex integrated CMOS based sensor with embedded amplification, lock-in detection and digital output streaming. For characterization purposes several droplet arrangements have been raster-scanned with focused beam. The droplets above near three free-space wavelength actuates as diffraction-limited near perfect black region, while the rest of the array had near complete reflection.

Neuro-MEMS - Deep-brain silicon multi-electrodes with surface-modified Pt recording sites

A. Pongrácz, G. Márton, Z. Fekete, and G. Juhász (ELTE)

Extreme-long (up to 70 mm) Si neural multi-electrodes and their fabrication technology were developed. Probes with different shaft lengths (15-70 mm) were formed by deep reactive ion etching and equipped with Pt recording sites of various configurations. *In vivo* measurements on rodents indicated good mechanical stability and robust implantation and targeting capability. The probes produced high quality signals from different locations of the cerebrum. The accompanied tissue damage was characterized by histology. Furthermore, by electroplating Pt onto the surface of the electrode sites electrical impedance reduction was achieved, the improved charge transfer capability was characterized by cyclic voltammetry.

Motivation

Micromanufactured Si- or polymer-based neural electrodes are frequently used for in vivo neural recordings close to the brain surface. To apply such silicon probes to access deeper (>1 cm) brain regions is highly unusual due to lack of appropriate devices. In our work we analyze whether much longer Si probes (up to 7 cm) can be manufactured using common MEMS processes. Using such dimensions the issues connected to mechanical and electrical behavior become critical, especially during implantation into the nervous tissue. Signal attenuation and signal-to-noise ratio are also determined by the electrochemical properties of platinum surfaces, which also have to be characterized.

Results

During the development of long Si probes a special fabrication method was worked out, the probes were characterized electrically, Pt electrode surface was modification in order to minimize its impedance and *in vivo* tests of the first extreme-long Si multi-electrodes were performed (Fig. 1).

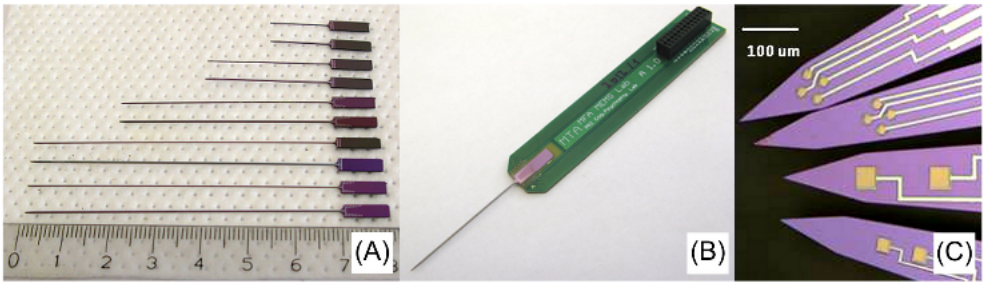


Figure 1. *A) Realized silicon deep-brain probes with 15-70 mm shaft length, B) Wire bonded multielectrode on PCB for acute in vivo testing, C) Different electrode designs.*

Various Si probes with 4-16 Pt recording sites have been created by MEMS technology: 15-70 mm long, 206 and 400 µm wide and 200 µm thick. Schematic step-by-step cross sectional view of the probe during the fabrication process is shown in Fig. 2.

Testing the devices *in vivo*, various, healthy activities could be recorded from rat cortical layers and hippocampus. Afterwards we revealed the injured cells around the implantation site with Gallyas ("dark neuron") staining procedure and found no abnormal cell loss (Fig. 3).

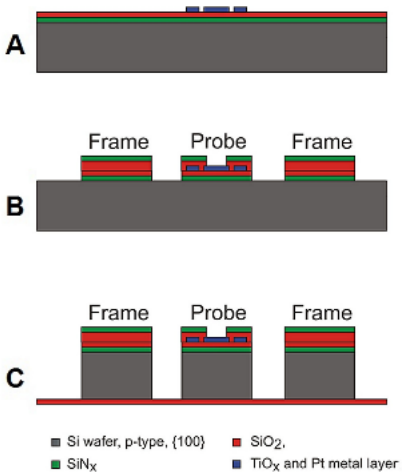


Figure 2. *Fabrication steps. Forming lower insulator and patterned metal layers (A), upper insulator layers, opened at the sites (B), silicon dry etching with Bosch process (C).*

Electrical characterization and surface modification of the Pt recording sites was carried out. Sufficiently low impedance of the electrodes is a key factor in obtaining good quality recordings.

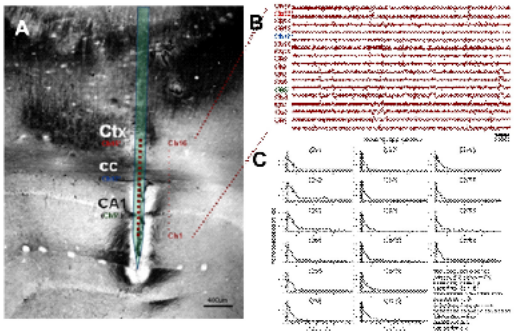


Figure 3. *Histological section, showing multisite silicon probe track and acutely injured "dark" neurons near the track (A). Representative depth profiles of local field potentials patterns (B) and their power spectral densities, which show diverse activities on different channels (C).*

Cyclic voltammetry with a 0.5 M H_2SO_4 solution was used in order to clean and validate the metal electrode surfaces and successfully increased their roughness factor from around 10 to 100s with deposition of Pt from solutions containing $PtCl_4$ and HCl in various concentrations. Our study revealed that even if the length of the multi-electrode is extreme (up to 7 cm) mechanical and electrical properties of the probe are good enough for high quality in vivo signal recording (Fig. 4).

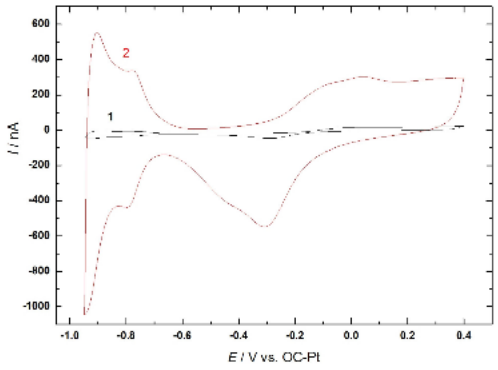


Figure 4. *Cyclic voltammograms of an electrode site before (black curve) and after (red curve) electroplating platinum.*

Deep-brain silicon multi-electrodes for simultaneous neural recording and drug delivery

A. Pongrácz, G. Márton, Z. Fekete, and G. Juhász (ELTE)

Silicon based deep brain multi-electrodes (up to 70 mm) with monolithically integrated microfluidic channels have been realized to perform electrical recording and drug delivery in deep brain regions at the same time. Fabrication process of the drug delivery channels and the Pt recording sites is presented here. Electrical characterization, impedance tuning, and *in vivo* testing of the probes is also presented. The functionality of the microfluidic channel is demonstrated and pressure-flow characteristic of the channels is discussed.

Motivation and results

During the last decade deep brain stimulation (DBS) has become a routine method for the treatment of advanced Parkinson's disease. DBS of selected brain regions can dramatically relieve tremor and rigidity. Multiple groups are attempting to extend this mode of treatment to dystonia, Tourette syndrome, variety of pain, depression, and obsessive-compulsive disorder. Simultaneous chemical and electric interactions with the very same groups of cells of an active brain might induce a huge progress in these studies. Long-term stability of electrophysiologic implants is to be enhanced with the help of continuous dosage of anti-inflammatory drugs. Micromachined neural probes