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

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Fifth semester

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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

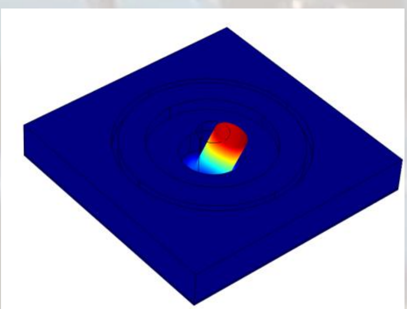
Operation:

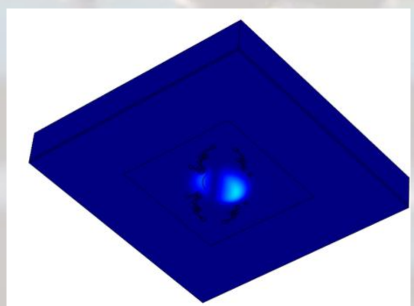
- Deforming c-Si membrane
- 4 embedded piezorezistors
- 4 Voltage dividers or Wheatstone-bridges
- Calculation of vectorial components:

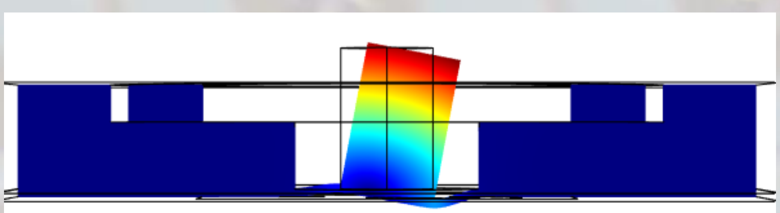
$$F_x = \frac{1}{V_0 \alpha_{ls} \pi_{44}} \left(\Delta V_{right} - \Delta V_{left} \right),$$

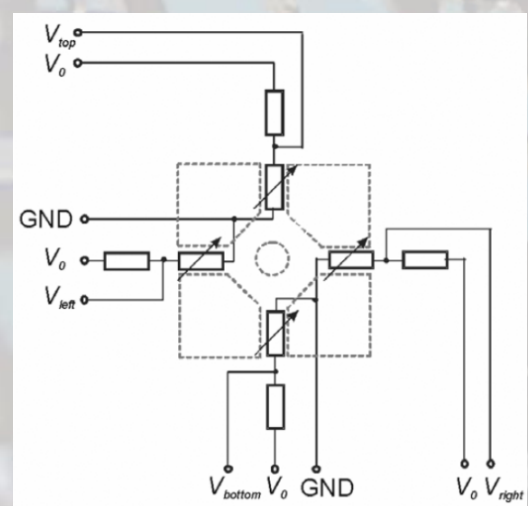
$$F_y = \frac{1}{V_0 \alpha_{ls} \pi_{44}} \left(\Delta V_{top} - \Delta V_{bottom} \right),$$

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





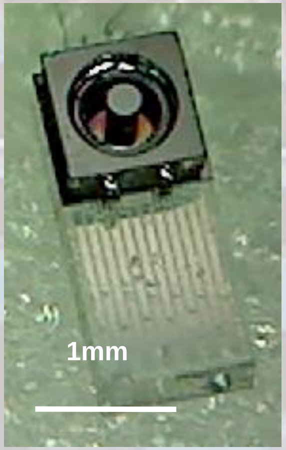


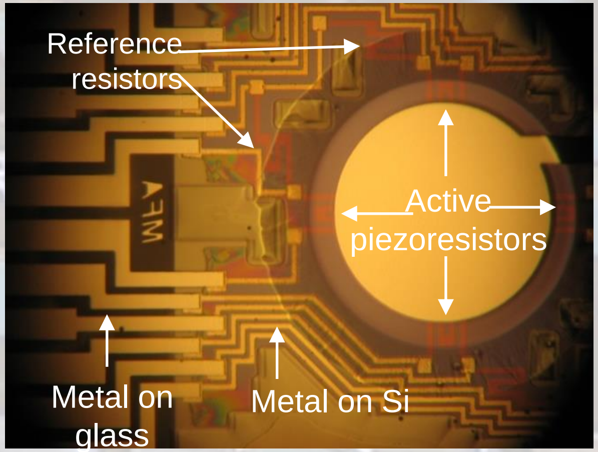


Piezoresistive 3D force sensors - Integration in a laparoscopic tool

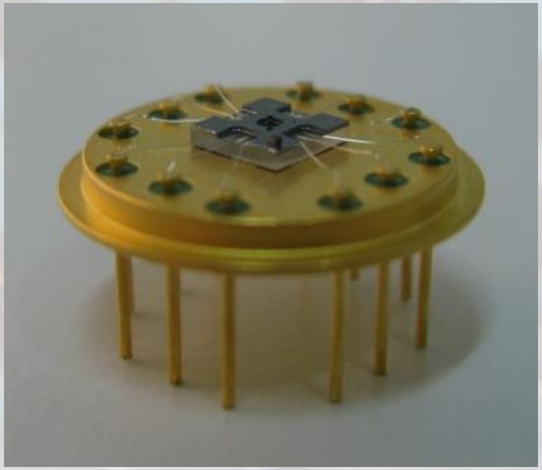
Previous work

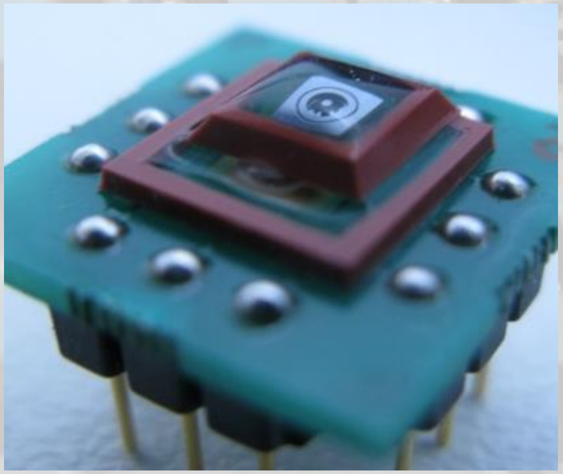
- Fabrication





- Testing





Piezoresistive 3D force sensors - Integration in a laparoscopic tool

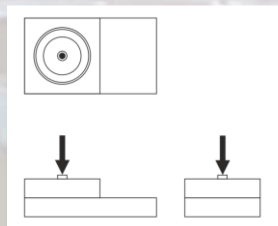
Previous work

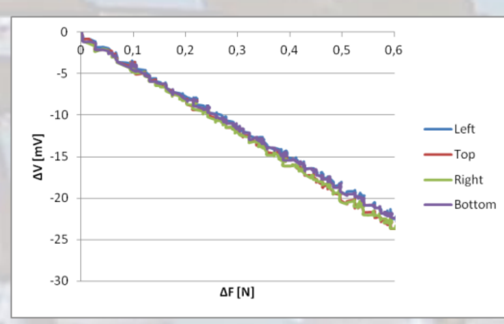
- Measurements

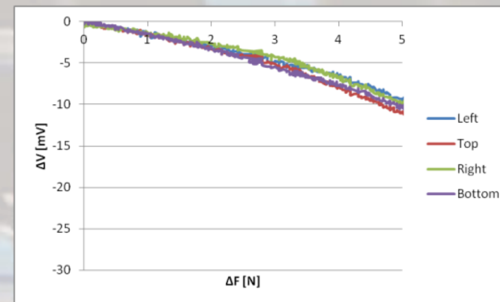
Effect of elastic coating

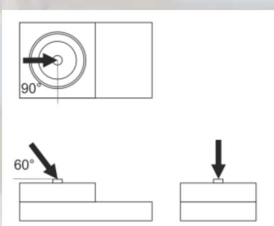
Bare sensor

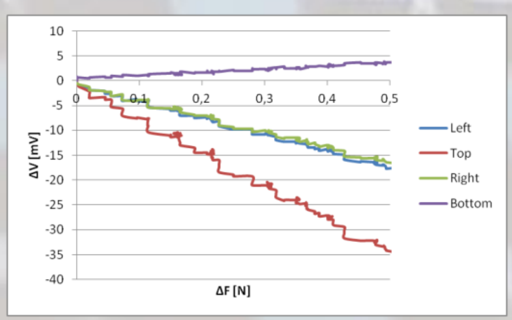
Covered sensor

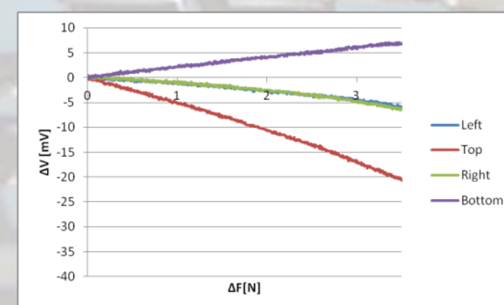


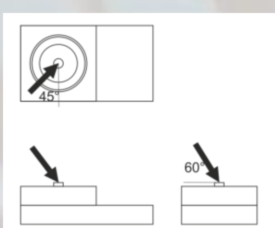


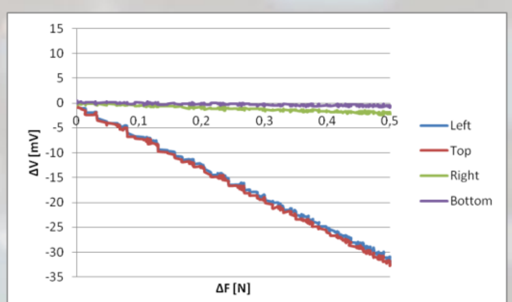


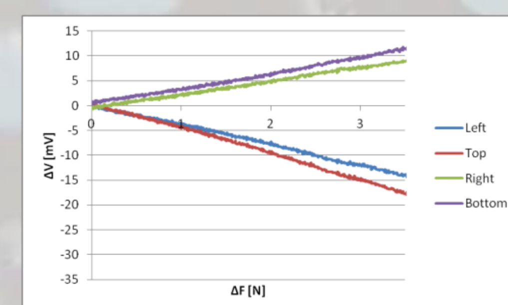






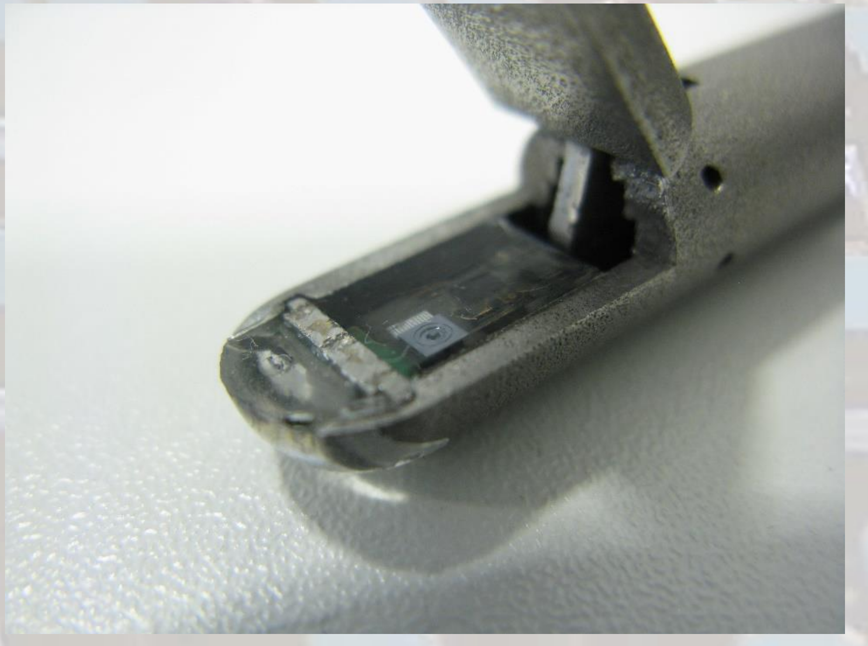






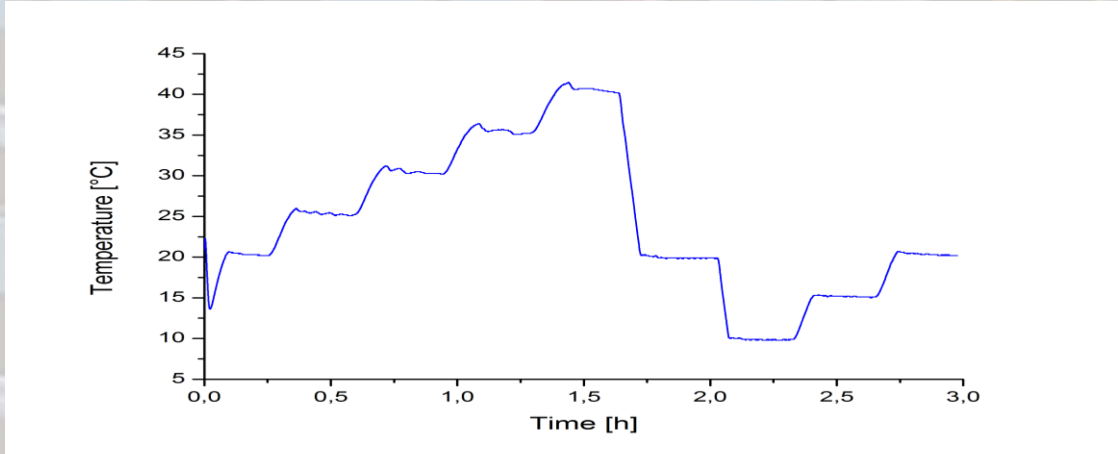
Piezoresistive 3D force sensors - Integration in a laparoscopic tool

Previous work – metal gripper and biocompatible coating (Nusil MED-6215)

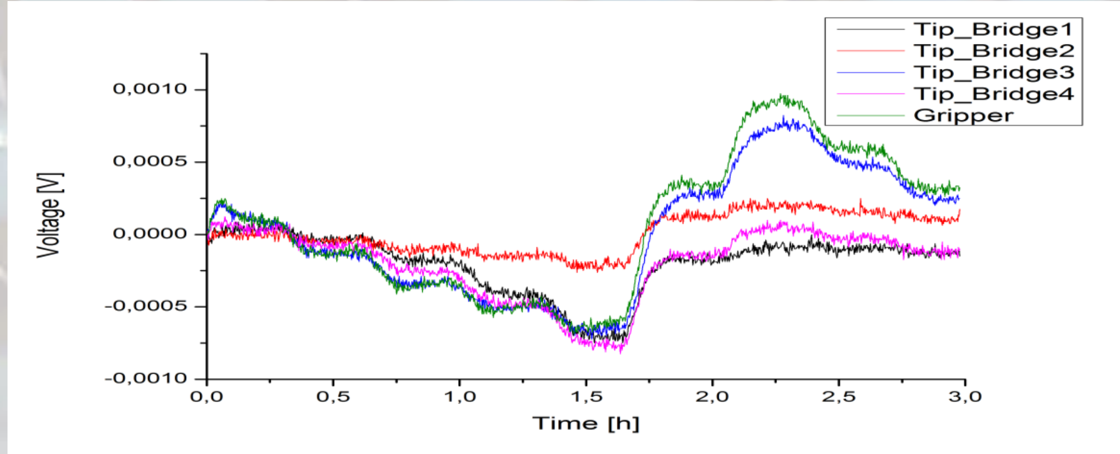


Piezoresistive 3D force sensors - Integration in a laparoscopic tool

Previous work – temperature tests



Temperature profile

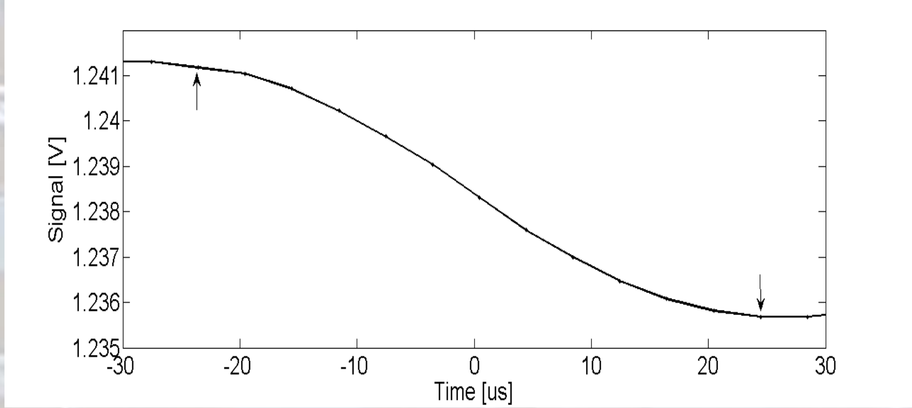


Offset signals

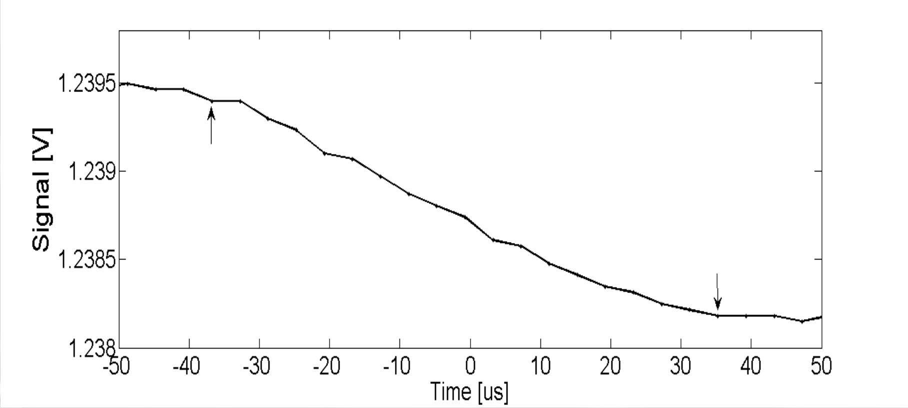
Climate chamber

Piezoresistive 3D force sensors - Integration in a laparoscopic tool

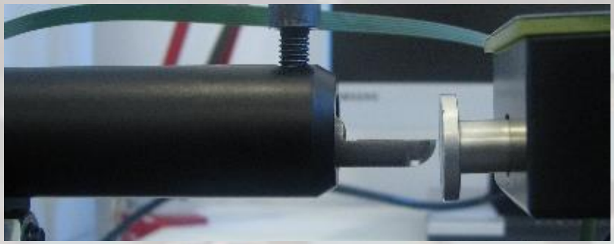
Previous work – response time



Bare sensor

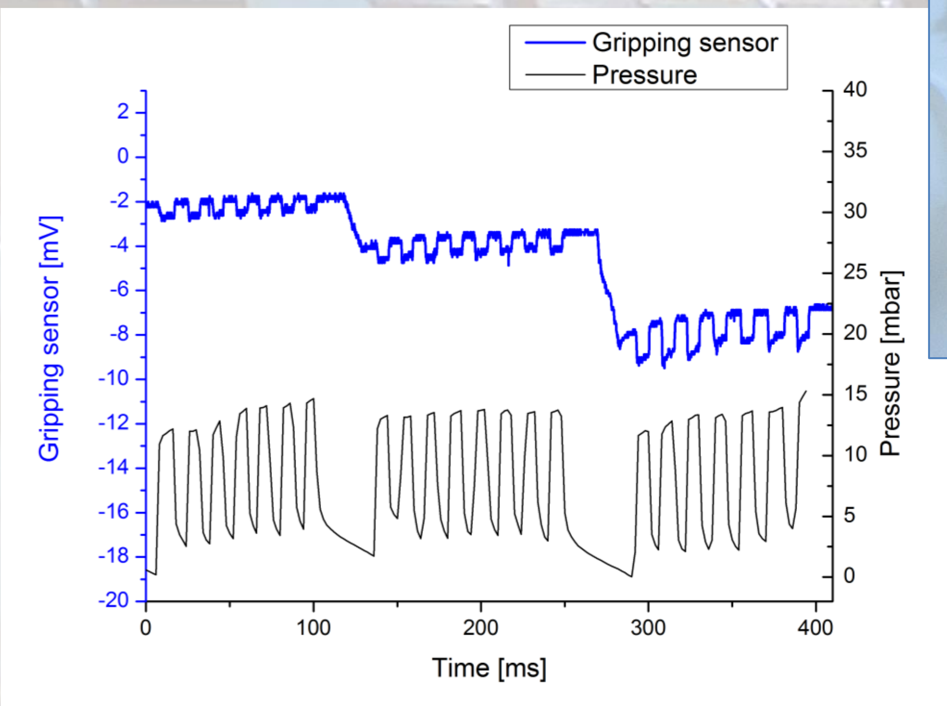


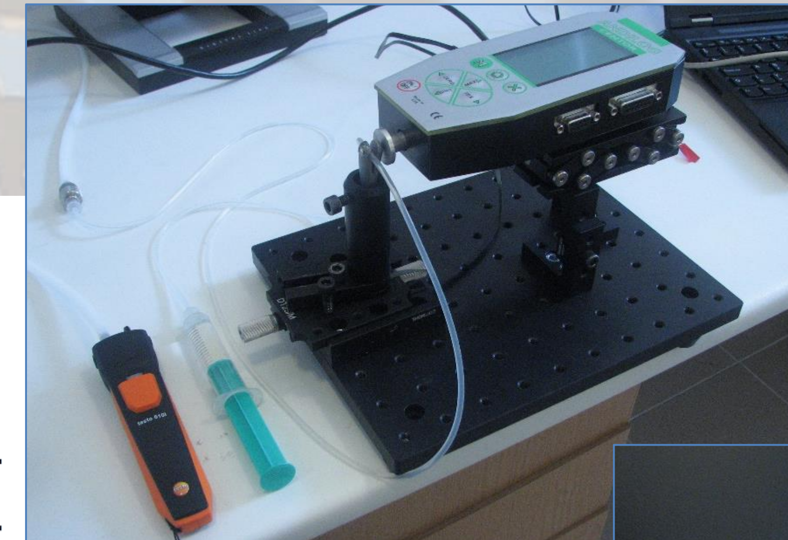
Covered sensor

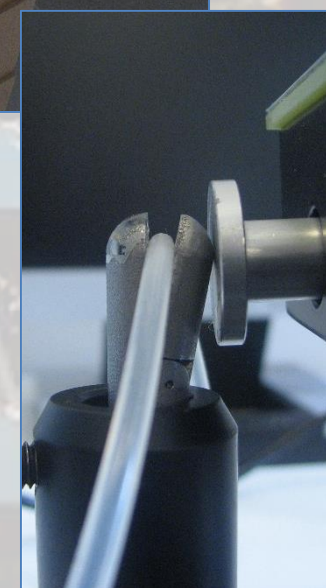


Piezoresistive 3D force sensors - Integration in a laparoscopic tool

Previous work – biomechanical tests



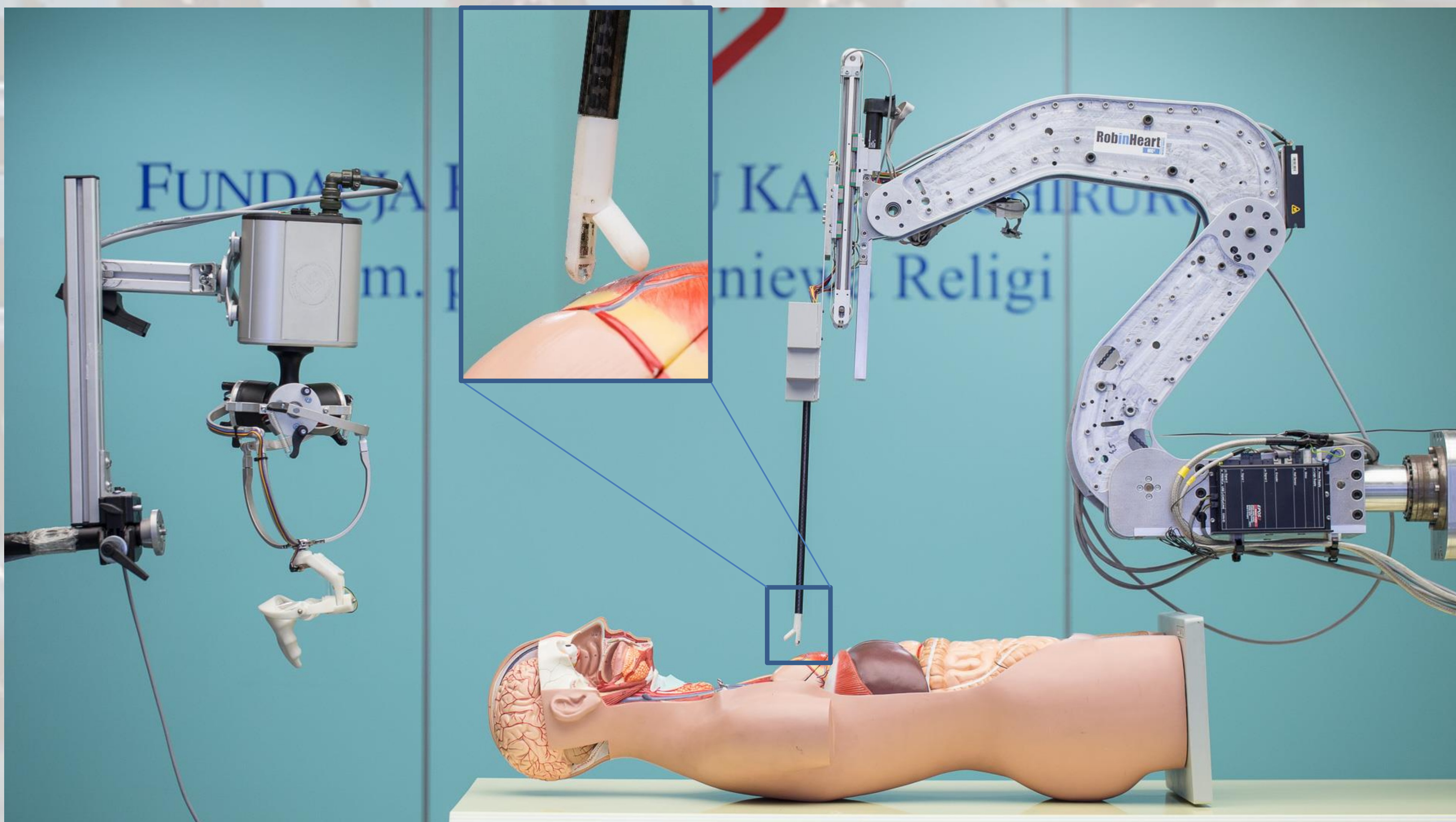




80 – 120Hgmm
106 – 160mBar

Piezoresistive 3D force sensors - Integration in a laparoscopic tool

Previous work – completed test device

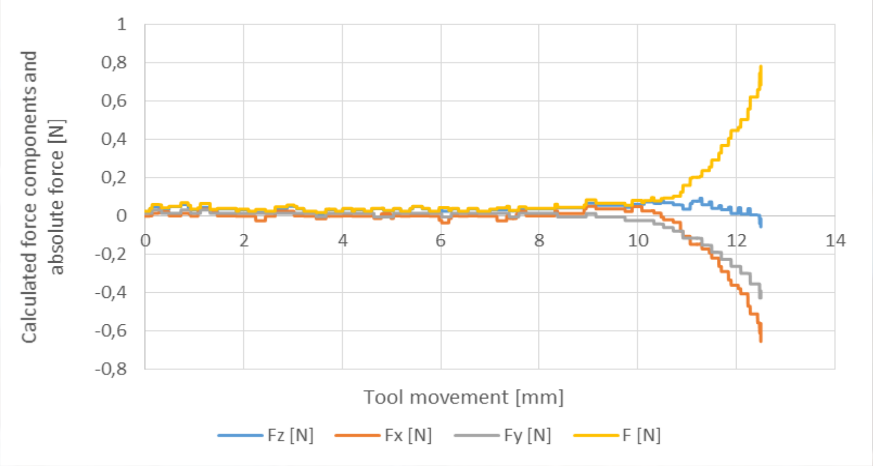


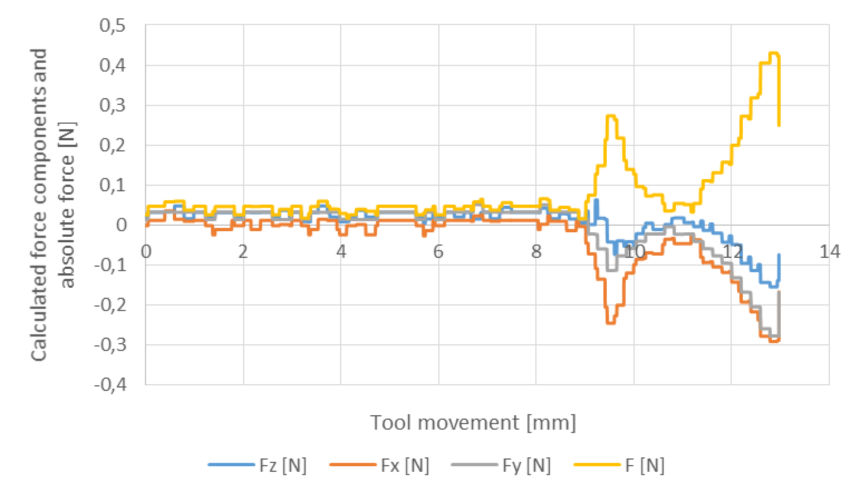
Piezoresistive 3D force sensors - Integration in a laparoscopic tool

Previous work – biomechanical tests

Piezoresistive 3D force sensors - Integration in a laparoscopic tool

Previous work – biomechanical tests



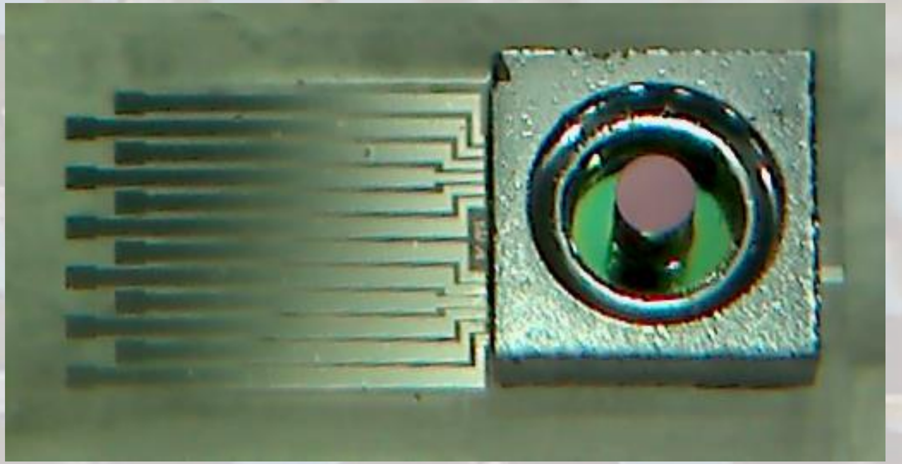


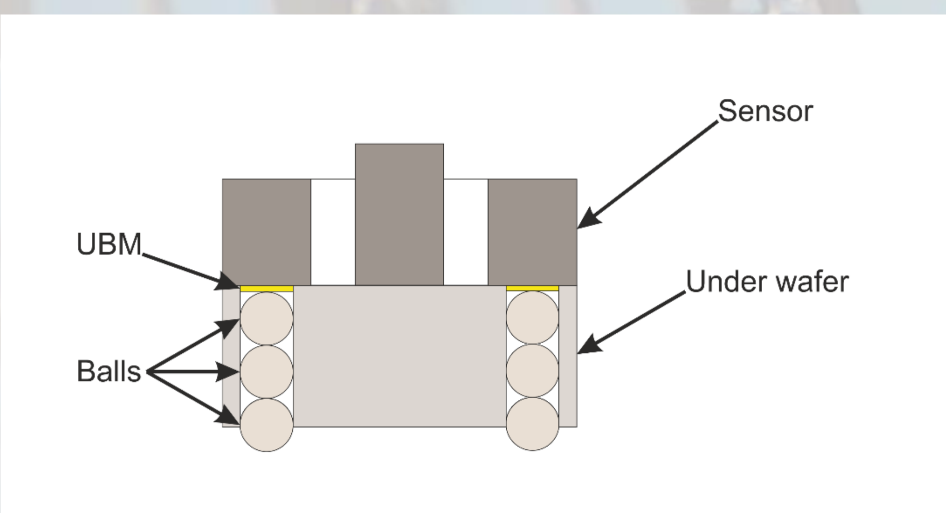
Piezoresistive 3D force sensors – Reducing chip size

(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

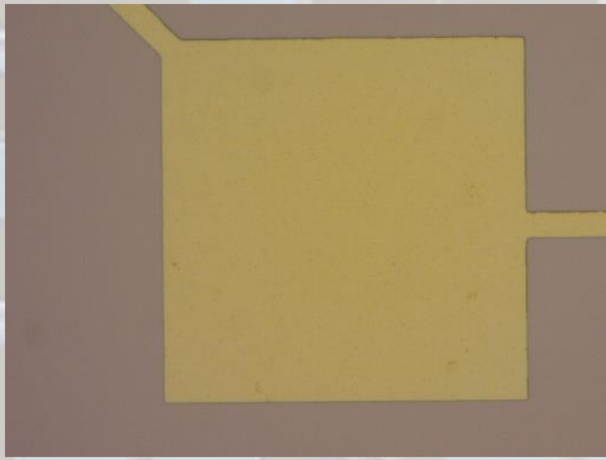




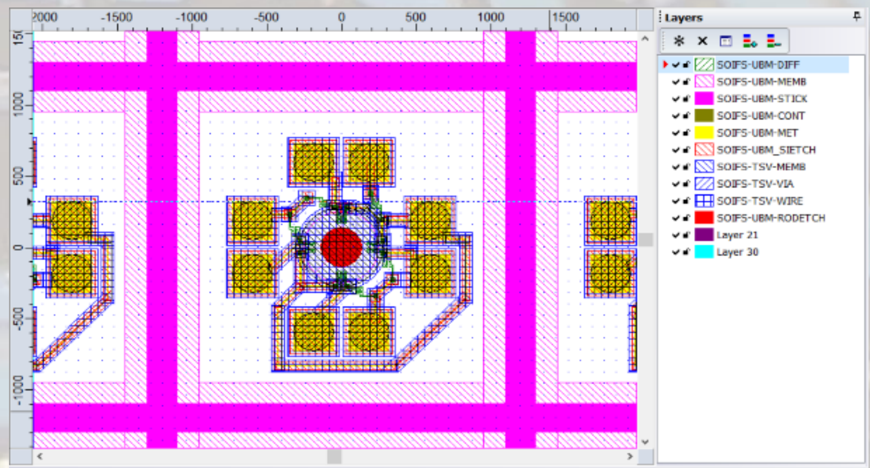
Piezoresistive 3D force sensors - Reducing chip size

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

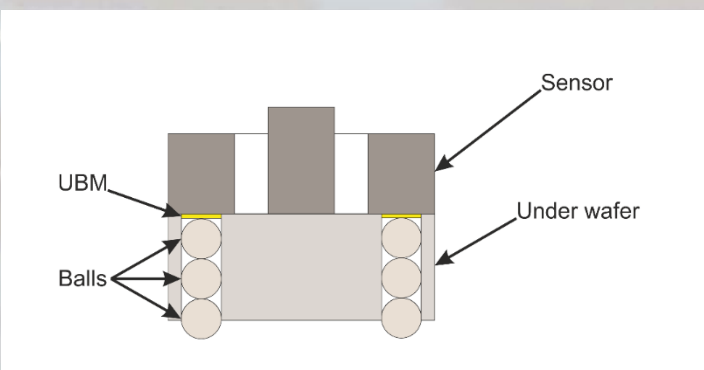
Under bump metallization

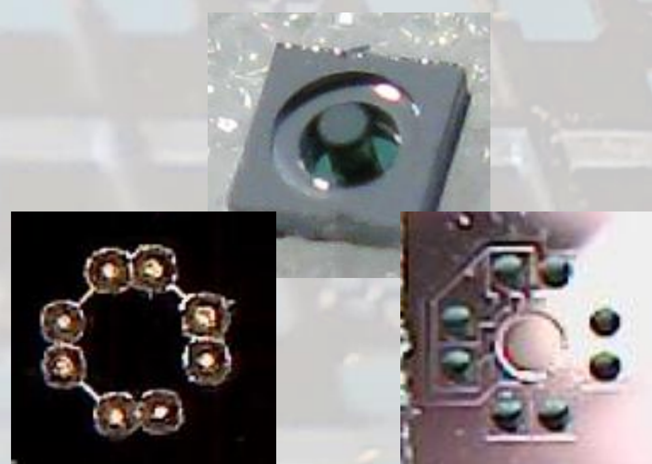


Design and layouts



Top and bottom parts





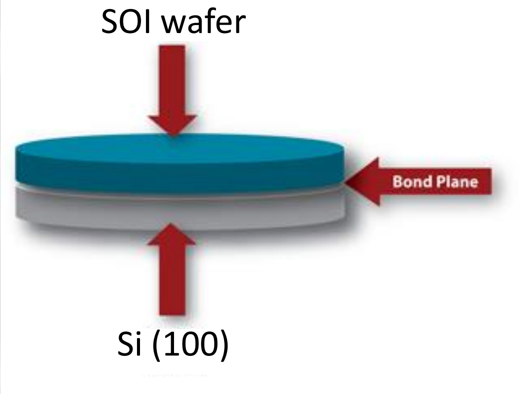
Piezoresistive 3D force sensors - Reducing chip size

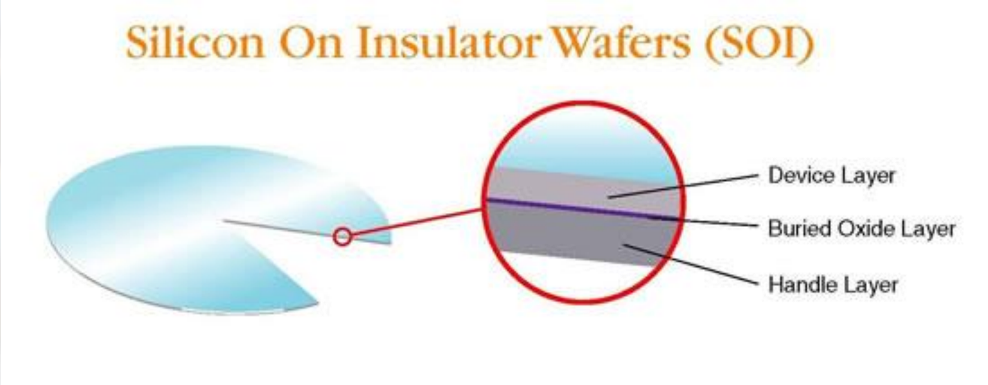
(Supported by the ÚNKP-17-3-I-OE-779/47 New National Excellence Program of the Ministry Of Human Capacities)

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

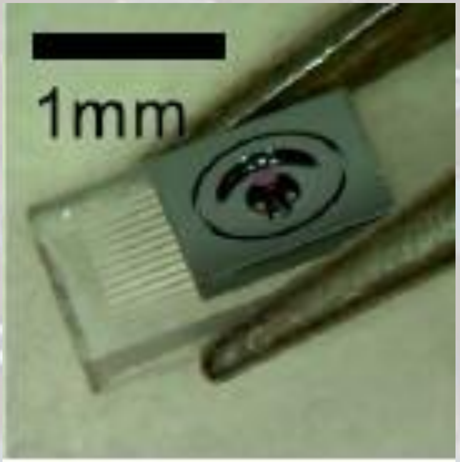
<u>Publications in this topic</u>

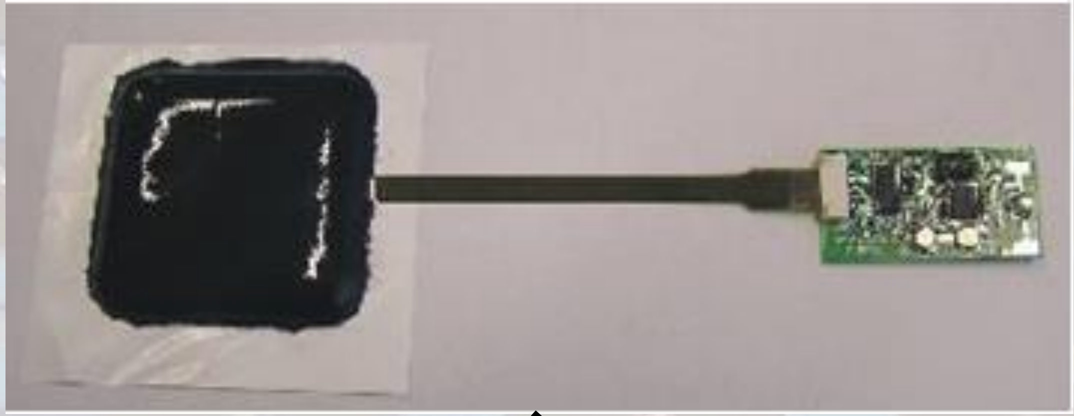
- **5 Papers (min. 4. pages)**
- **5 oral presentations (in English)**
- **3 posters**

Piezoresistive 3D force sensors - Integration in a vehicle tyre

Previous work

- Implantation of 3D force sensor in a special rubber



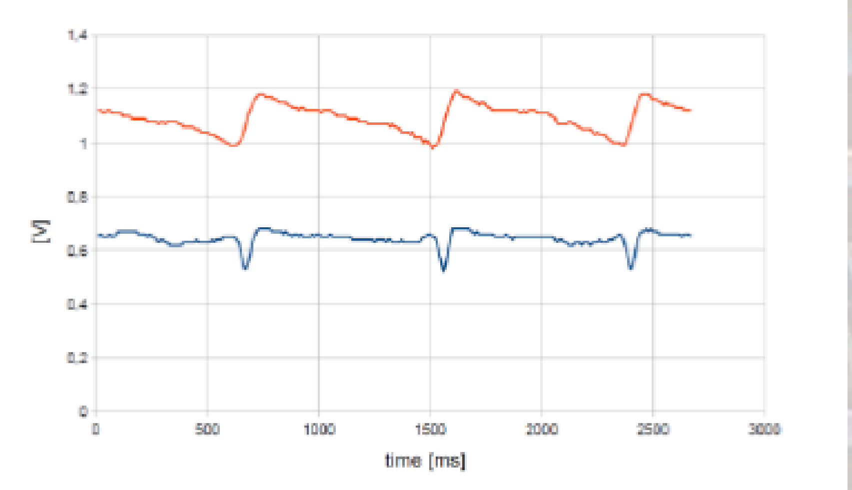


- Integration of test tool in a vehicle tyre

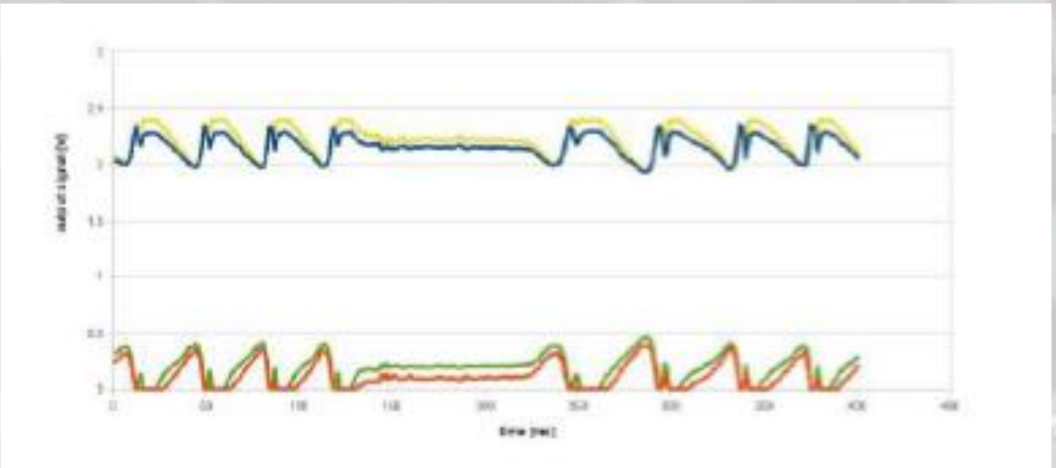
Piezoresistive 3D force sensors - Integration in a vehicle tyre

Previous work

- Measurements – normal road conditions



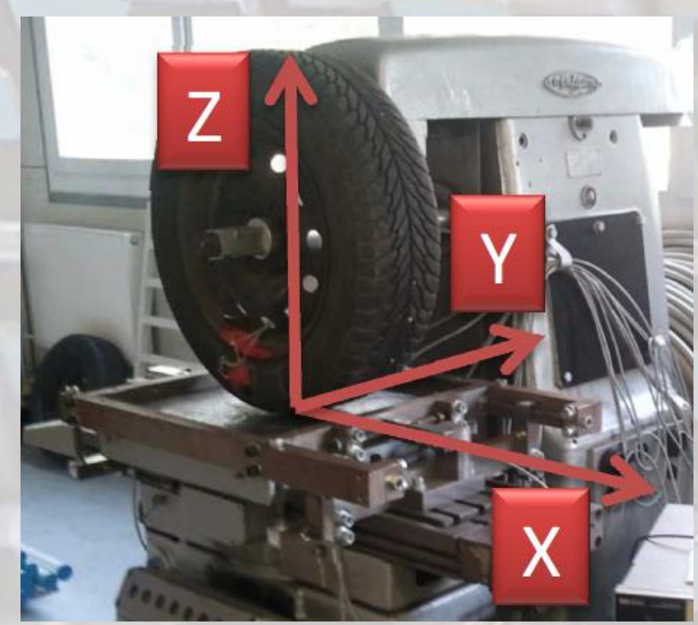
- Measurements – the wheel is blocked



Piezoresistive 3D force sensors - Integration in a vehicle tyre

Previous work

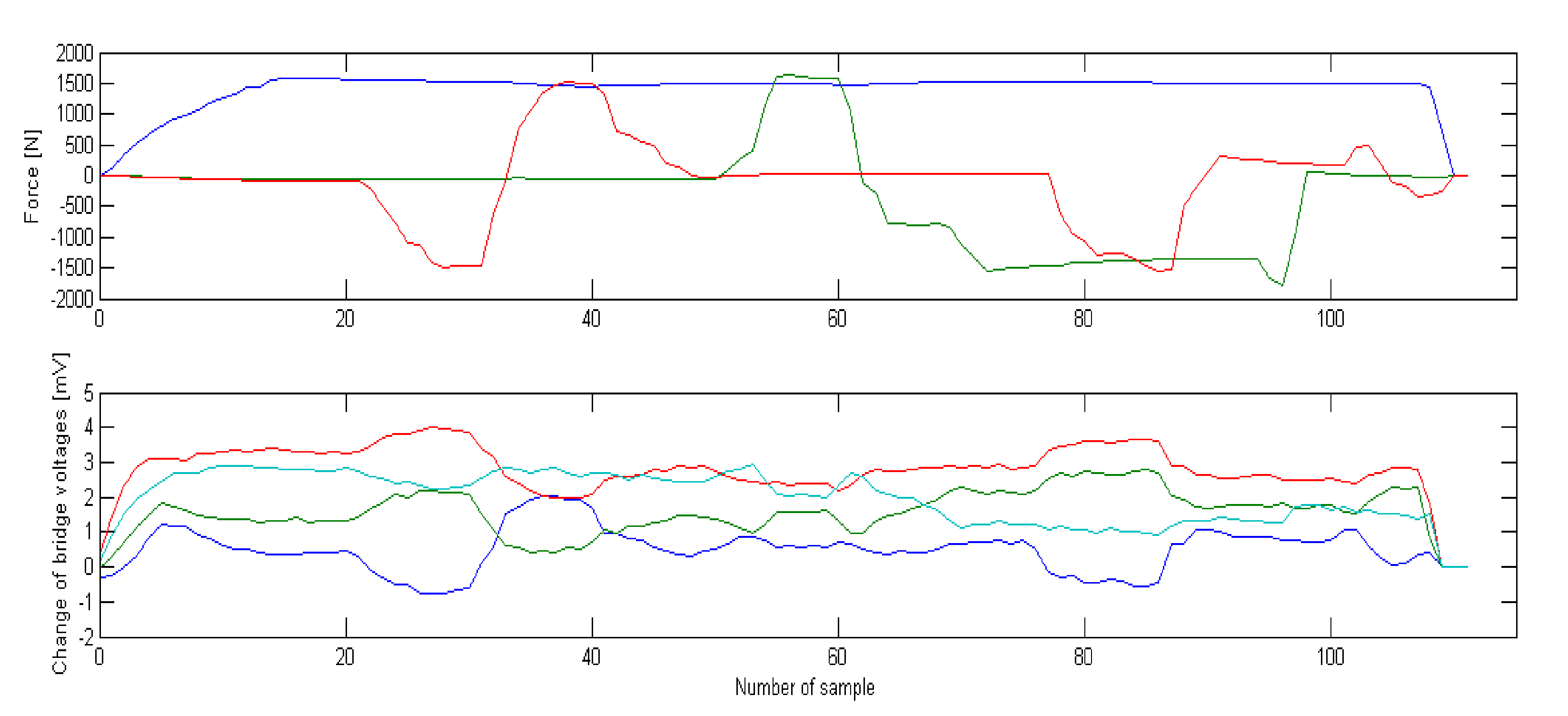
- Functional test: static loading



Piezoresistive 3D force sensors - Integration in a vehicle tyre

Previous work

- Results of static measurement

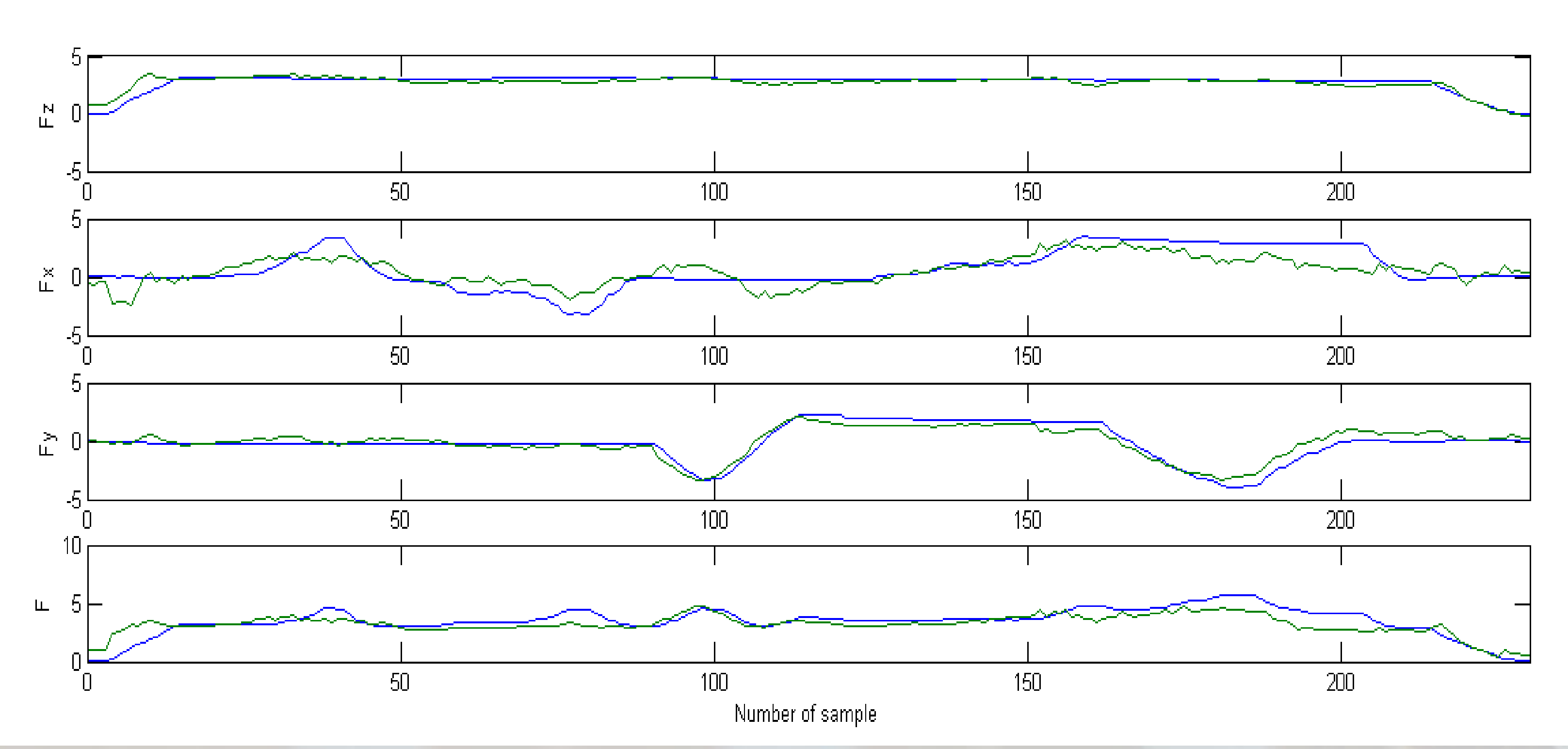


F_x
F_y
F_z

Piezoresistive 3D force sensors - Integration in a vehicle tyre

Previous work

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



Piezoresistive 3D force sensors - Integration in a vehicle tyre

Current work

- 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

Future work

- Preliminary tests at the KFKI Campus
- Further tests in Győr

Publications in this topic

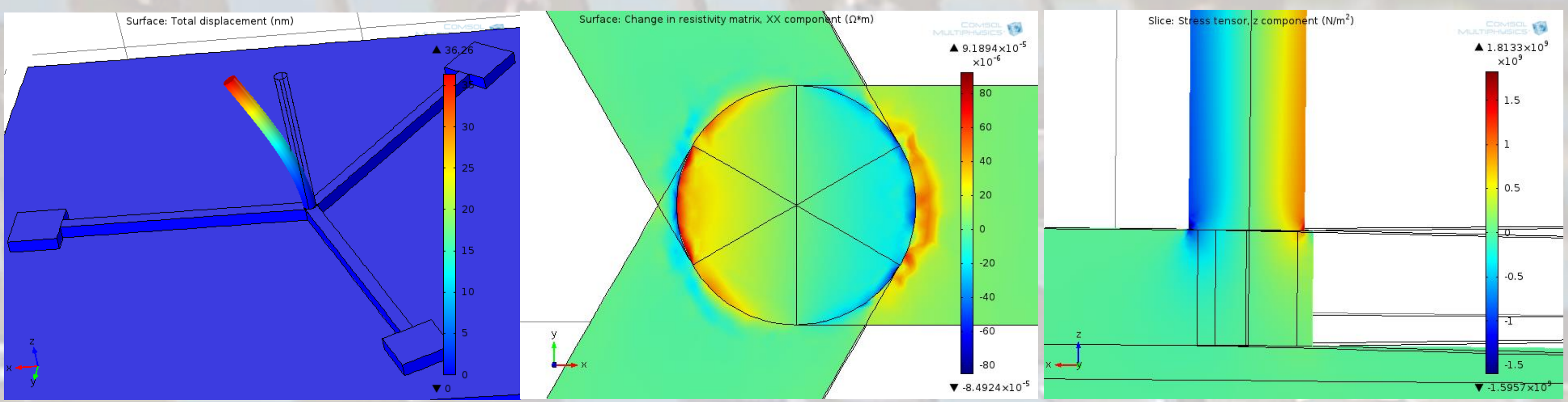
Oral presentation (in English):

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

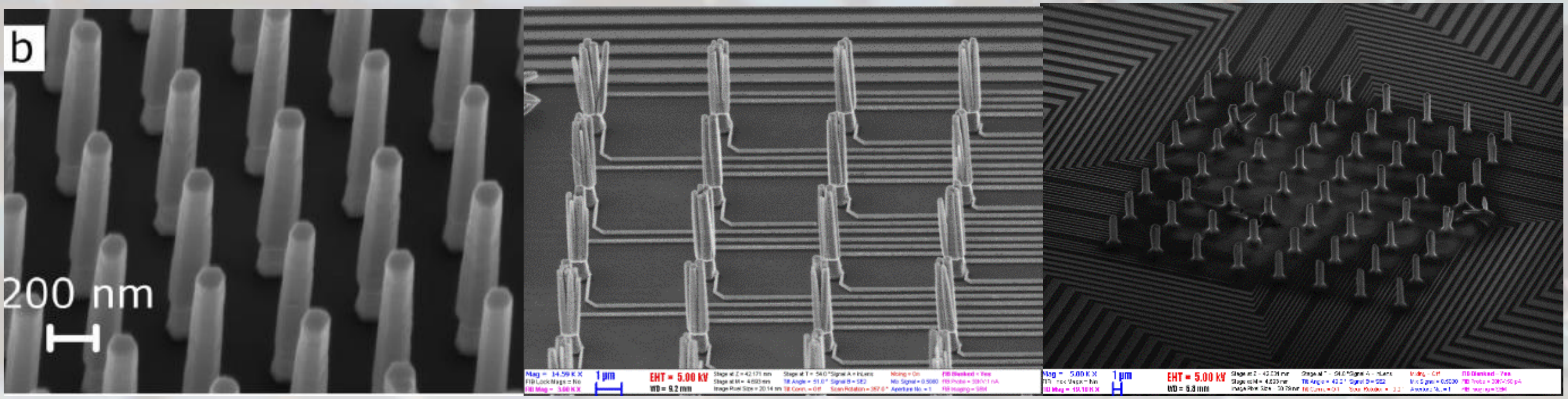
Piezoelectric ZnO nano-rods – for high-resoultion fingerprint sensing

Previous work

- Simulation



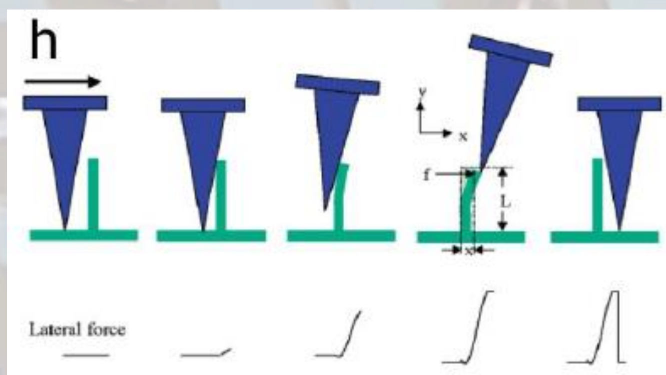
- Growing of the rods (hydrothermal growing: Zinc-nitrate hexahydrate and hexamethylen tetramin)

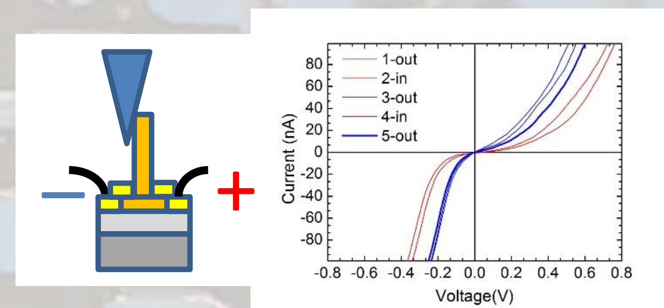


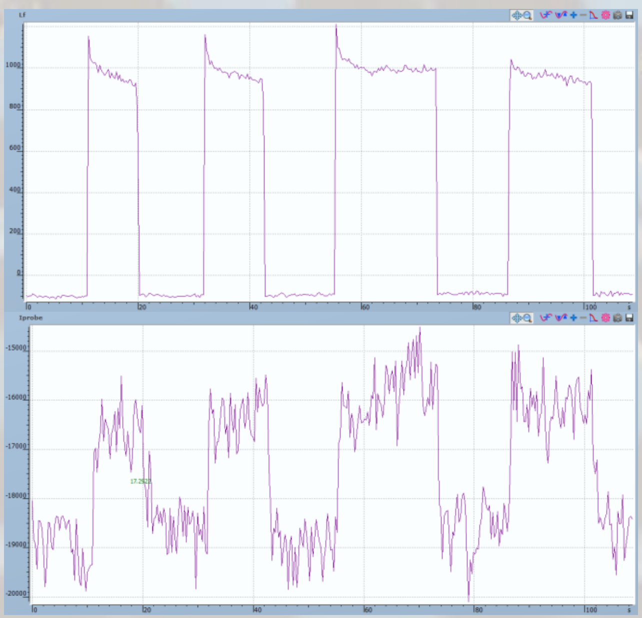
Piezoelectric ZnO nano-rods – for high-resoultion fingerprint sensing

Previous work

- Bending and measurement in Atomic Force Microscope



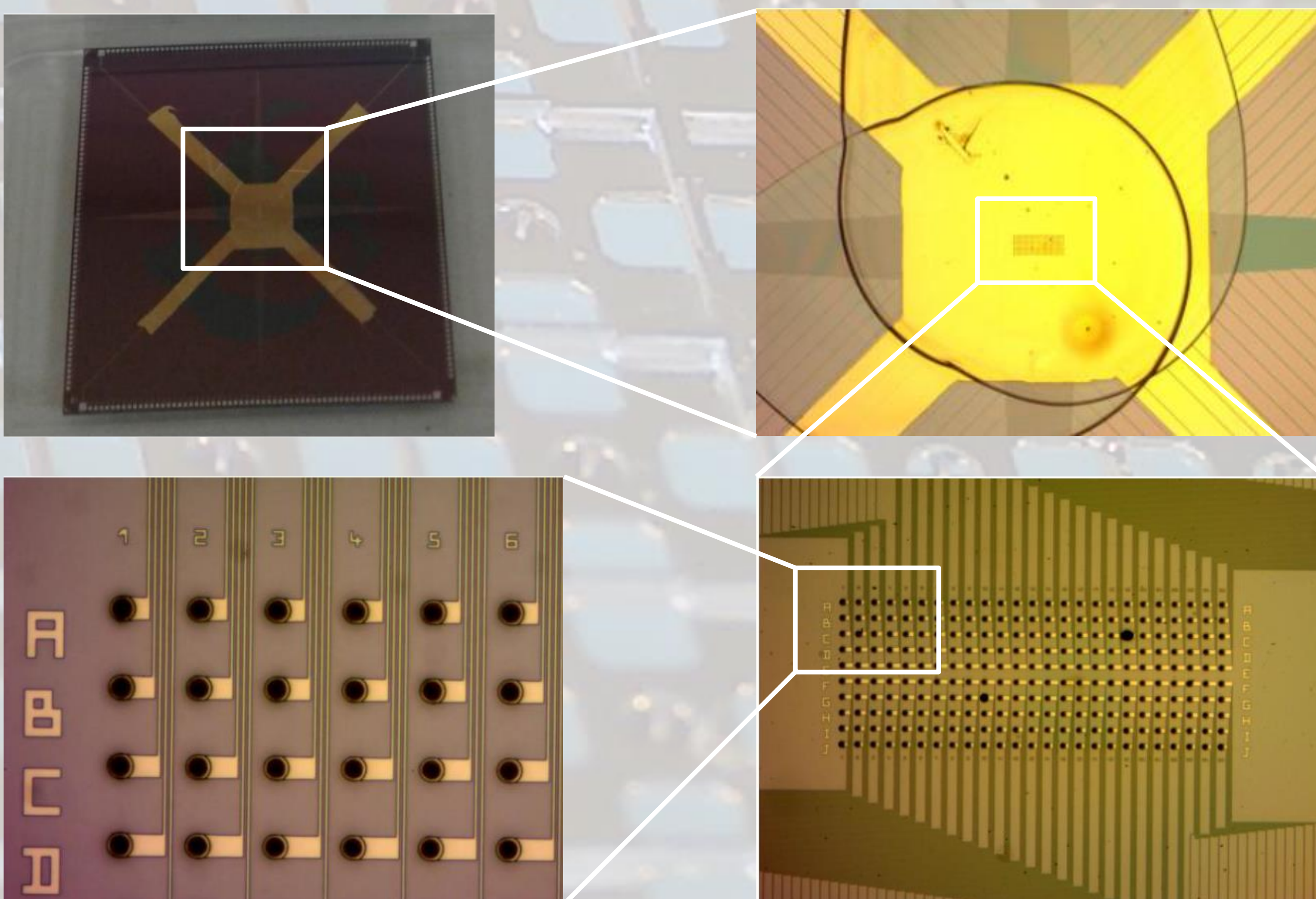




Piezoelectric ZnO nano-rods – for high-resoultion fingerprint sensing

Previous work

- Design and fabrication a 25x10 nano-array



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

Previous work

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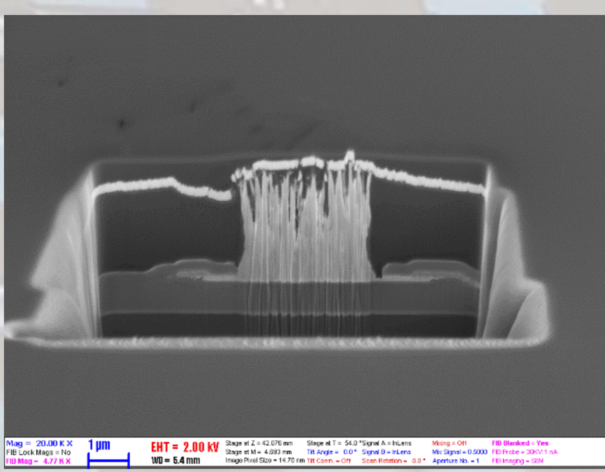
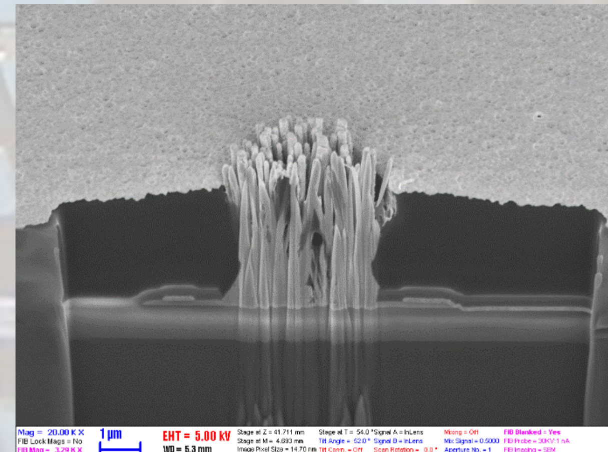
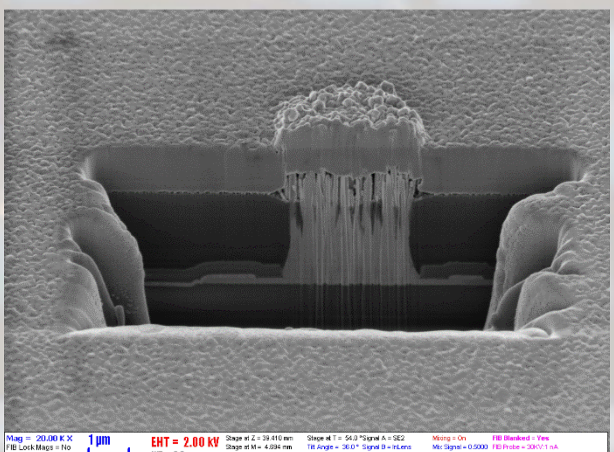
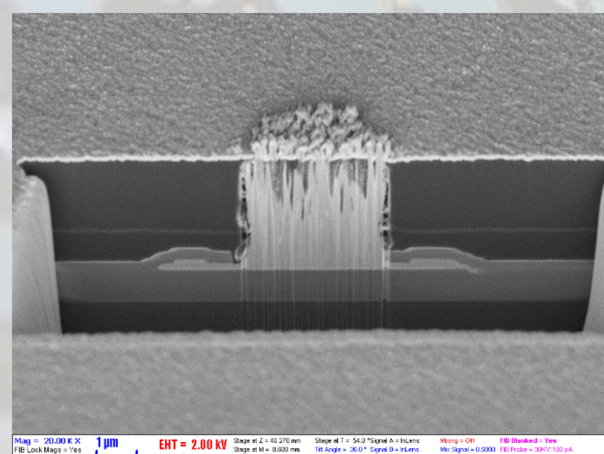




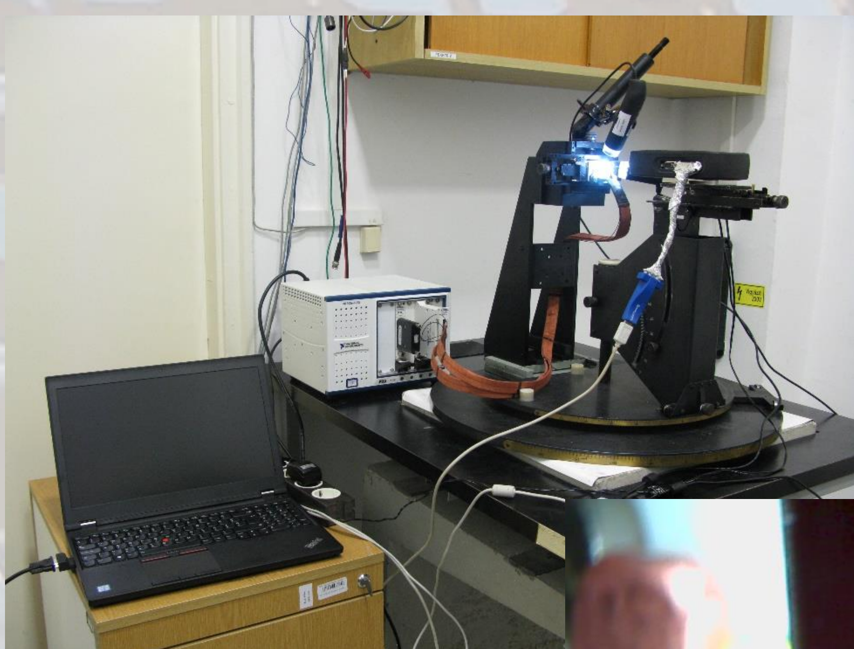


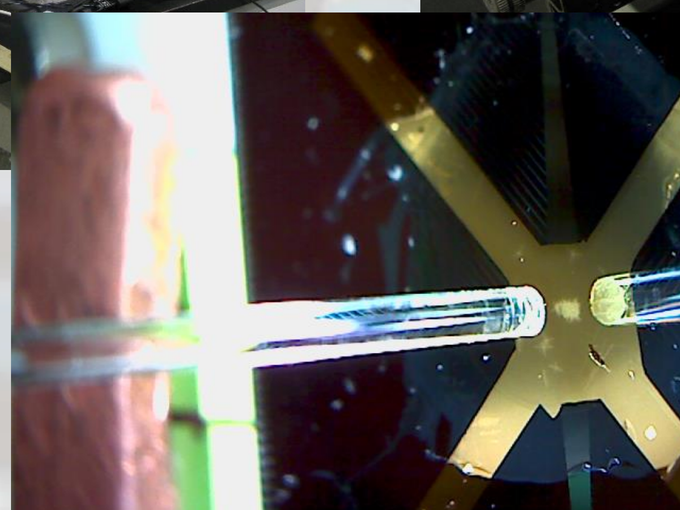


Piezoelectric ZnO nano-rods – for high-resoultion fingerprint sensing

Previous work

- Assembling a new measurement setup

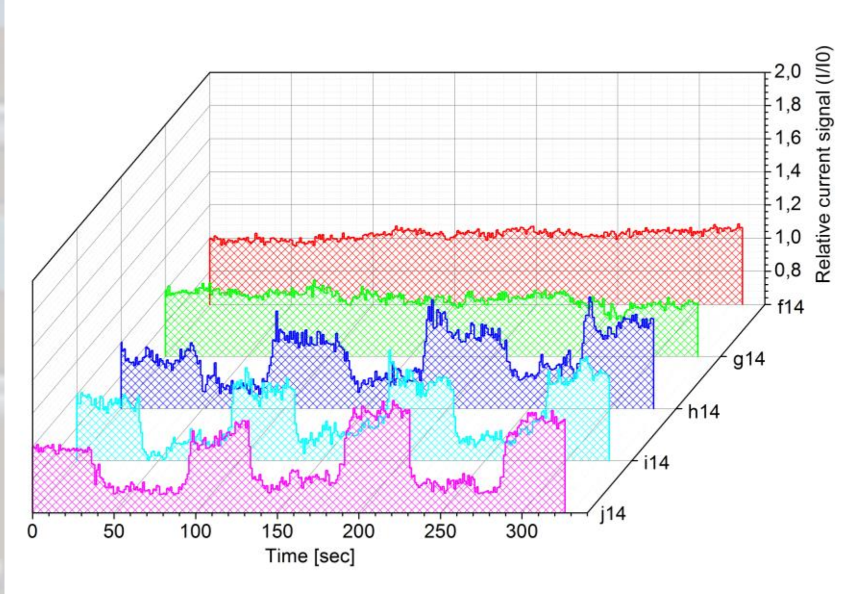


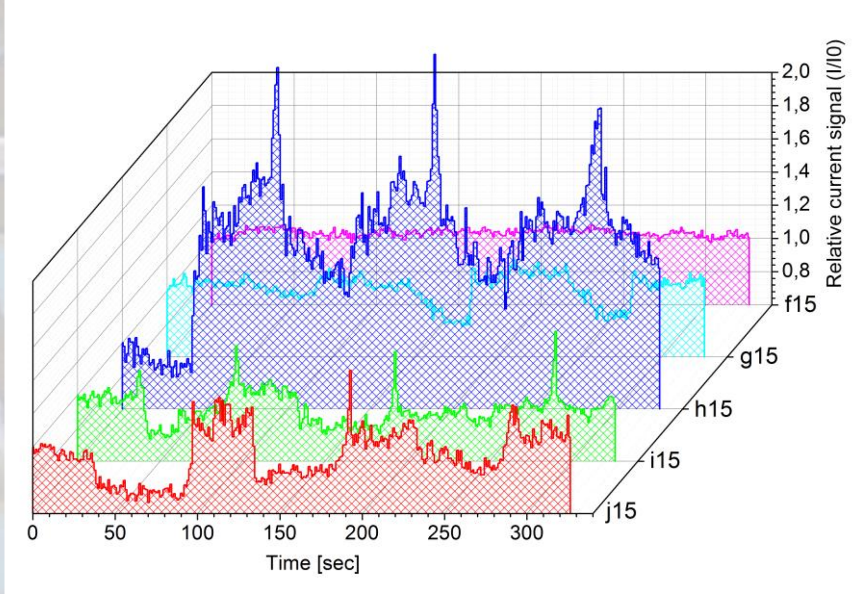


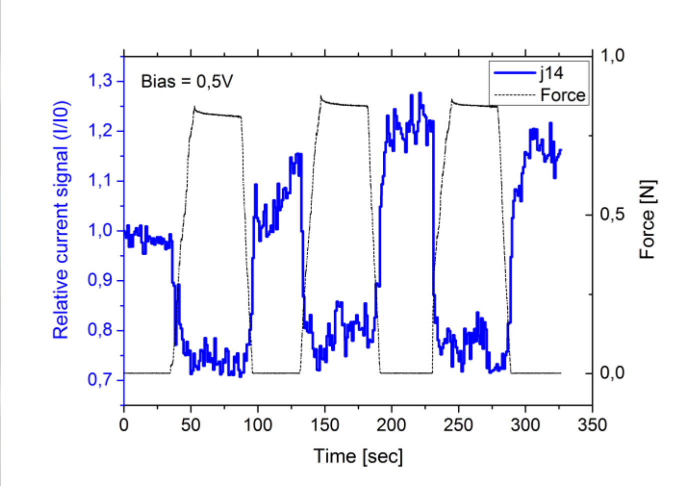
Piezoelectric ZnO nano-rods – for high-resoultion fingerprint sensing

Previous work

- Results





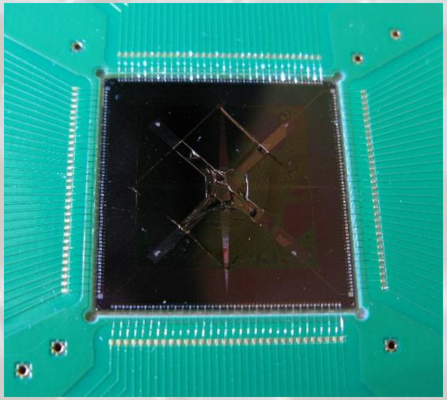


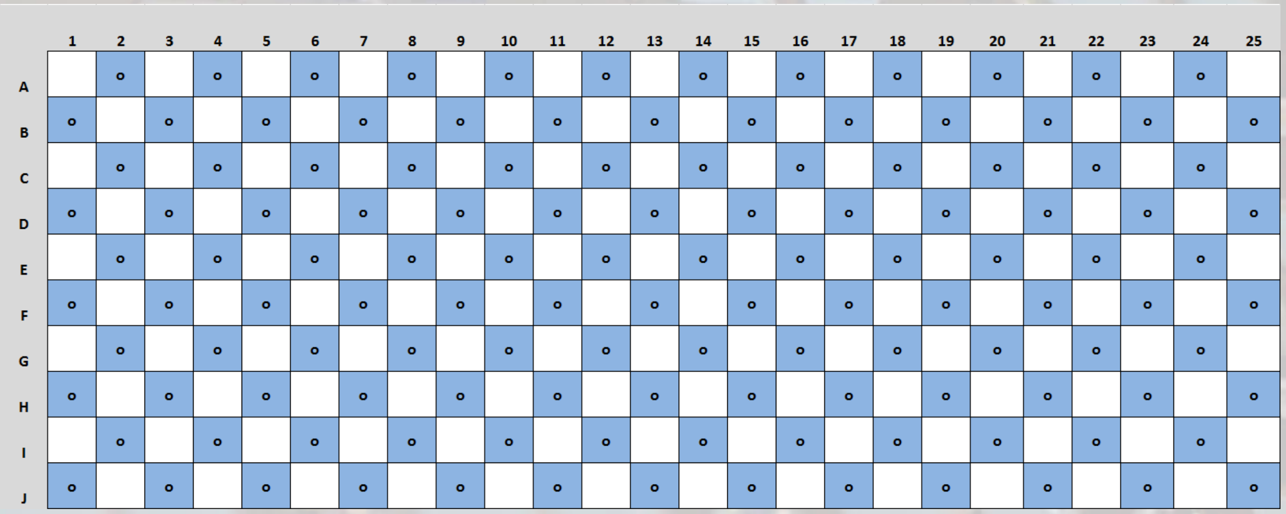
Piezoelectric ZnO nano-rods

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

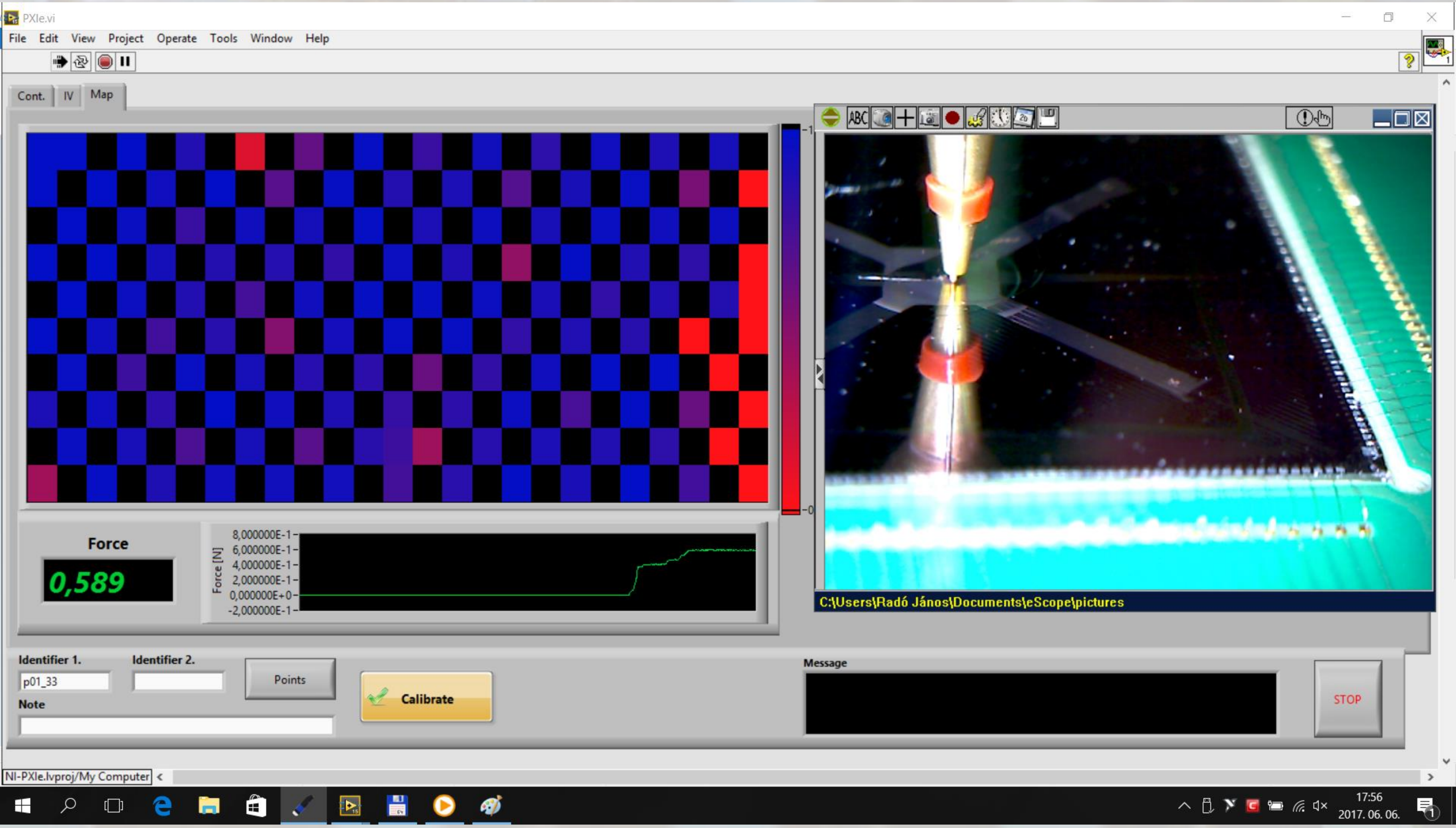
Previous work

- Measurement of the entire array in the same time





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

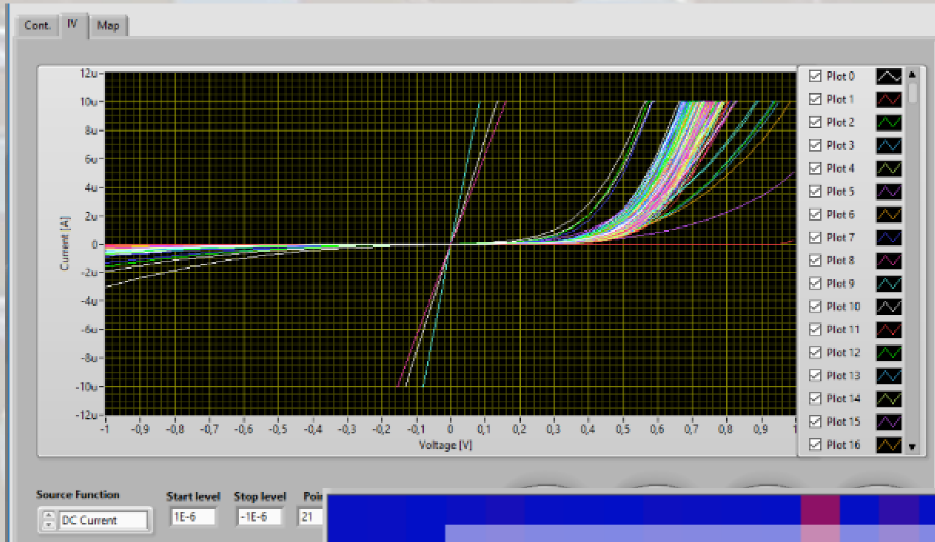


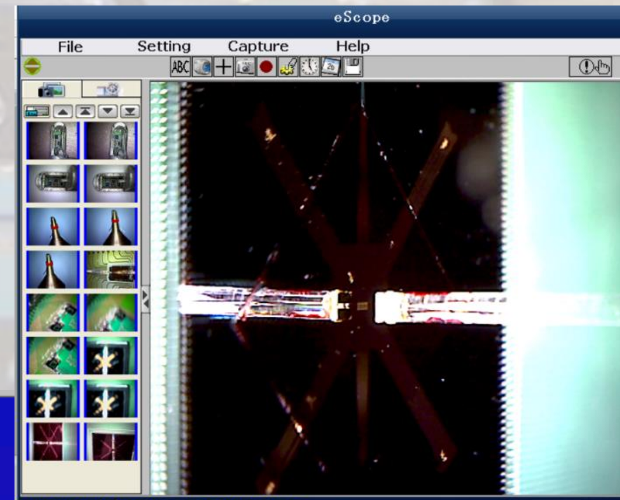
Piezoelectric ZnO nano-rods

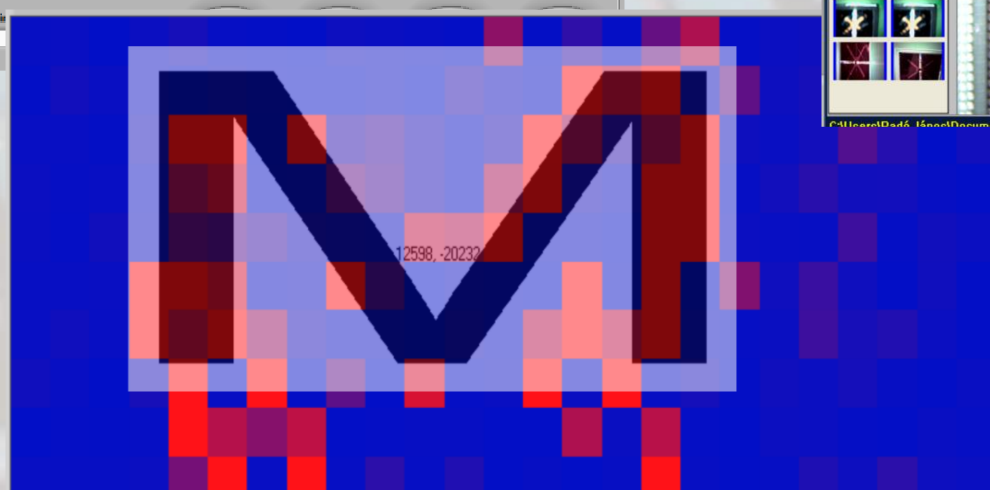
(Supported by the ÚNKP-17-3-I-OE-779/47 New National Excellence Program of the Ministry Of Human Capacities)

Current work

- 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)

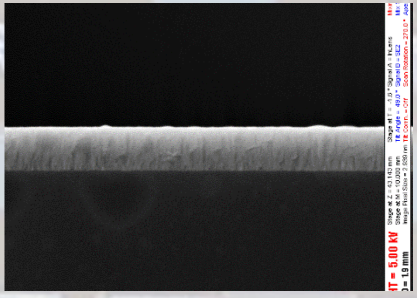
Oral presentation:

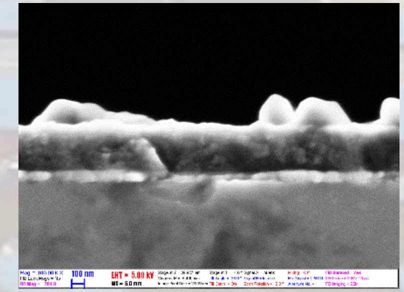
- János Volk, István E. Lukács, Nguyen Quoc Khánh, János Radó, Róbert Erdélyi: **Bottom contacted piezoelectric nanowire arrays,** NGPT 2016, Rome, Italy
- J. Volk, J. Radó, I. E. Lukács, N. Q. Khánh, R. Erdélyi, G. Battistig, C. Sturm, M. Grundmann, A. Graillot, C. Loubat: **Integrated piezoelectric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

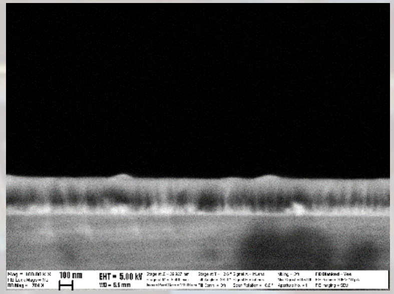
Piezoelectric AlN thin film for 3D force sensor

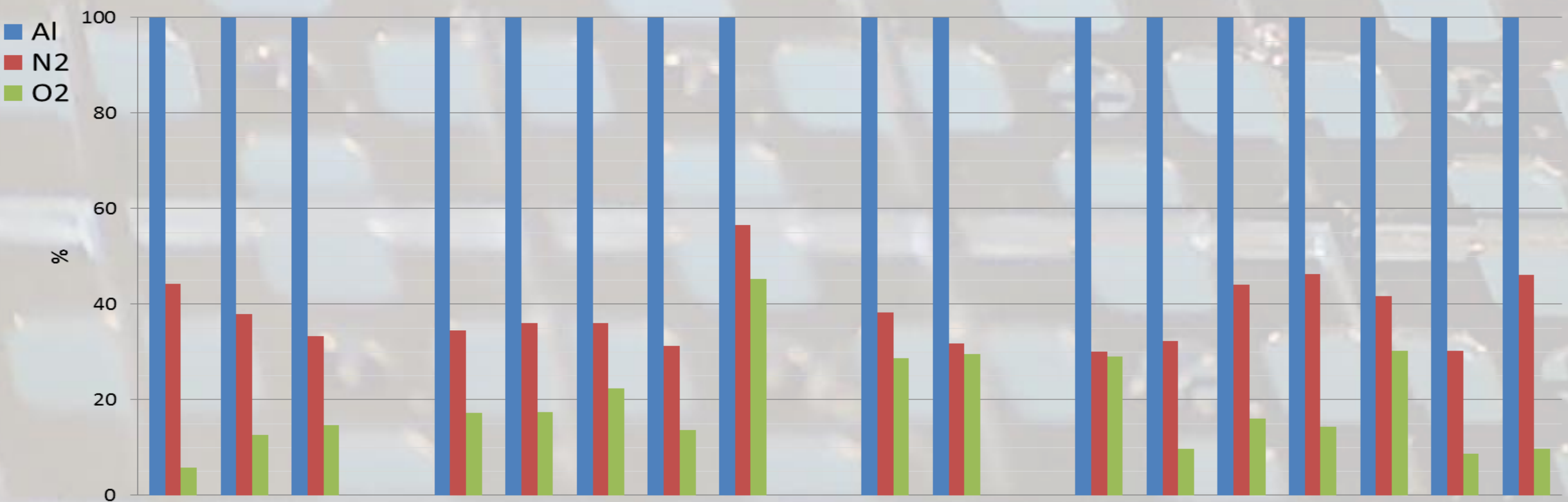
Previous work

- Test deposition with different parameters
- Qualification of complete thin films



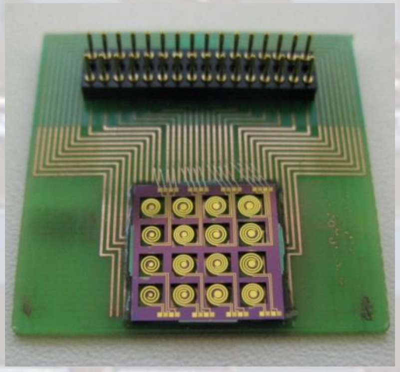


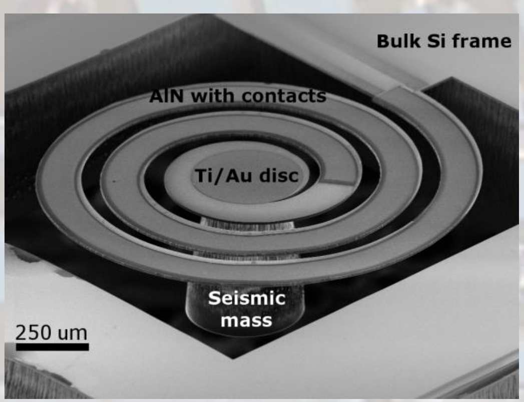


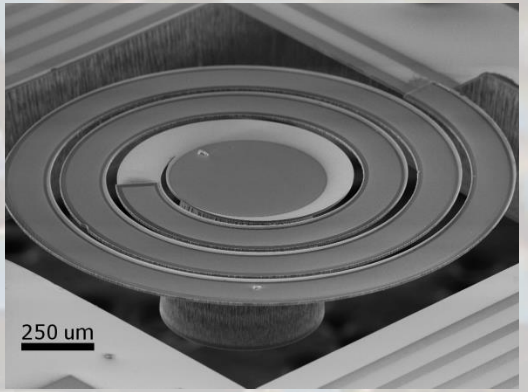


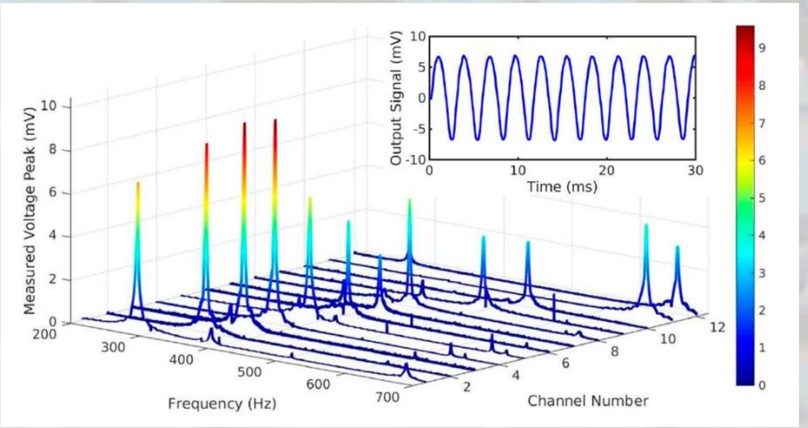
Piezoelectric AlN thin film for 3D force sensor

Previous work





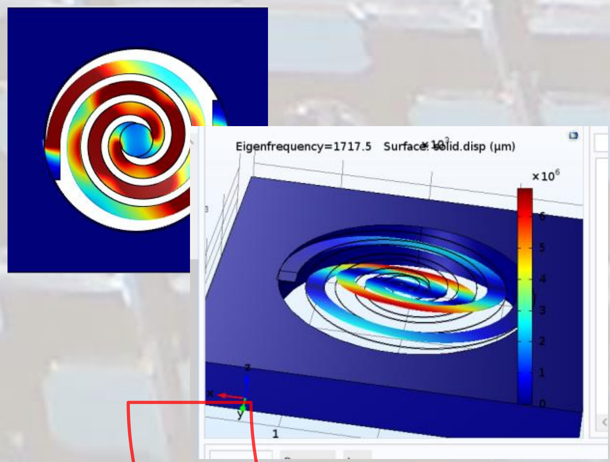




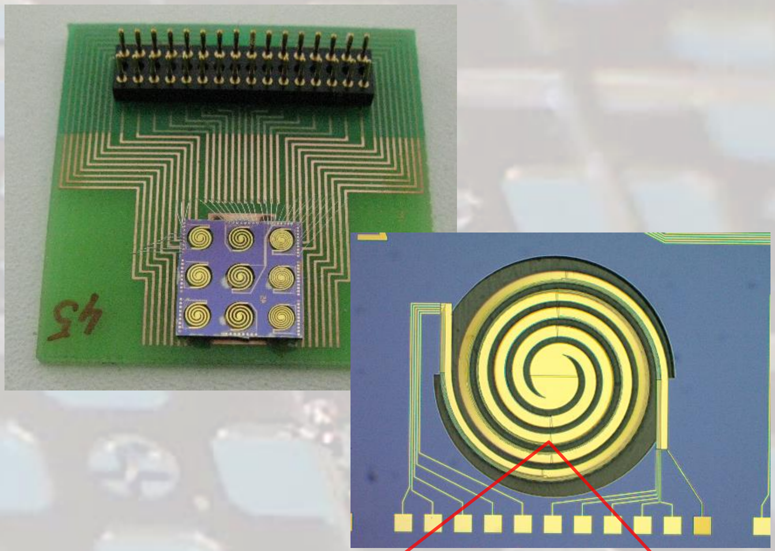
Piezoelectric AlN thin film for 3D force sensor

Current work

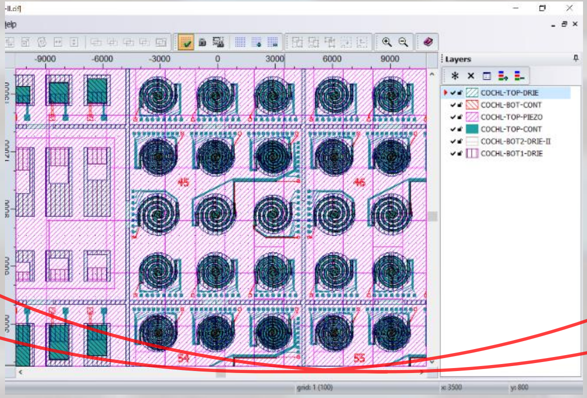
Simulation



Fabrication



Design



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**, Accepted at Eurosensors 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!