Fabrication and application of 3D force sensors based on piezoelectric and piezoresistive effects

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MTA EK MFA MEMS labratory

Last semester

Supervisors: Péter Fürjes, János Volk

Introduction

3 parts of my work

- *Piezoresistive 3D force sensors*
- *Piezoelectric ZnO nano-rods*
- *Piezoelectric thin films (for 3D force sensor)*

Piezoresistive 3D force sensors

Applications

- *Integration in a surgery robot’s laparoscope*

- *Integration in a vehicle tyre*

Piezoresistive 3D force sensors - Integration in a laparoscopic tool

3D force sensor chip

Specific requirements:

- Reduced size (down to 1x1mm^2) to enable integration
- Sensitivity: 1-20N for gripping force, 10-1000mN for tactile sensing
- Robustness (vs. sensitivity)
- Biocompatible coating can withstand sterilization

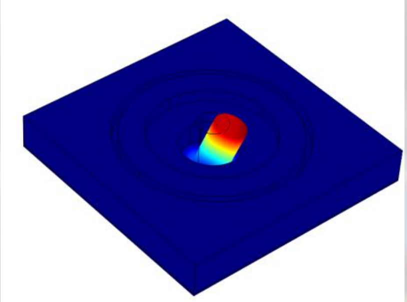
Operation:

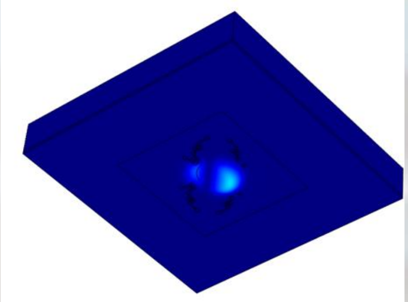
- Deforming c-Si membrane
- 4 embedded piezorezistors
- 4 Voltage dividers or Wheatstone-bridges
- Calculation of vectorial components:

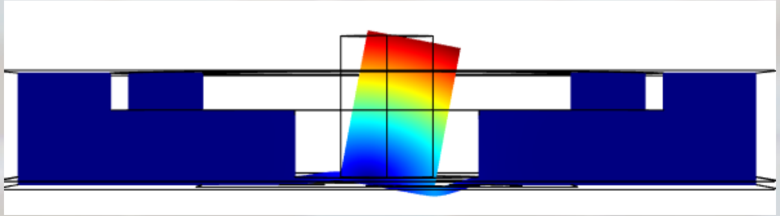
$$F_x = \frac{1}{V_0 \alpha_{ls} \pi_{44}} \left(\Delta V_{right} - \Delta V_{left} \right),$$

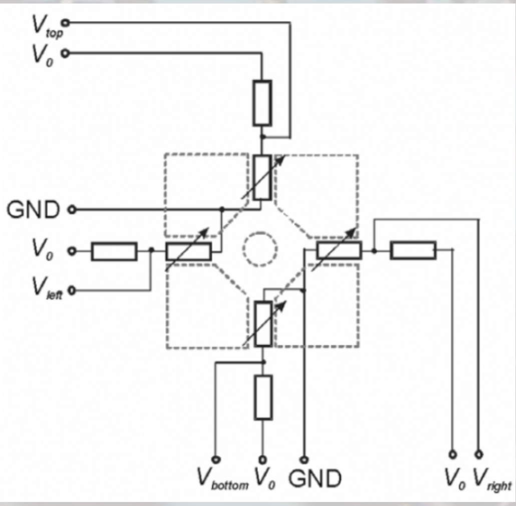
$$F_y = \frac{1}{V_0 \alpha_{ls} \pi_{44}} \left(\Delta V_{top} - \Delta V_{bottom} \right),$$

$$F_z = \frac{1}{V_0 \alpha_{ln} \pi_{44}} \frac{\left(\Delta V_{left} + \Delta V_{right} + \Delta V_{top} + \Delta V_{bottom} \right)}{2}$$





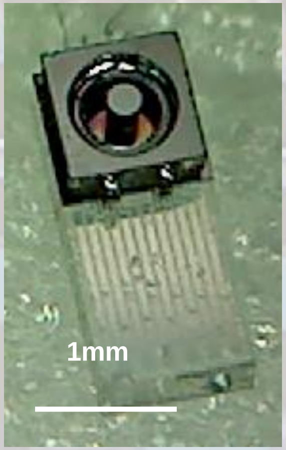


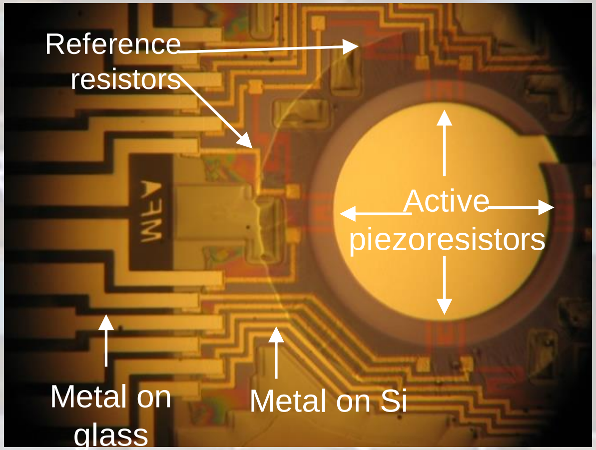


Piezoresistive 3D force sensors - Integration in a laparoscopic tool

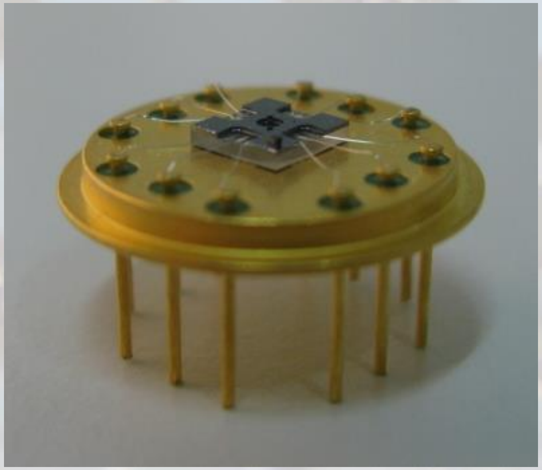
Accomplished tasks

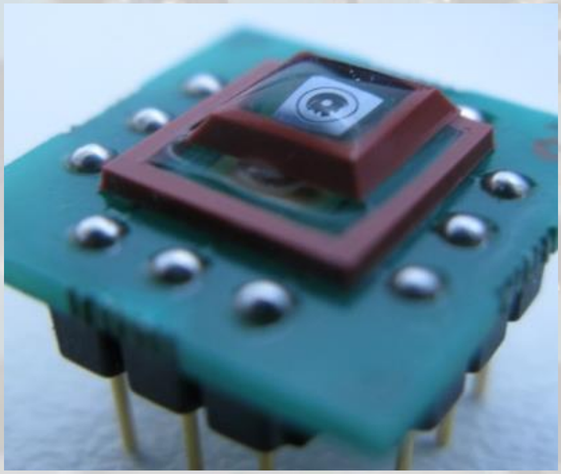
- Fabrication





- Testing

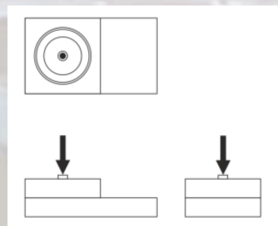


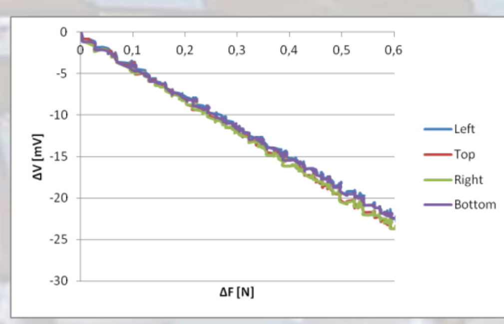


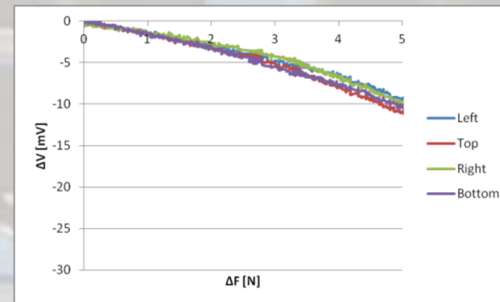
Piezoresistive 3D force sensors - Integration in a laparoscopic tool

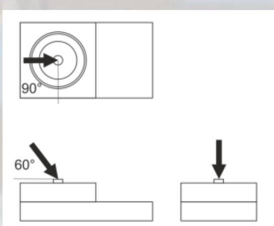
- Measurements

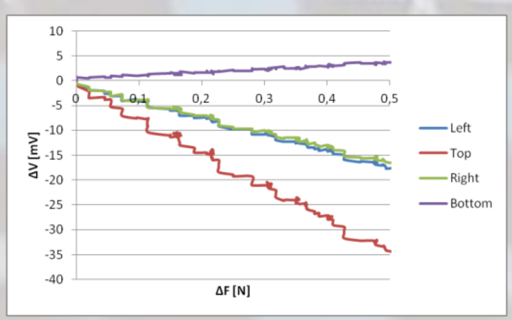
Effect of elastic coating | Bare sensor | Covered sensor

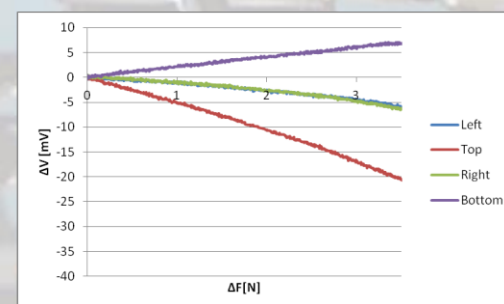


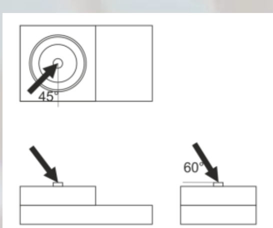


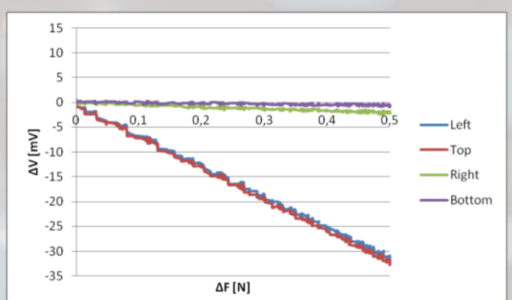


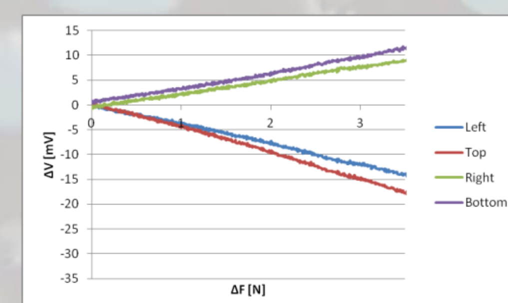






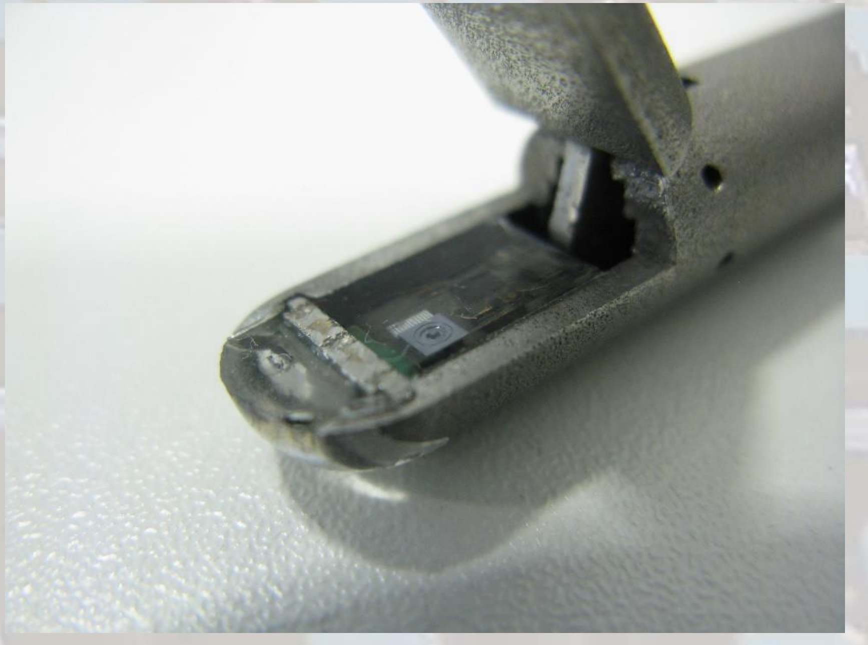






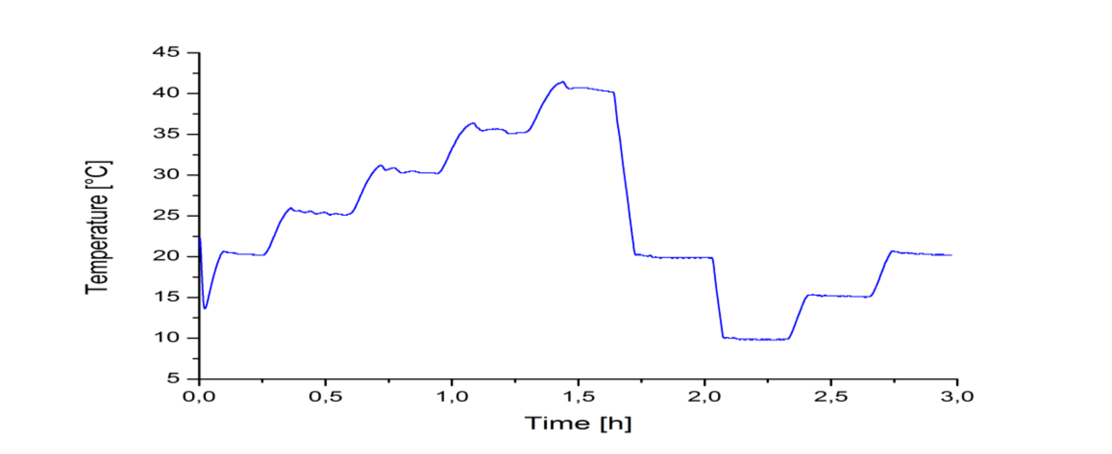
Piezoresistive 3D force sensors - Integration in a laparoscopic tool

Metal gripper and biocompatible coating (Nusil MED-6215)

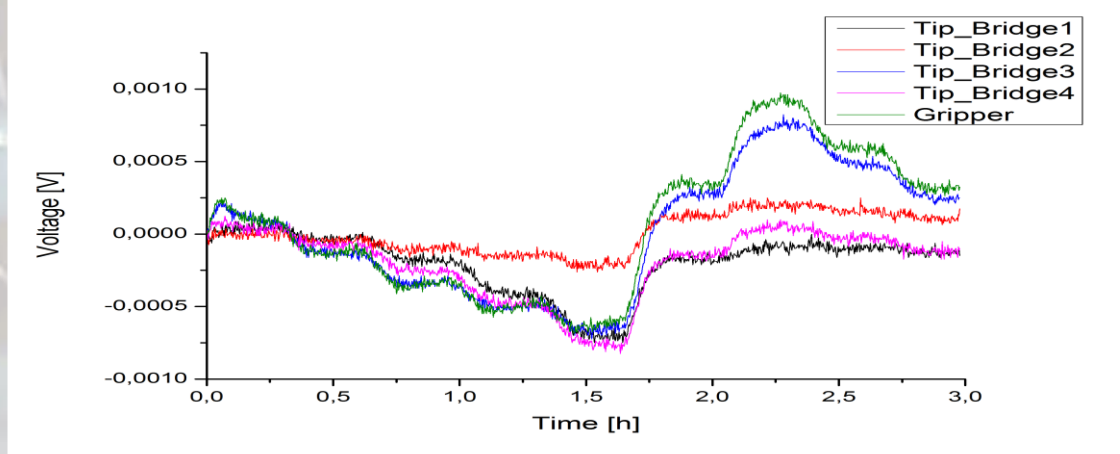


Piezoresistive 3D force sensors - Integration in a laparoscopic tool

Temperature tests



Temperature profile

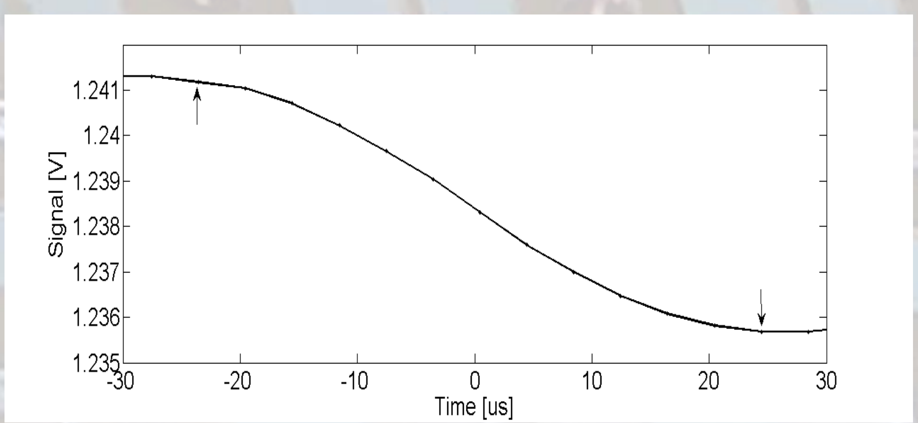


Offset signals

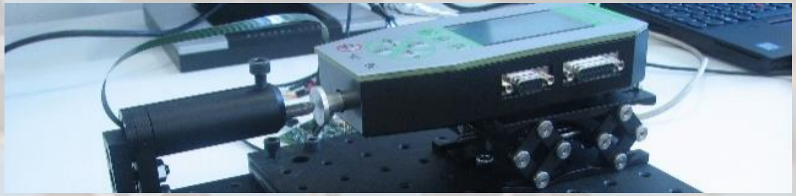
Climate chamber

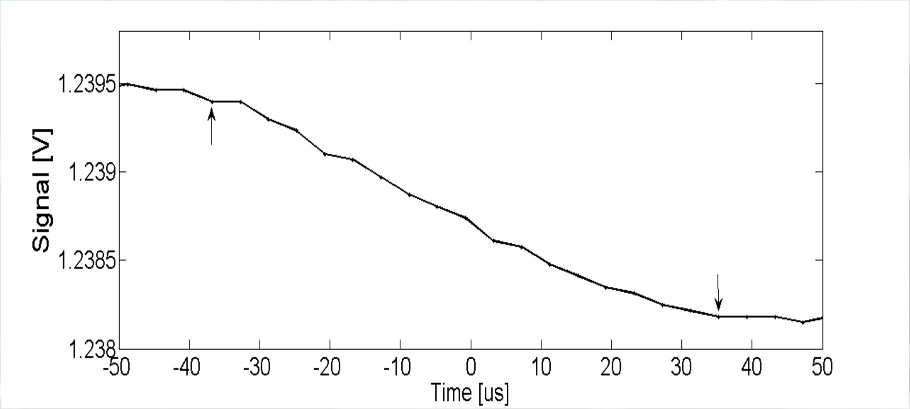
Piezoresistive 3D force sensors - Integration in a laparoscopic tool

Response time

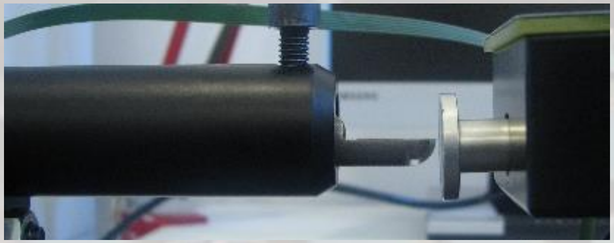


Bare sensor



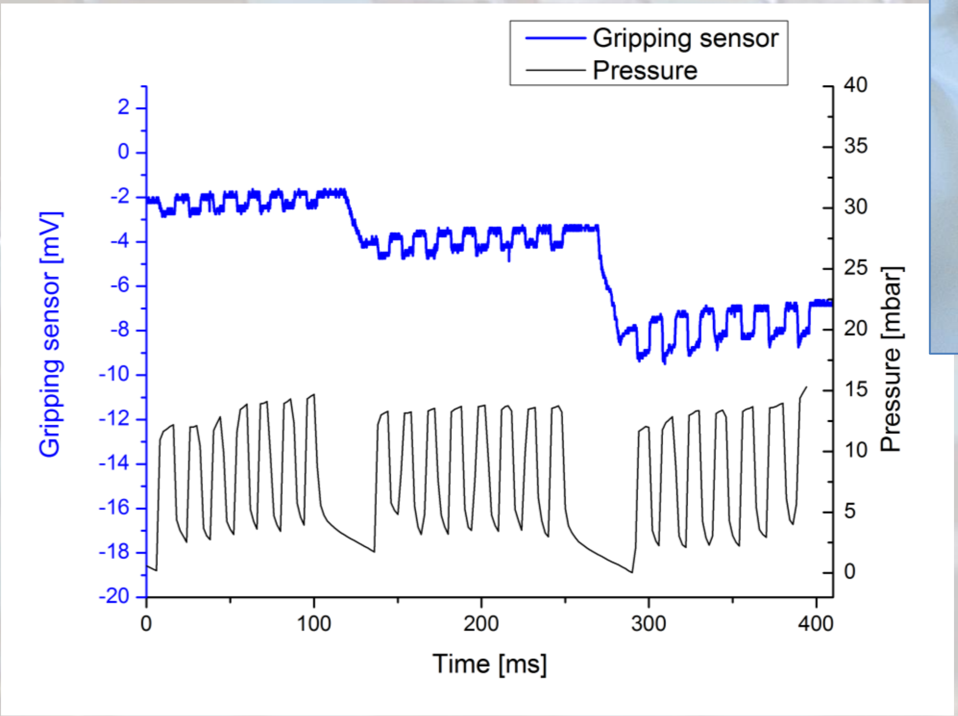


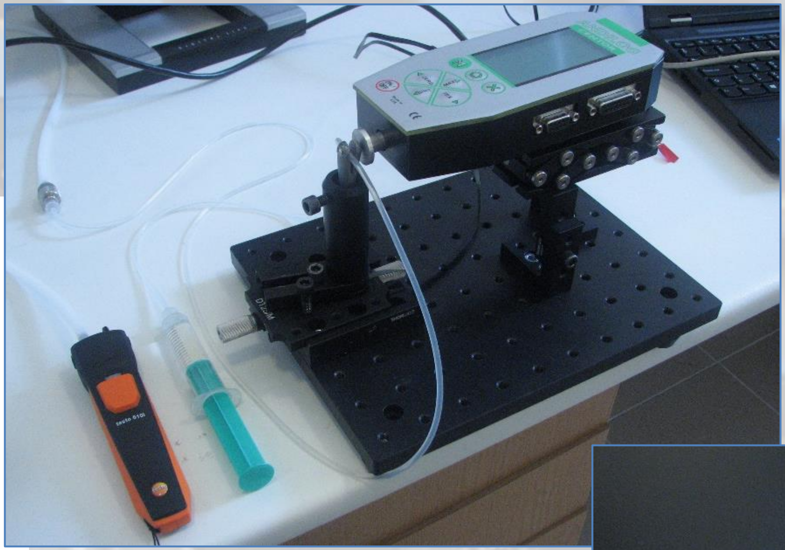
Covered sensor

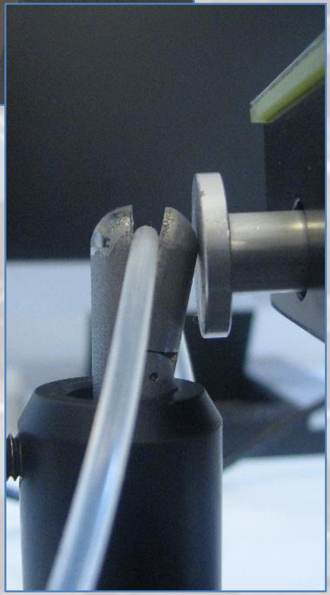


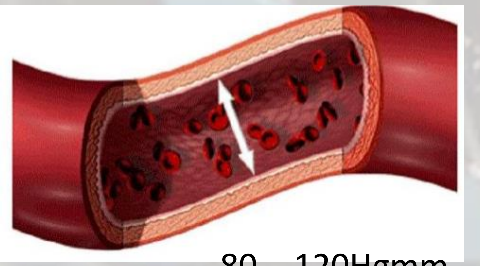
Piezoresistive 3D force sensors - Integration in a laparoscopic tool

Biomechanical tests





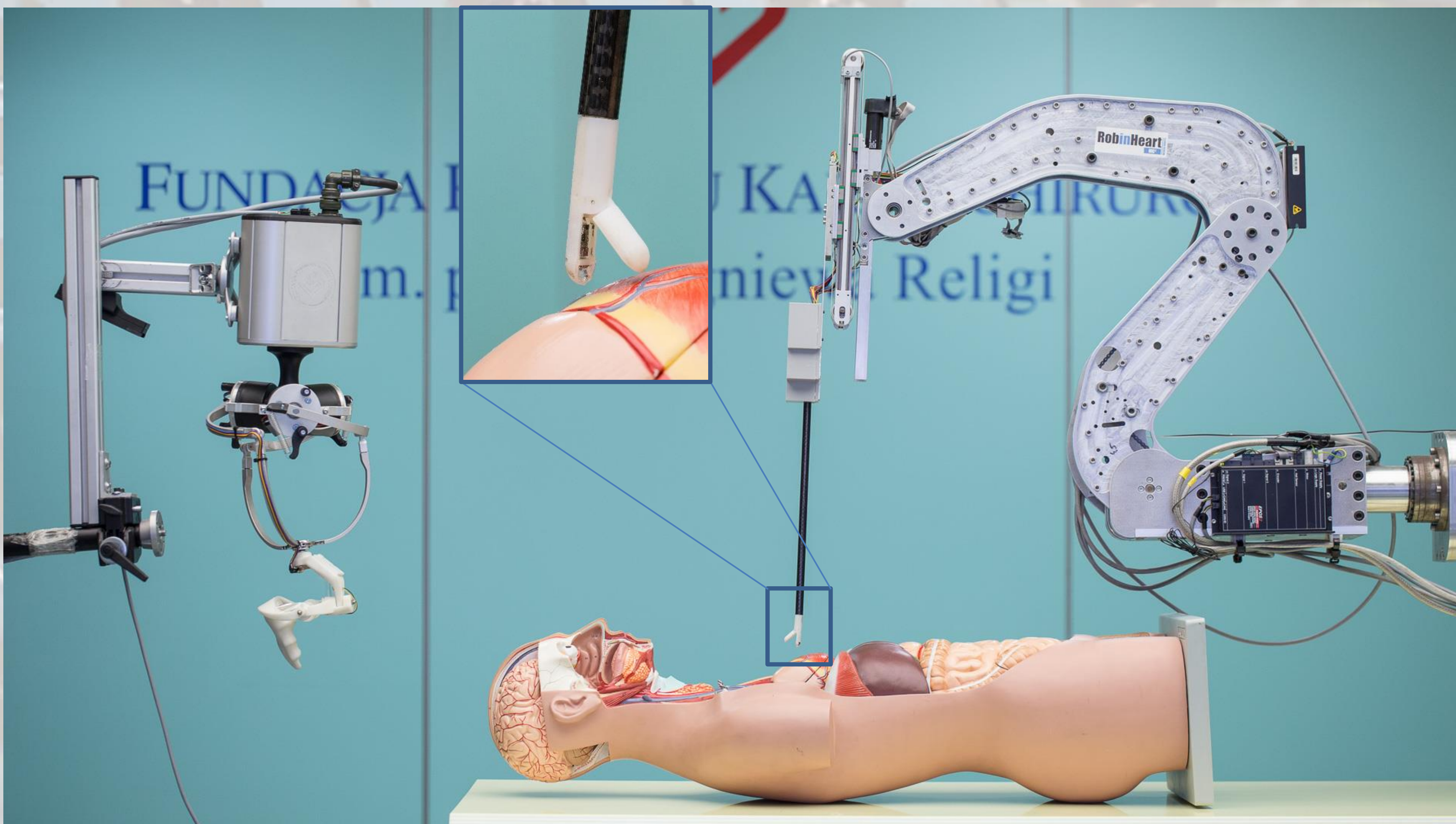




80 – 120Hgmm
106 – 160mBar

Piezoresistive 3D force sensors - Integration in a laparoscopic tool

Completed test device

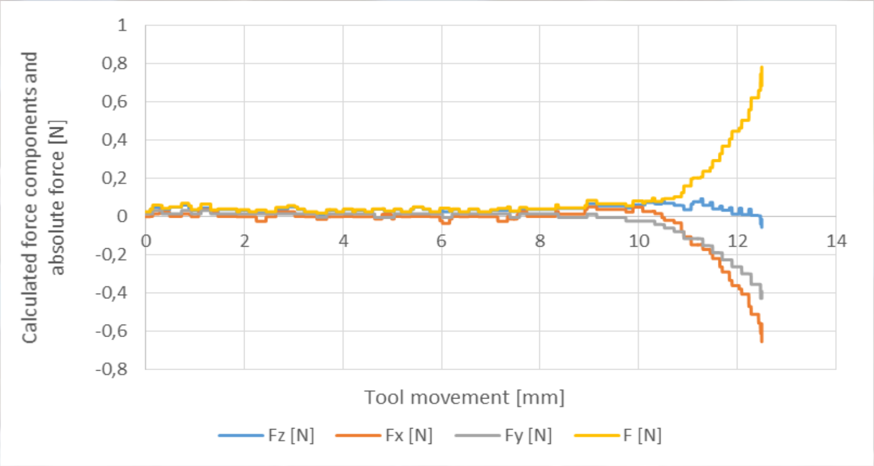


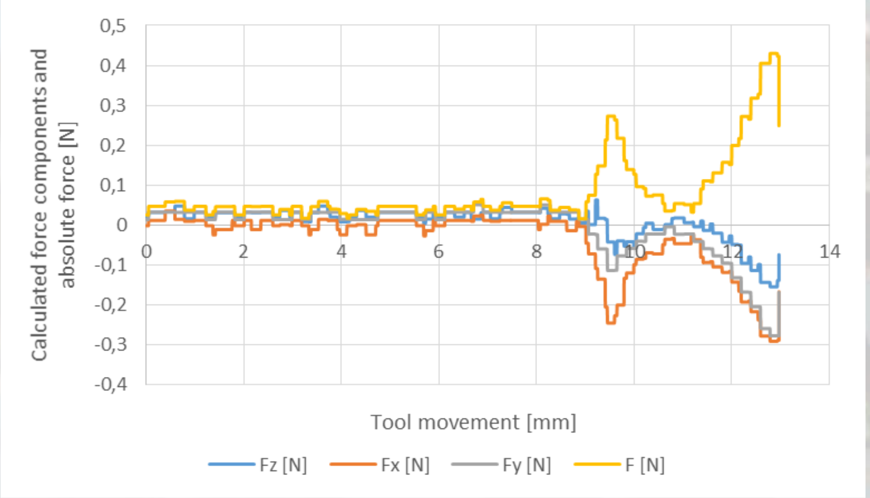
Piezoresistive 3D force sensors - Integration in a laparoscopic tool

Biomechanical tests

Piezoresistive 3D force sensors - Integration in a laparoscopic tool

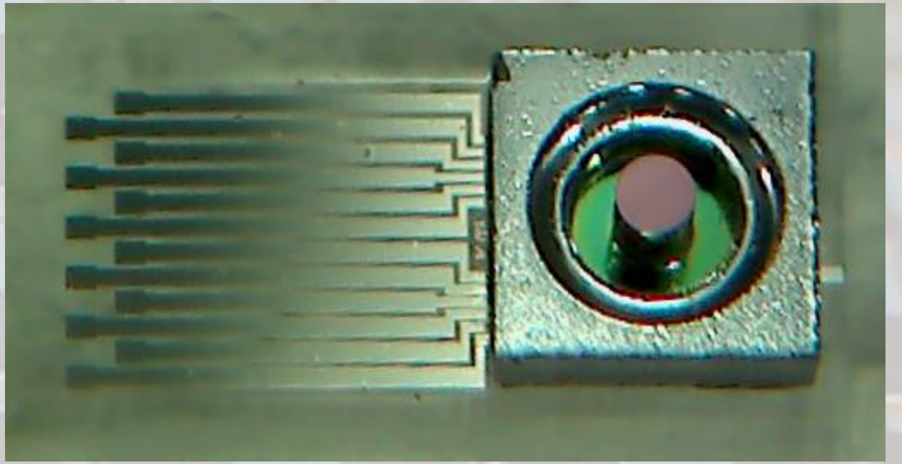
Biomechanical tests





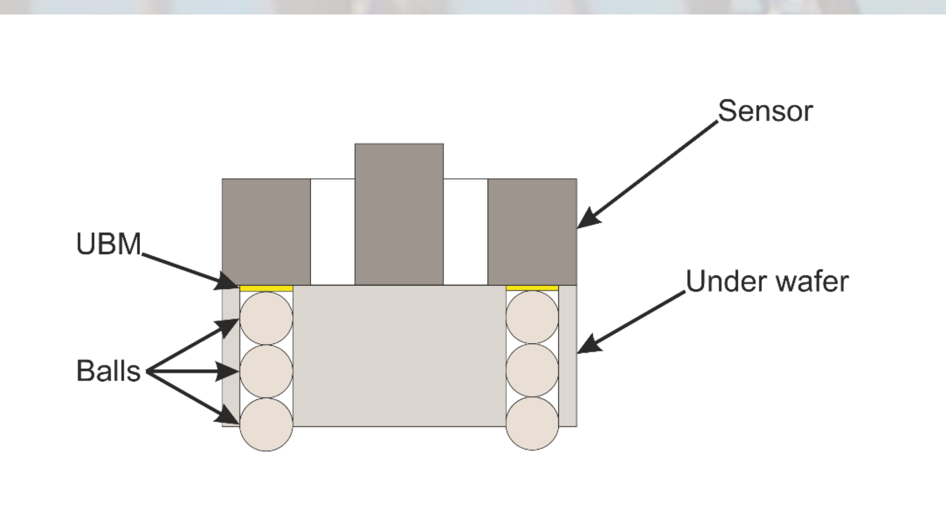
Piezoresistive 3D force sensors – Reducing chip size

(Supported by the ÚNKP-17-3-I-OE-779/47 New National Excellence Program of the Ministry Of Human Capacities)



Means:

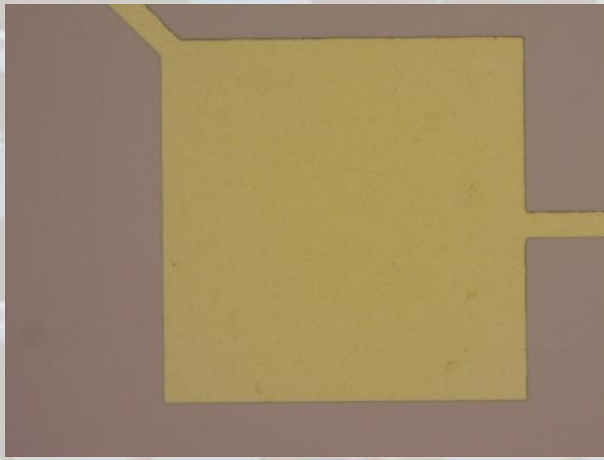
- Replacement of glass substrate
- Application of new contacs
- Design new read-out electronics



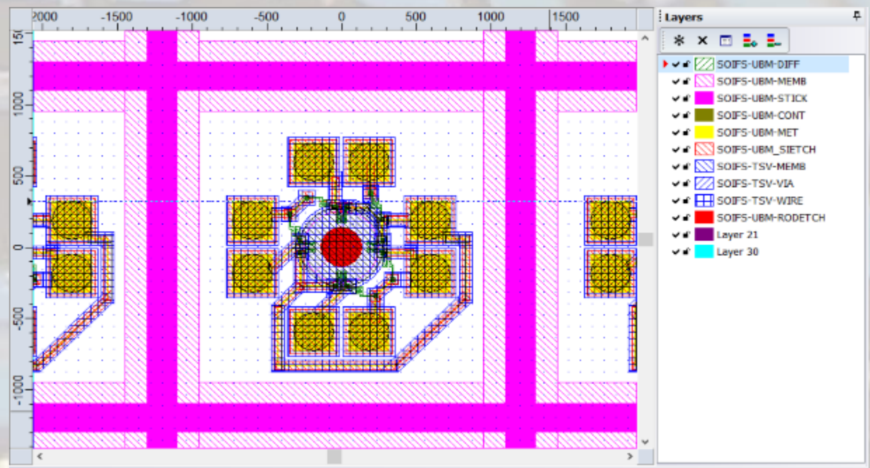
Piezoresistive 3D force sensors - Reducing chip size

(Supported by the ÚNKP-17-3-I-OE-779/47 New National Excellence Program of the Ministry Of Human Capacities)

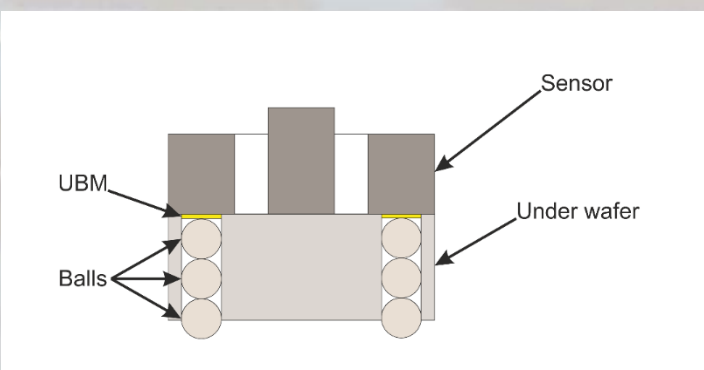
Under bump metallization

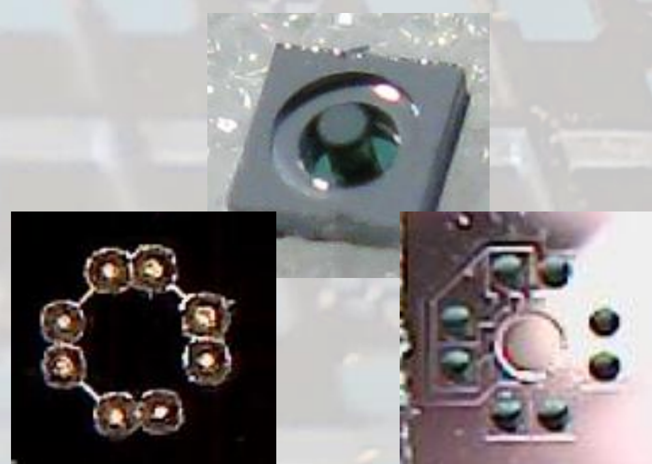


Design and layouts



Top and bottom parts





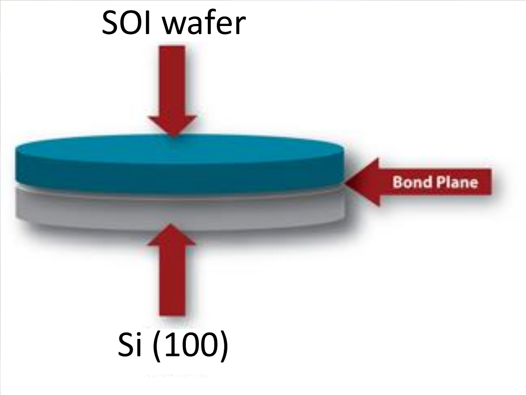
Piezoresistive 3D force sensors - Reducing chip size

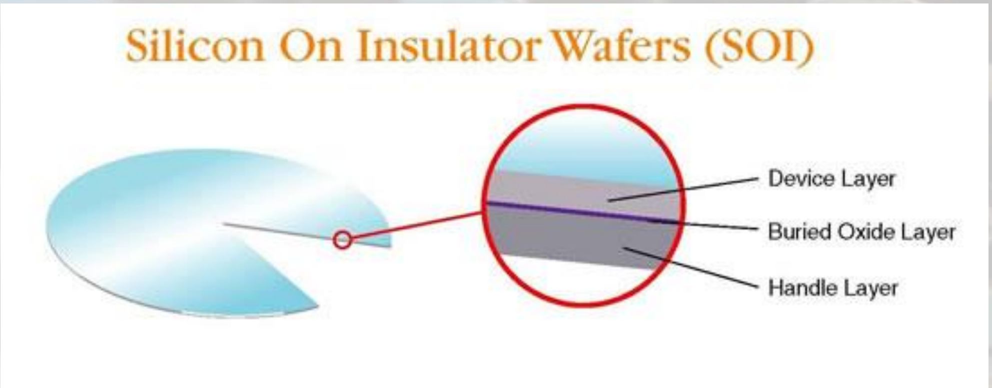
(Supported by the ÚNKP-17-3-I-OE-779/47 New National Excellence Program of the Ministry Of Human Capacities)

Wafer bonding

Aspects:

- Importance of cleanness of the surface
- Strong bond at low temperature
- Hard structured geometry
- Oxidized surface or native oxide?





Piezoresistive 3D force sensors - Integration in a laparoscopic tool

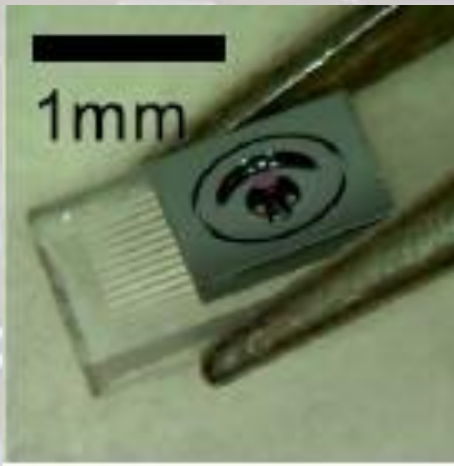
Publications in this topic

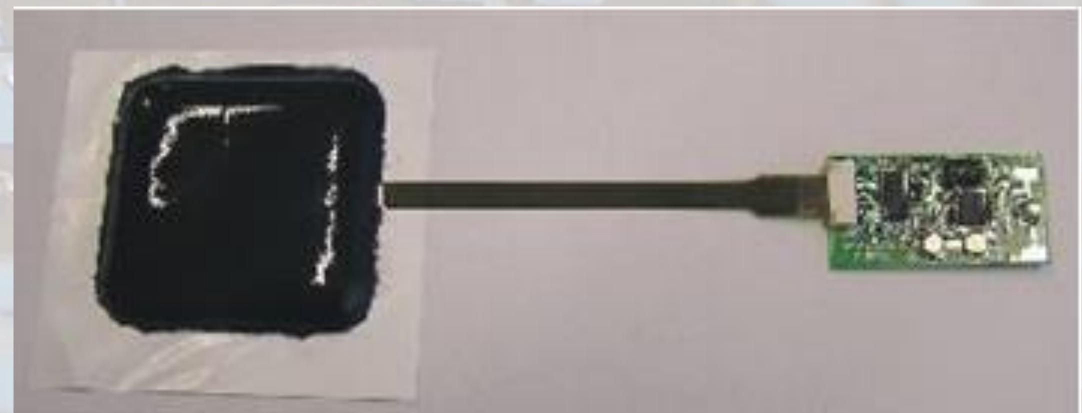
- **5 Papers (min. 4. pages)**
- **5 oral presentations (in English)**
- **3 posters**

Piezoresistive 3D force sensors - Integration in a vehicle tyre

Accomplished tasks preliminary design and tests

- Implantation of 3D force sensor in a special rubber

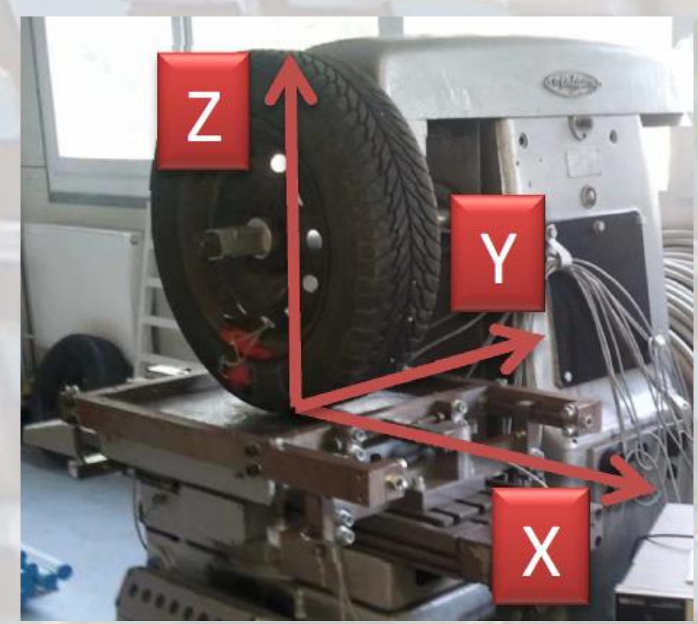




- Integration of test tool in a vehicle tyre

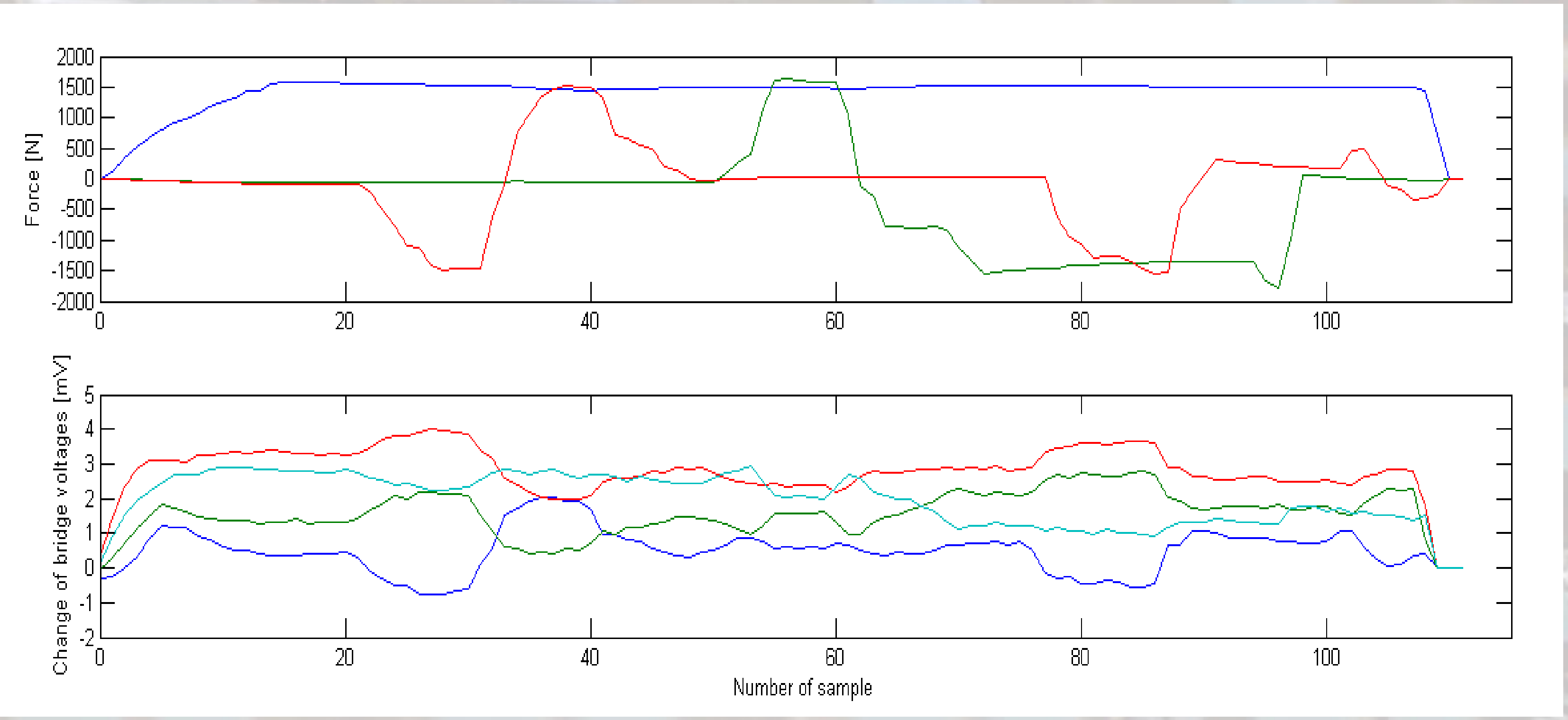
Piezoresistive 3D force sensors - Integration in a vehicle tyre

- Functional test: static loading



Piezoresistive 3D force sensors - Integration in a vehicle tyre

- Results of static measurement



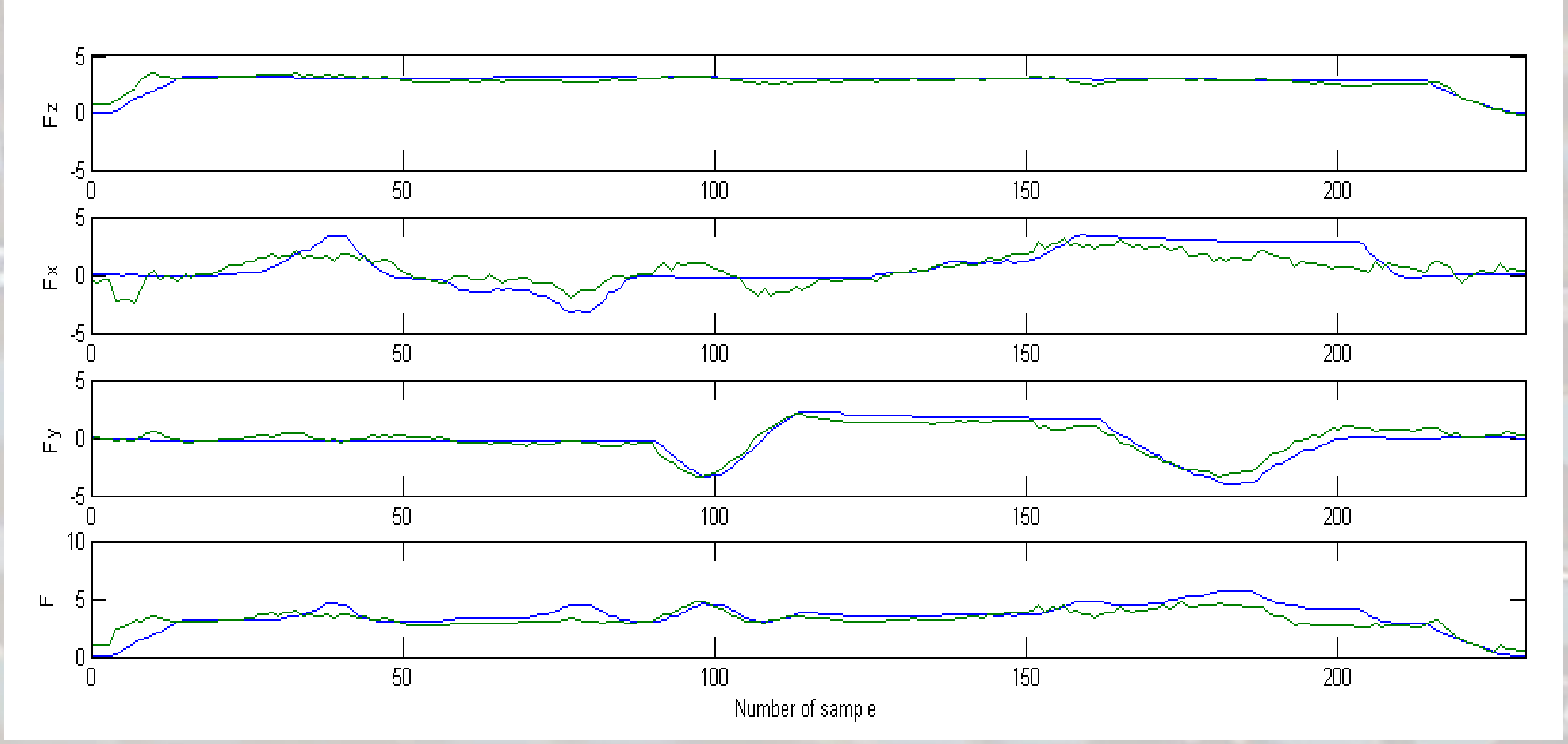
F_x

F_y

F_z

Piezoresistive 3D force sensors - Integration in a vehicle tyre

- **Multiple regression:** demonstration of proportional relationship between tyre deformation and acting forces on the wheel

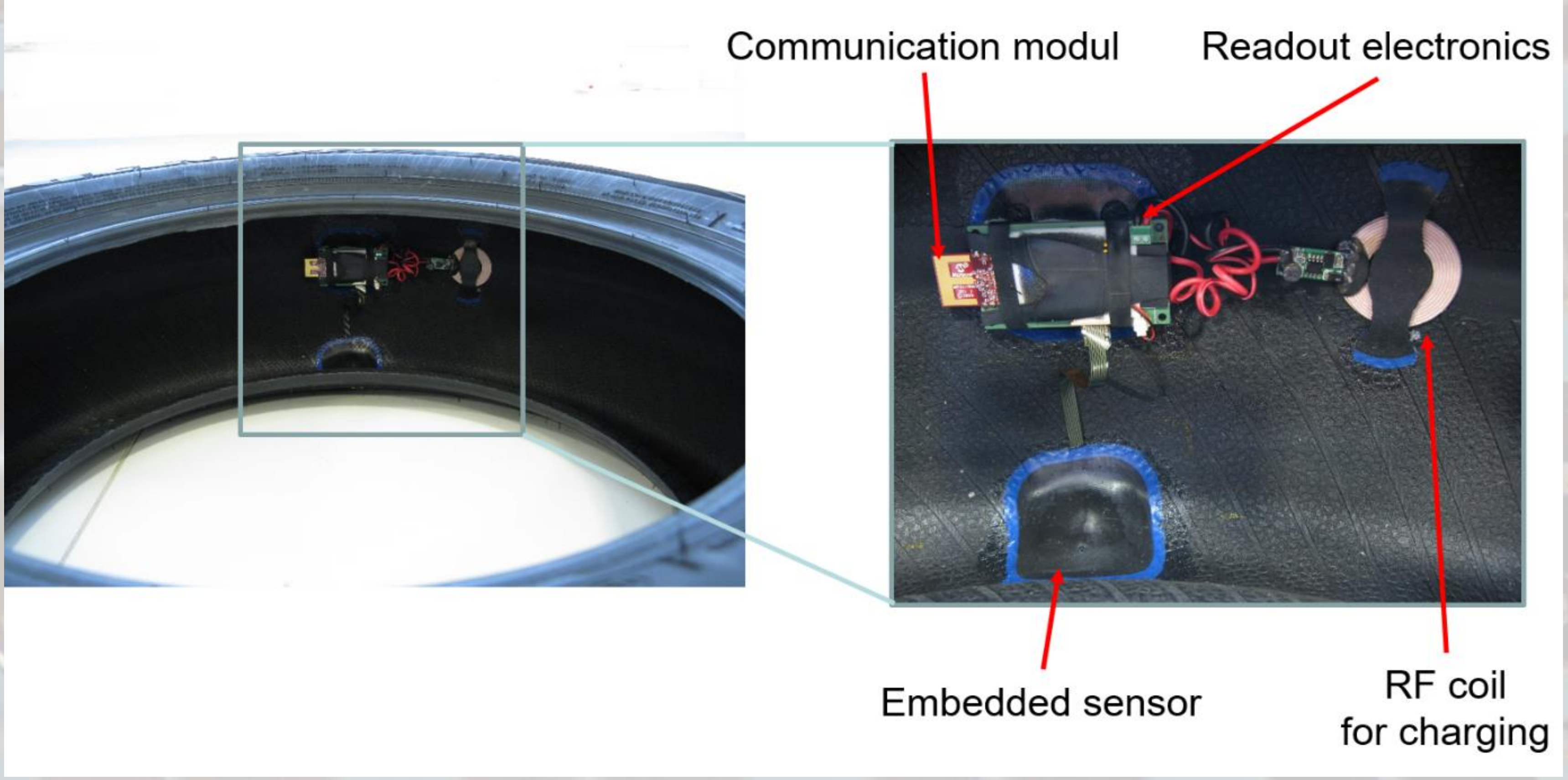


Calculated data
Measured data

Piezoresistive 3D force sensors - Integration in a vehicle tyre

New design

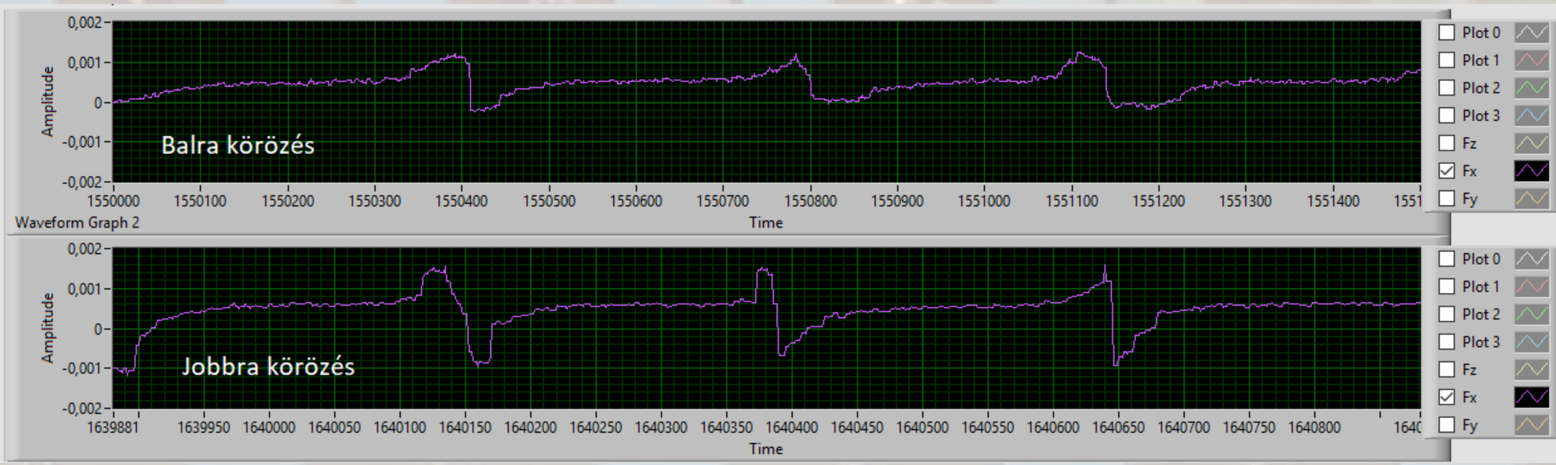
- New wireless read-out electronic
- Definition of the sensor position based on the results of the static measurement



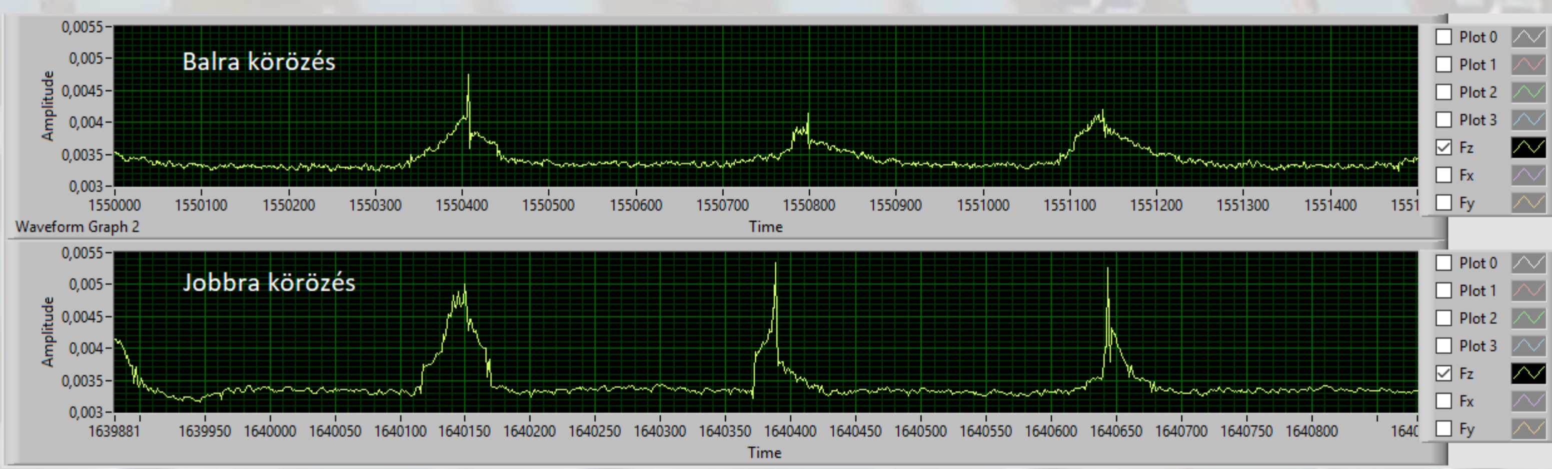
Piezoresistive 3D force sensors - Integration in a vehicle tyre

Latest results

- Preliminary tests at the KFKI Campus



Out-of-balance voltage proportional to radial force component (F_x)



Out-of-balance voltage proportional to perpendicular force component (F_z)

Piezoresistive 3D force sensors - Integration in a vehicle tyre

Latest results

- The test tyre was mounted on the SZTAKI's Nissan Leaf
- First raw data are under examination
- Long operation life is demonstrated

Piezoresistive 3D force sensors - Integration in a vehicle tyre

Publications in this topic

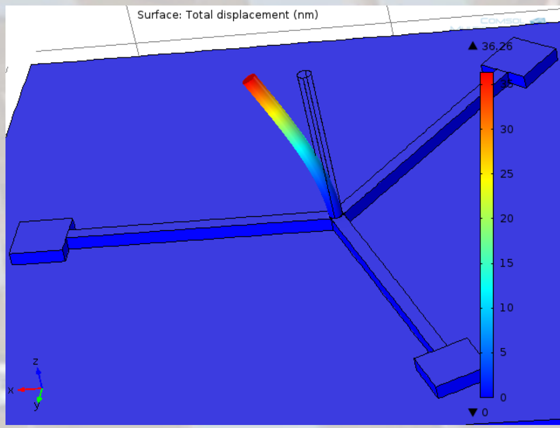
Oral presentation (in English):

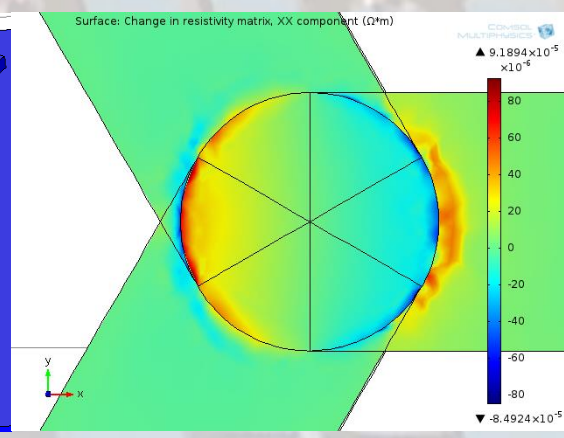
- J. Radó, G. Battistig, S. Kuliniy, R. Végvári, I. Bársony, **Monitoring the tyre deformation on a vehicle on the run,** EUROSENSORS 2016, Budapest, Hungary

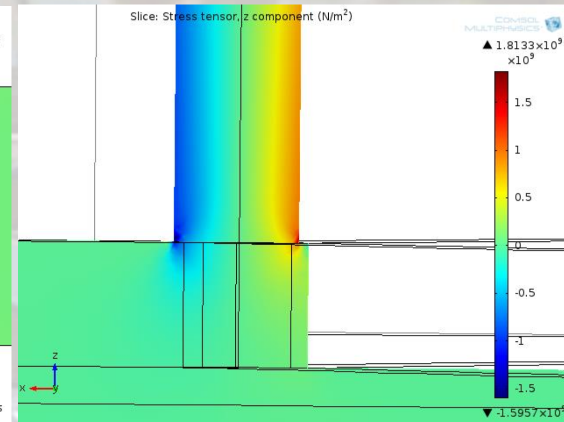
Piezoelectric ZnO nano-rods – for high-resoultion fingerprint sensing

Accomplished tasks

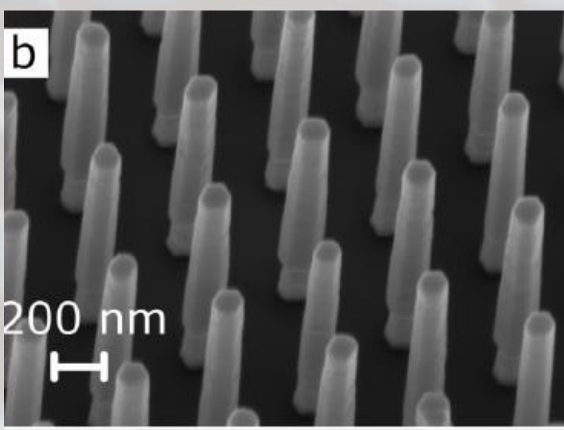
- Simulation

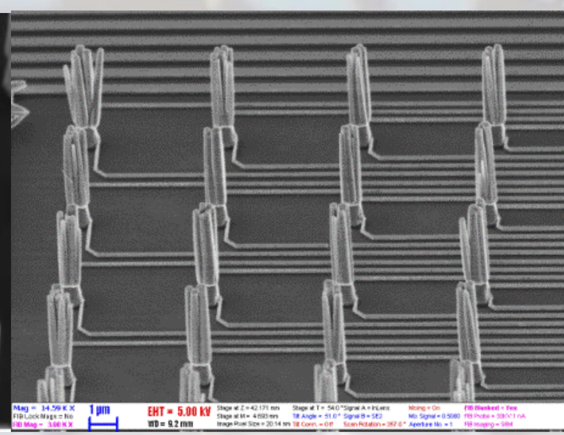


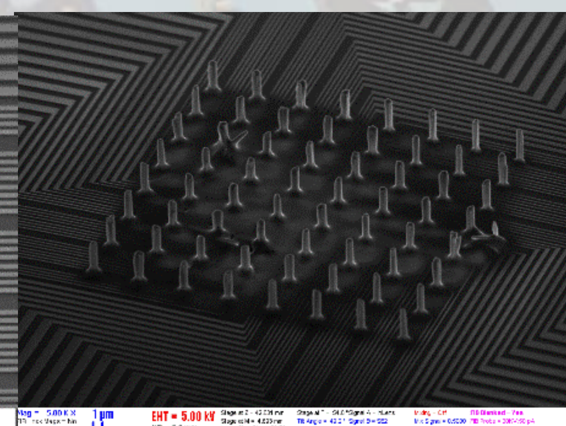




- Growing of the rods (hydrothermal growing: Zinc-nitrate hexahydrate and hexamethylen tetramin)

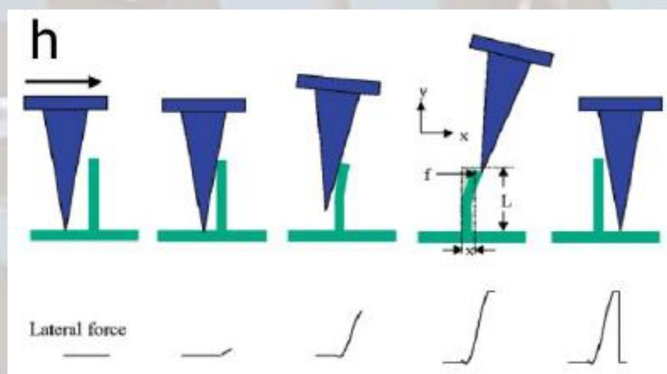


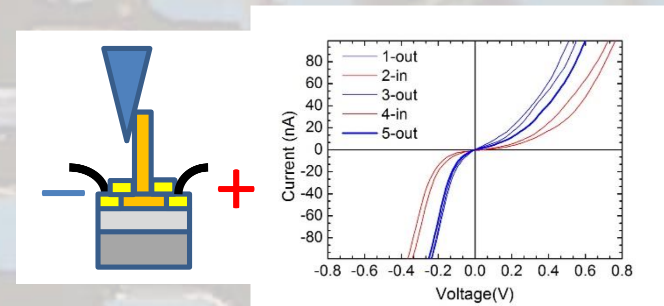


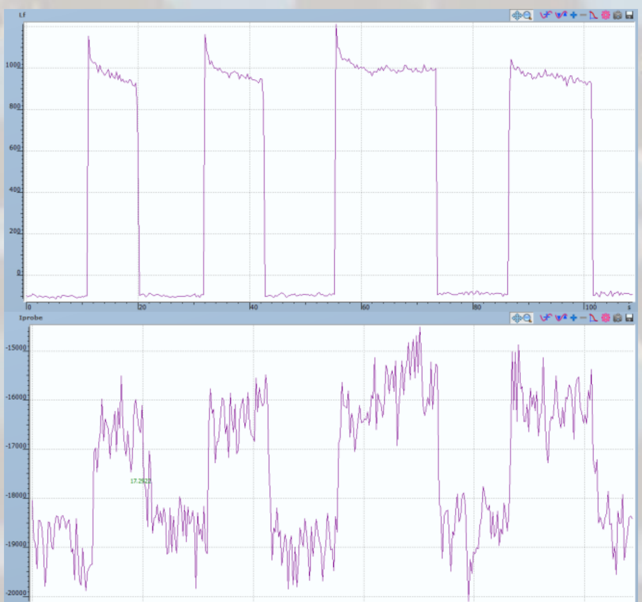


Piezoelectric ZnO nano-rods – for high-resoultion fingerprint sensing

- Bending and measurement in Atomic Force Microscope

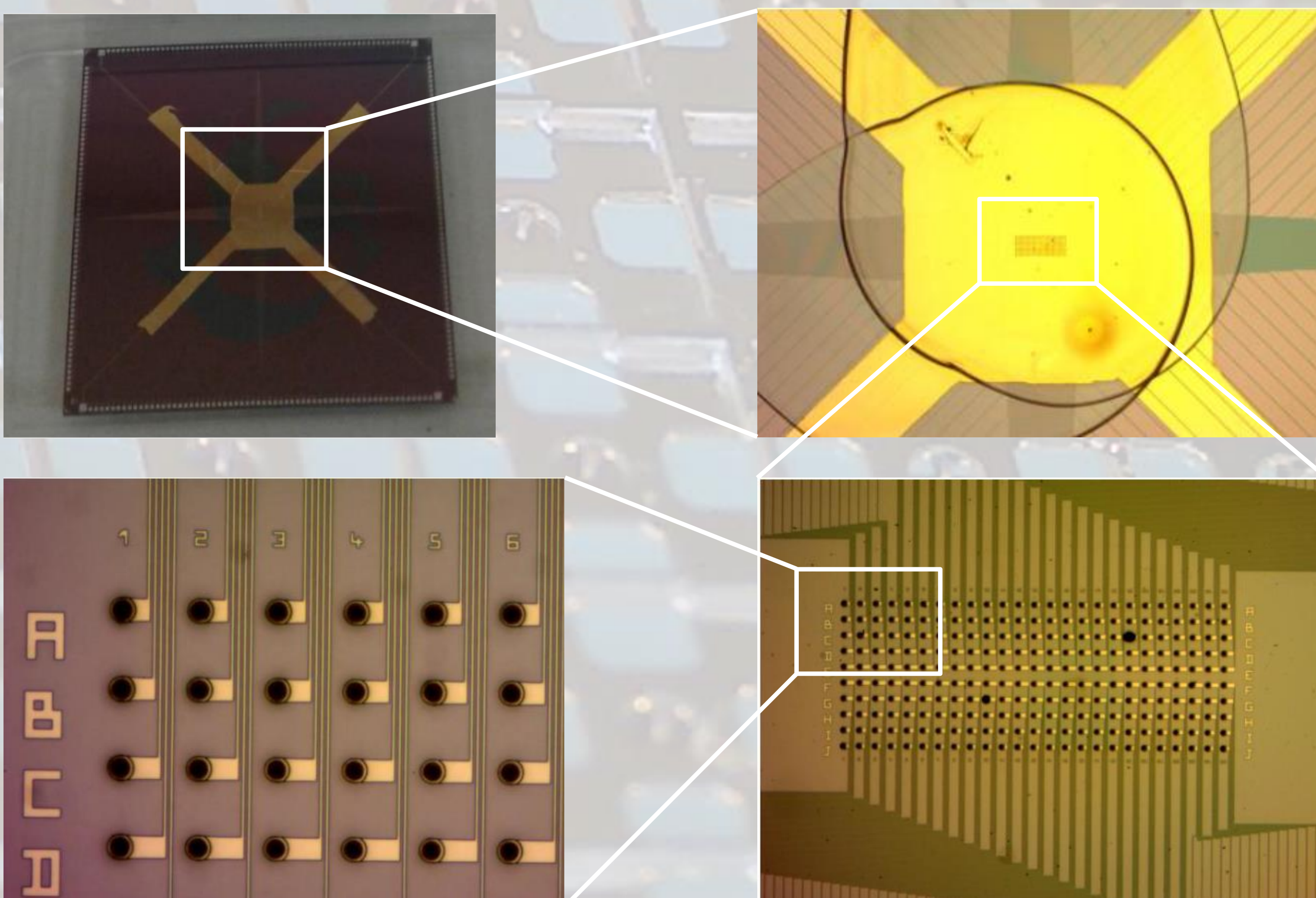






Piezoelectric ZnO nano-rods – for high-resoultion fingerprint sensing

- Design and fabrication a 25x10 nano-array



Piezoelectric ZnO nano-rods – for high-resoultion fingerprint sensing

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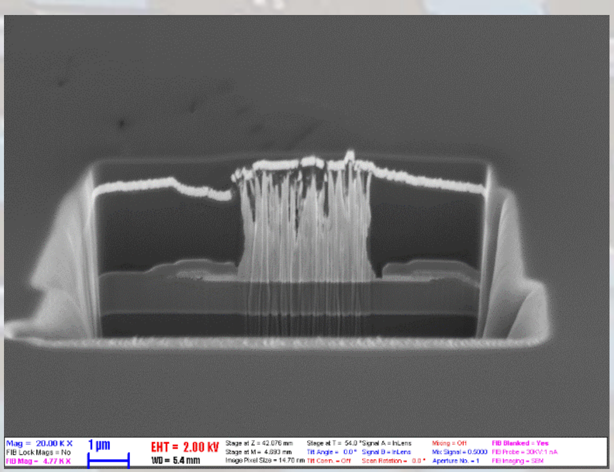
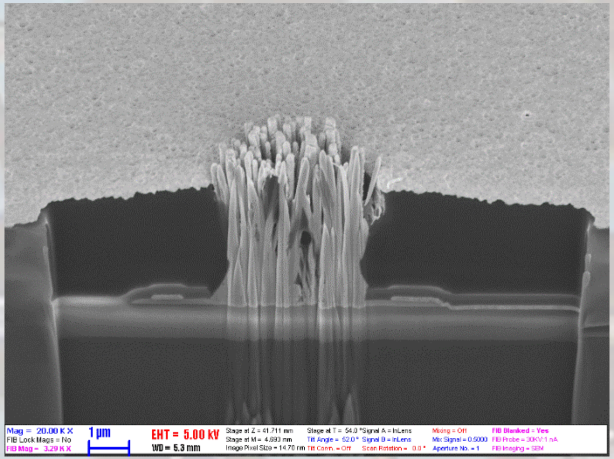
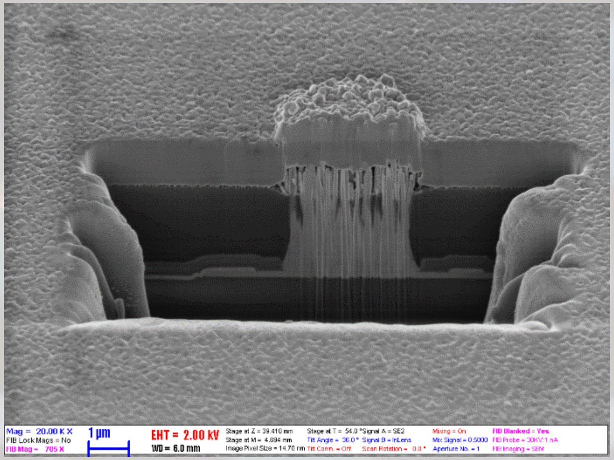
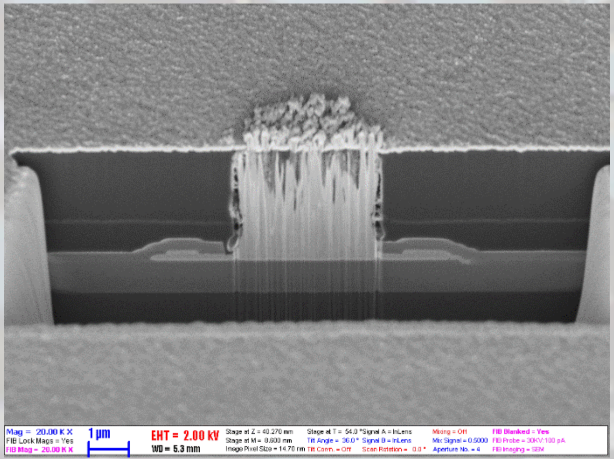


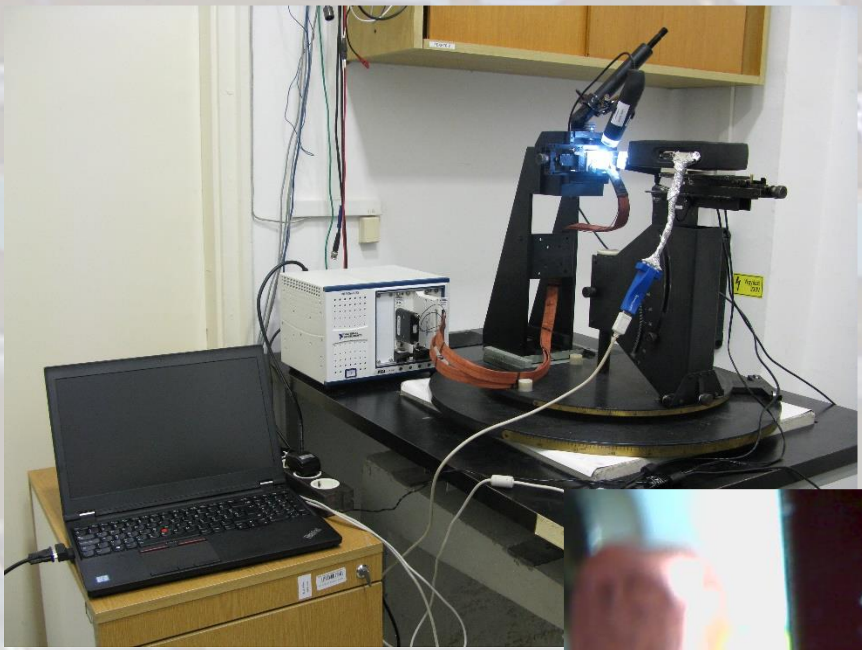


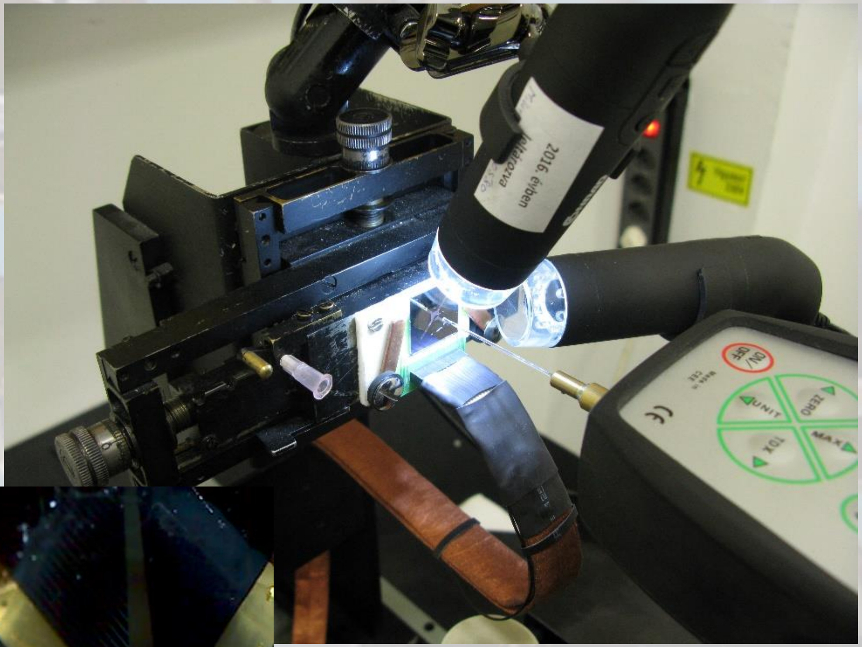


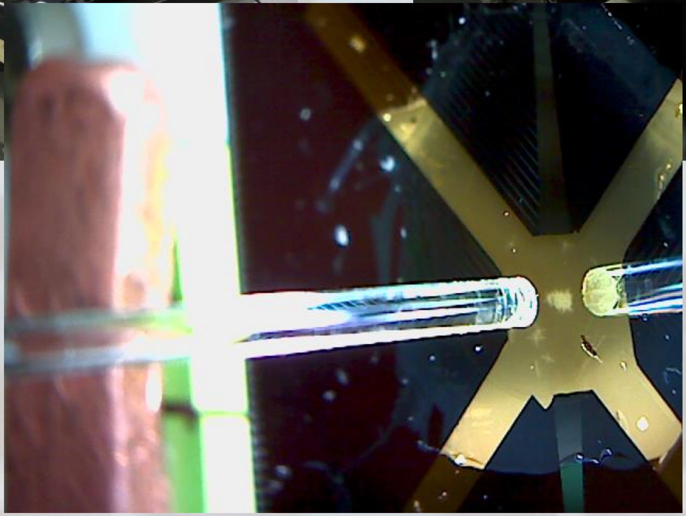


Piezoelectric ZnO nano-rods – for high-resoultion fingerprint sensing

- Assembling a new measurement setup

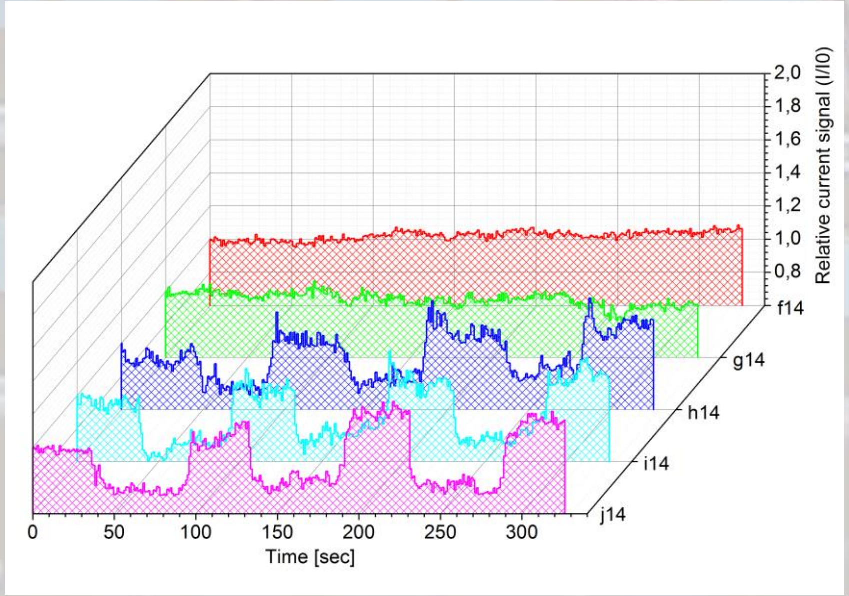


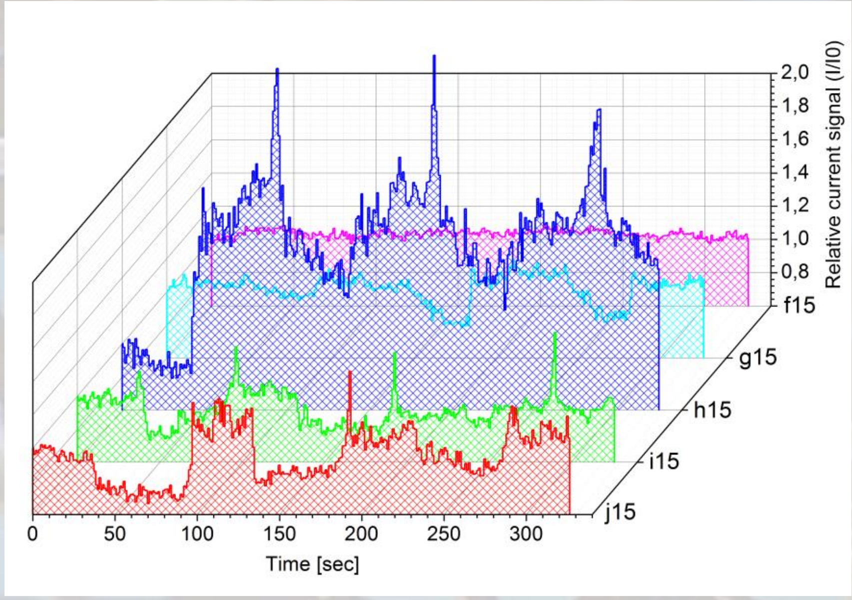


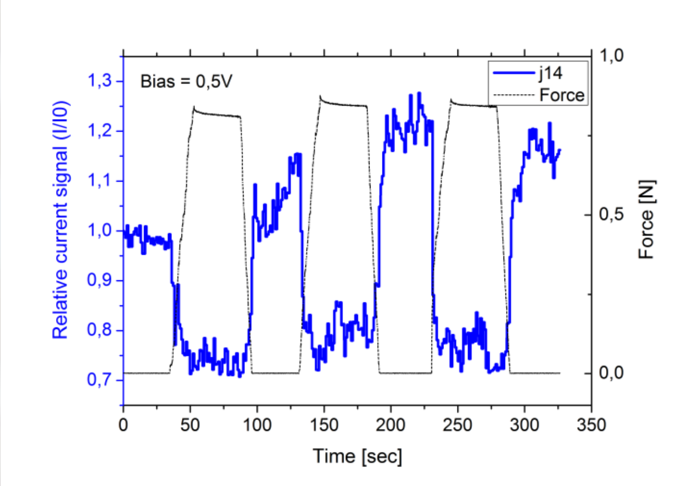


Piezoelectric ZnO nano-rods – for high-resoultion fingerprint sensing

- Measurements



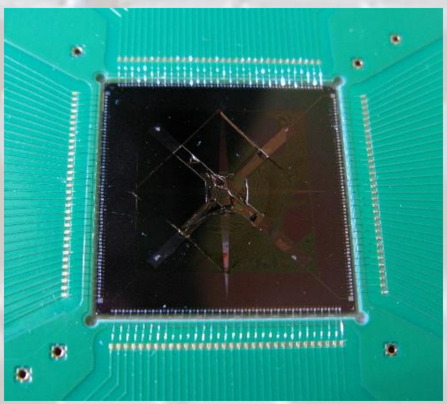




Piezoelectric ZnO nano-rods

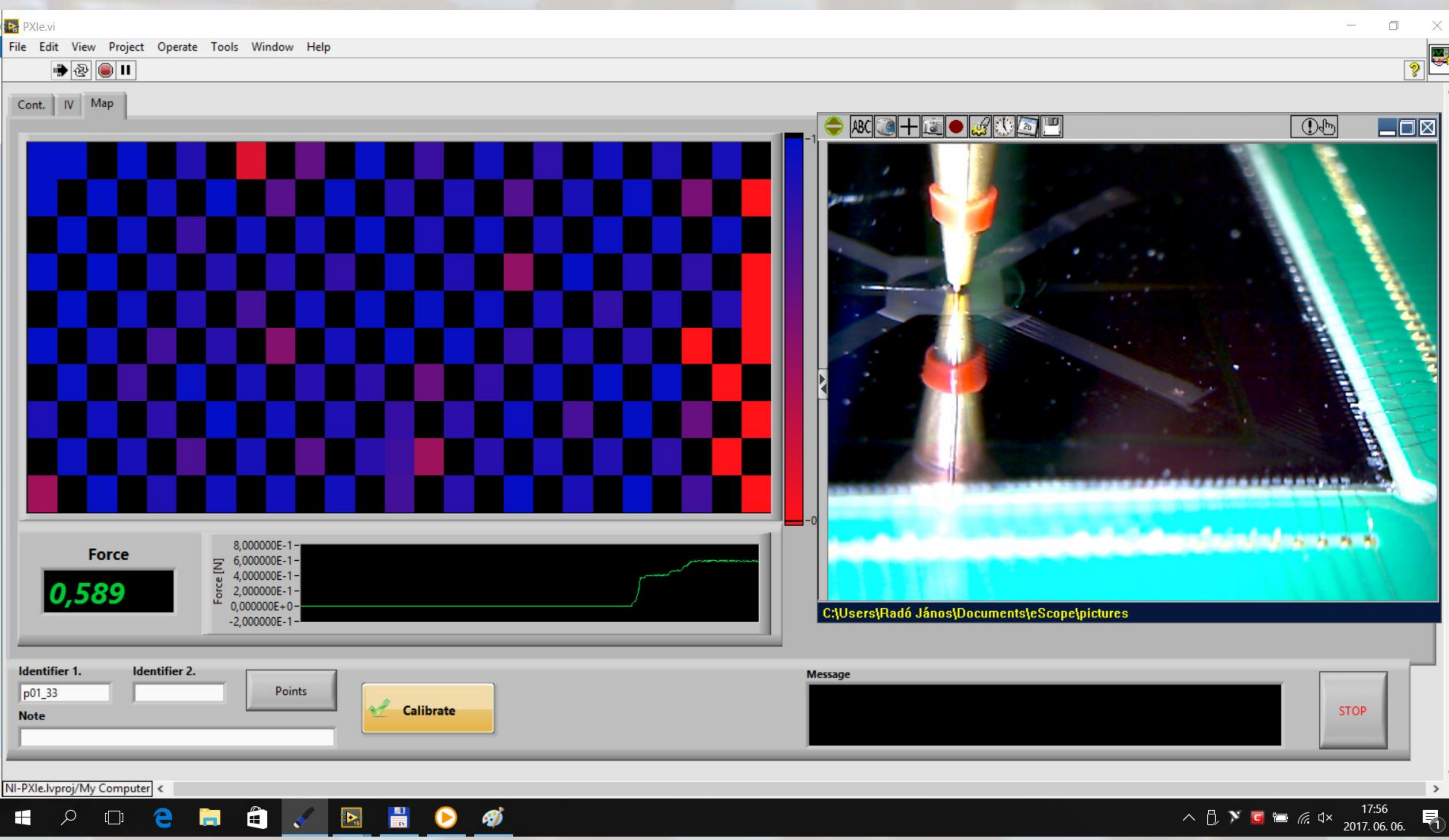
(Supported by the ÚNKP-17-3-I-OE-779/47 New National Excellence Program of the Ministry Of Human Capacities)

- Measurement of the entire array at the same time



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
A		o		o		o		o		o		o		o		o		o		o		o		o	
B	o		o		o		o		o		o		o		o		o		o		o		o		o
C		o		o		o		o		o		o		o		o		o		o		o		o	
D	o		o		o		o		o		o		o		o		o		o		o		o		o
E		o		o		o		o		o		o		o		o		o		o		o		o	
F	o		o		o		o		o		o		o		o		o		o		o		o		o
G		o		o		o		o		o		o		o		o		o		o		o		o	
H	o		o		o		o		o		o		o		o		o		o		o		o		o
I		o		o		o		o		o		o		o		o		o		o		o		o	
J	o		o		o		o		o		o		o		o		o		o		o		o		o

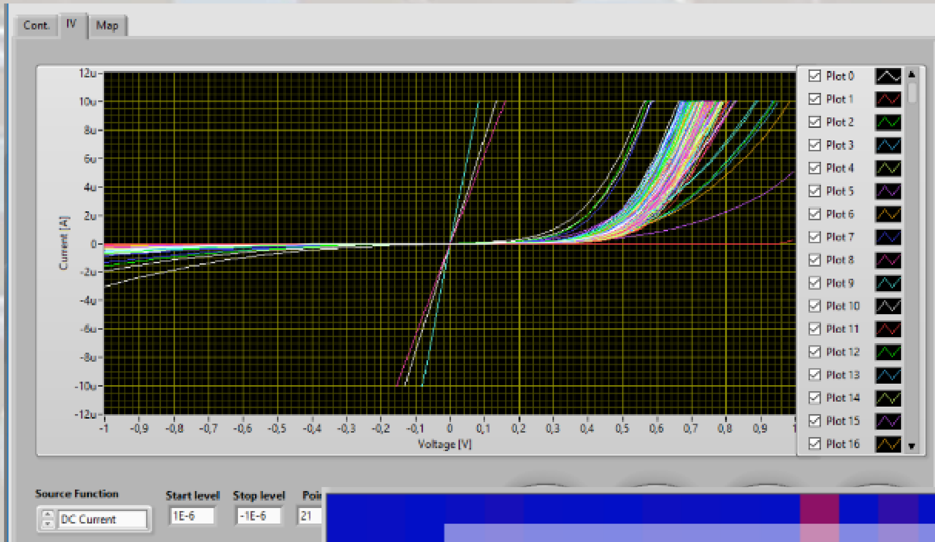
Piezoelectric ZnO nano-rods – for high-resoultion fingerprint sensing

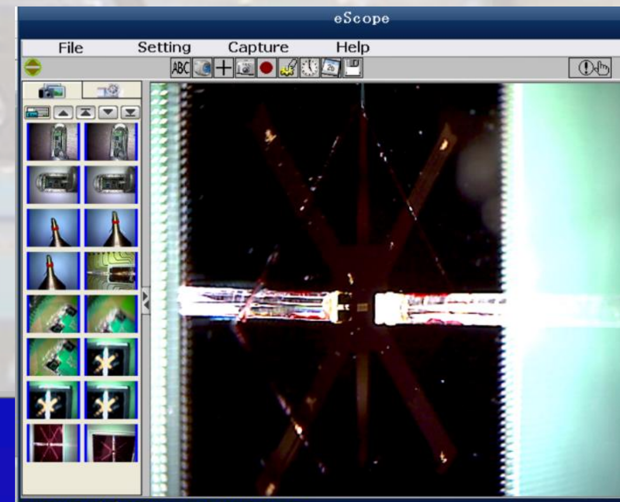


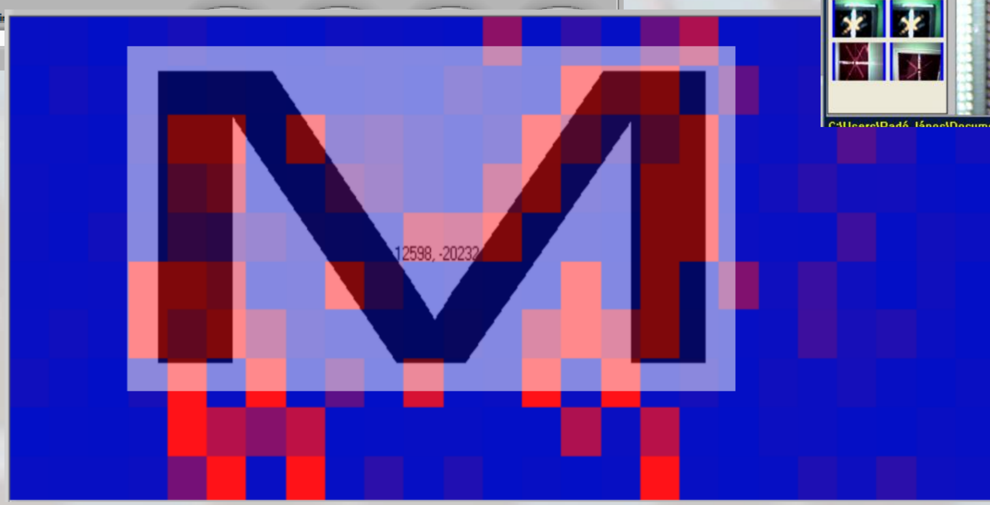
Piezoelectric ZnO nano-rods

(Supported by the ÚNKP-17-3-I-OE-779/47 New National Excellence Program of the Ministry Of Human Capacities)

- Pushing the whole array (250 nano-rods) with an M-letter







Piezoelectric ZnO nano-rods

Publications in this topic

Papers

- Bouvet-Marchand A, Graillot A, Volk J, Dauksevicius R, Sturm C, Grundmann M, Saoutieff E, Viana A, Christian B, Lebedev V, Rado J, Lukacs I E, N Q Khanh, Grosso D, Loubat C, **Design of UV-crosslinked polymeric thin layers for encapsulation of piezoelectric ZnO nanowires for pressure-based fingerprint sensors,** JOURNAL OF MATERIALS CHEMISTRY C in press: p. in press. (2018)
- Seifikar Masoud, Christian Björn P, Volk János, Radó János, Lukács István E, Dauksevicius Rolanas, Gaidys Rimvydas, Lebedev Vadim, Viana Antoine, O'Reilly Eoin P, **Direct observation of spontaneous polarization induced electron charge transfer in stressed ZnO nanorods,** NANO ENERGY 43: pp. 376-382. (2018)

Oral presentation:

- János Volk, István E. Lukács, Nguyen Quoc Khánh, János Radó, Róbert Erdélyi: **Bottom contacted piezoelectric nanowire arrays,** NGPT 2016, Rome, Italy
- J. Volk, J. Radó, I. E. Lukács, N. Q. Khánh, R. Erdélyi, G. Battistig, C. Sturm, M. Grundmann, A. Graillot, C. Loubat: **Integrated piezoelectric nanowire arrays for high resolution tactile mapping,** EUROSENSORS 2016, Budapest, Hungary

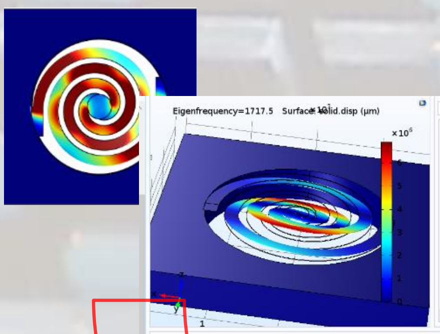
Piezoelectric AlN thin film for 3D force sensor

Main goals

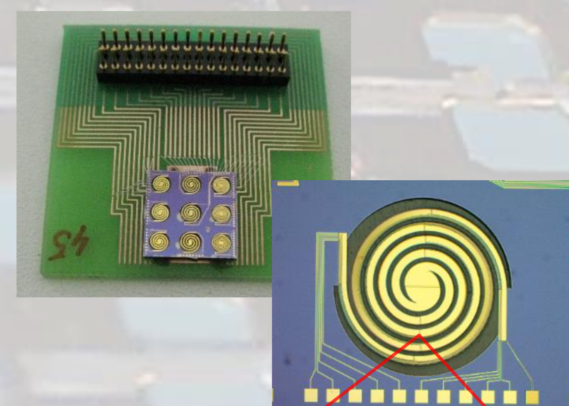
- Operation in the audible frequency range
- Multielectrode structure
- Implantable structure in the middle ear (tiny size)

Development chain

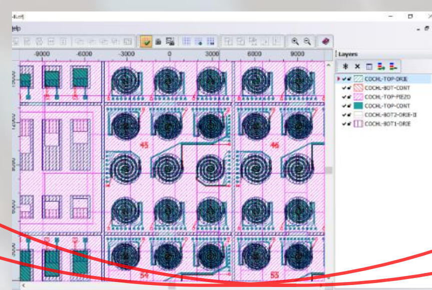
Simulation



Fabrication



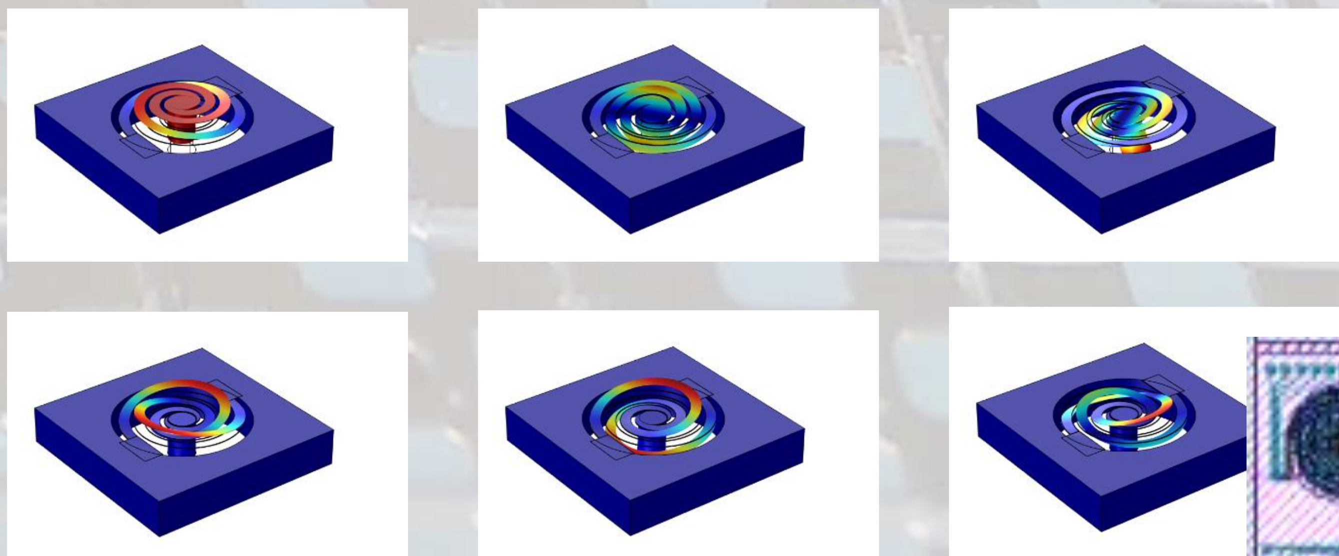
Design

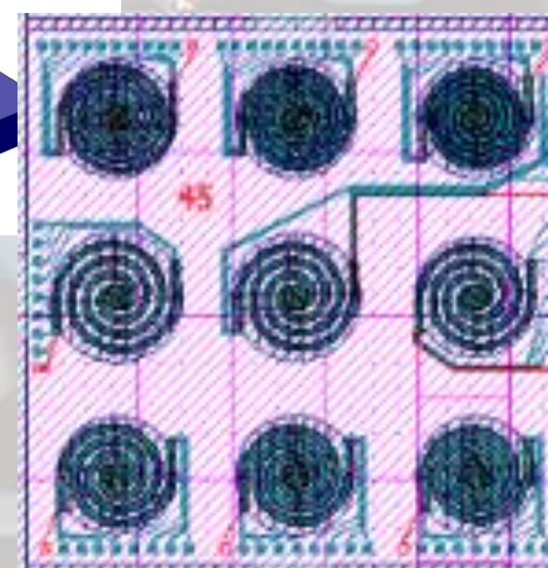


Piezoelectric AlN thin film for 3D force sensor

Accomplished tasks

- Simulation and design

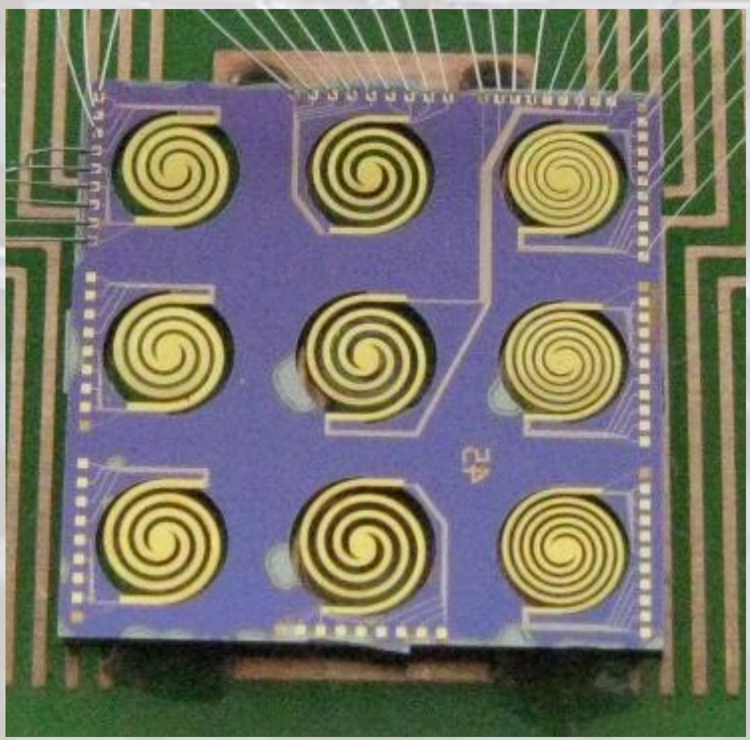


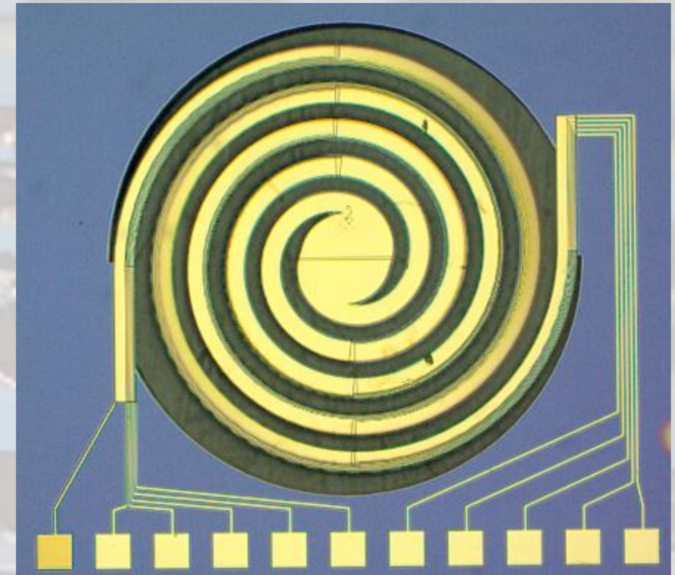


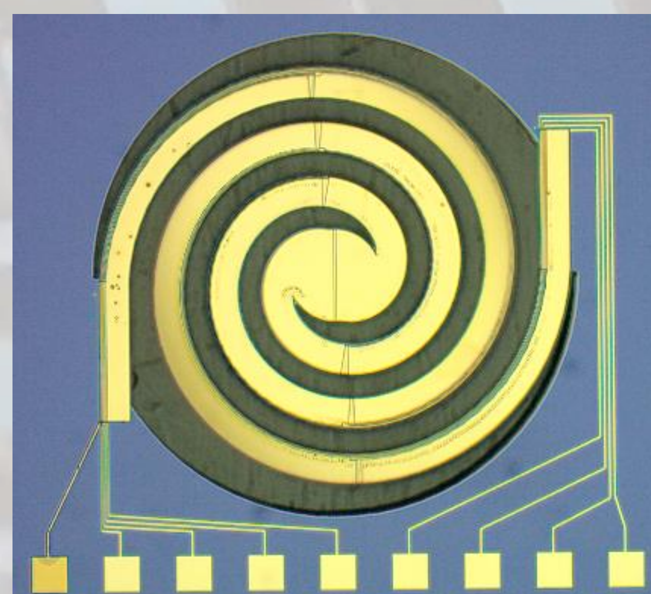
Piezoelectric AlN thin film for 3D force sensor

Accomplished tasks

- Fabrication



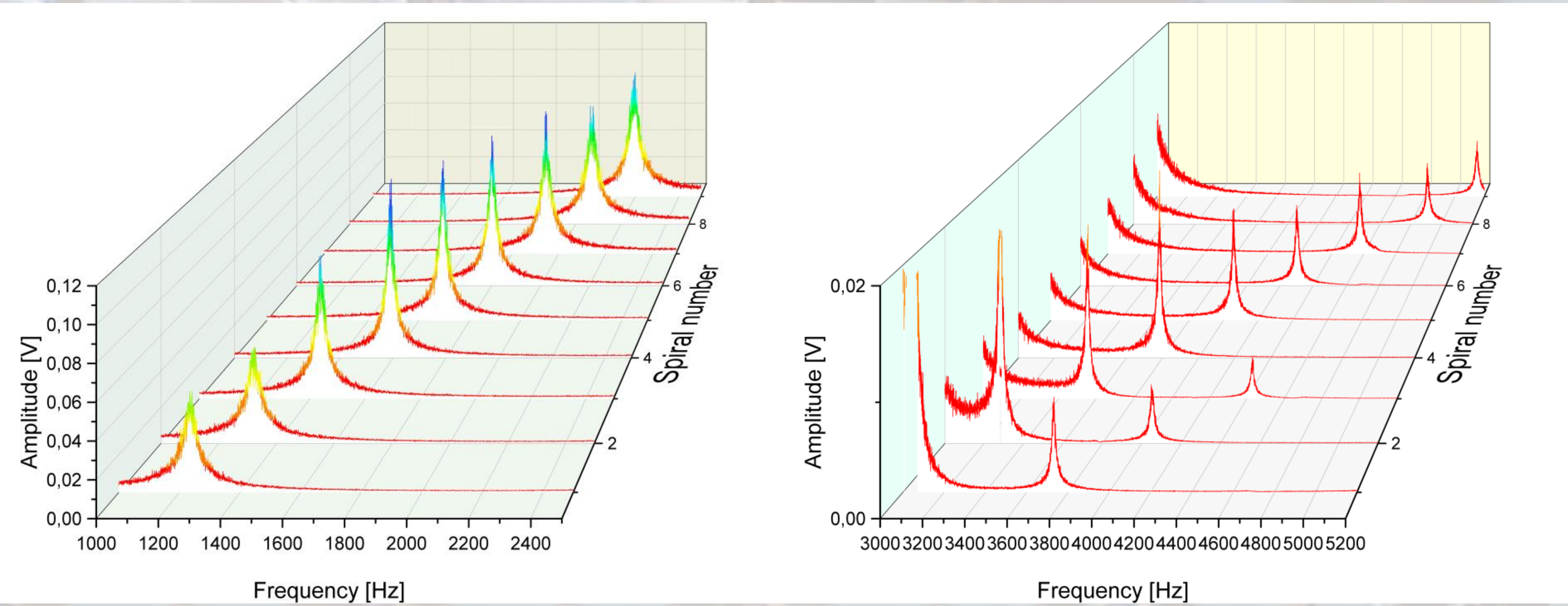




Piezoelectric AlN thin film for 3D force sensor

Accomplished tasks

- Measurements



Resonant frequencies

Harmonics

Piezoelectric AlN thin film for 3D force sensor

Publications in this topic

Paper

Udvardi Péter, Radó János, Straszner András, Ferencz János, Hajnal Zoltán, Soleimani Saeedeh, Schneider Michael, Schmid Ulrich, Révész Péter, Volk János, **Spiral-Shaped Piezoelectric MEMS Cantilever Array for Fully Implantable Hearing Systems,** MICROMACHINES 8:(10) Paper 311. 13 p. (2017)

János Radó, Péter Udvardi, Saeedeh Soleimani, István Bársony, Péter Révész and János Volk, **Low-frequency piezoelectric accelerometer array for fully implantable cochlear implants**, PROCEEDINGS 2 : 13 Paper: 1059 (2018)

Further information

Completed courses

- Szilárdtest kémia
- Nanotechnológia
- Polimerek kémiája és fizikája
- Mikroelektronikai anyagok és szerkezetek vizsgálati módszerei
- Félvezető technológiák
- Ragasztás mentes szeletkötés
- Mikro és nano elektromechanikus szerkezetek
- Önszerveződő alacsonydimenziós rendszerek

Participation in projects:

- Incite Eniac (Call 2013-1/621278-2)
- PiezoMat (grant no. 611019)
- KoFah (NVKP_16-1-2016-0018)

Further presentations

- Tapintásérzékelés az orvosi robotikában
  (MTA Székház-Magyar Tudomány Ünnepe–Emberközpontú Technológia)
- MEMS technológiával előállított 3D erőmérő szenzorok
  (Kandó Konferencia 2017)

Thank you for your attention!