Technologische Möglichkeiten am Fraunhofer IISB / LEB und Anwendungsbeispiele

InnoPlanT.NET Netzwerktreffen „Intelligente Implantate“, 23.2.2017

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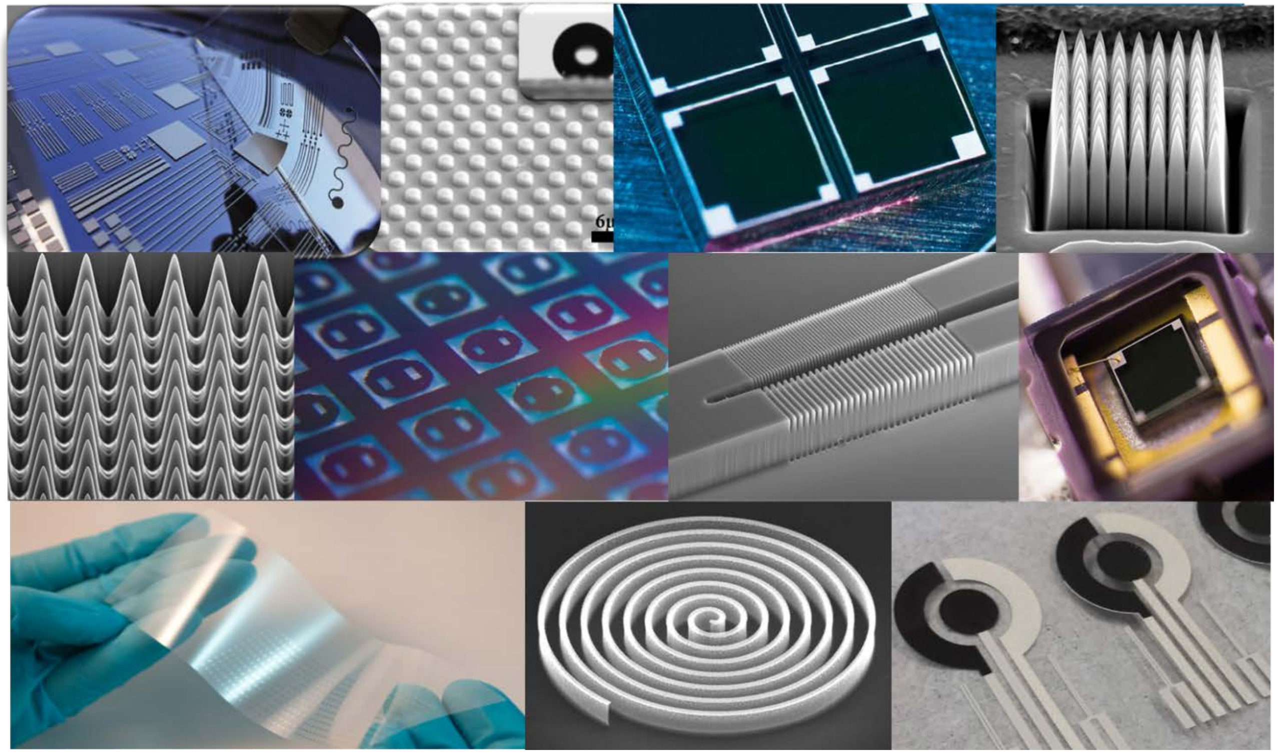
Lehrstuhl für Elektronische Bauelemente, FAU Erlangen-Nürnberg, Erlangen

Motivation/Introduction

- Intelligent implants
  - “passive” → surface topography, materials
  - “active” → sensors and/or actuators



Outline

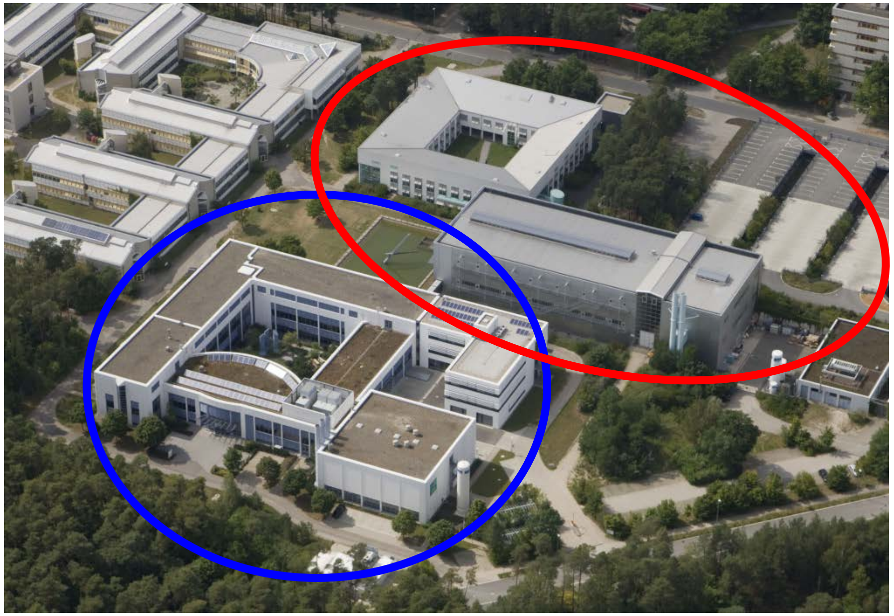
- Fraunhofer IISB - short overview

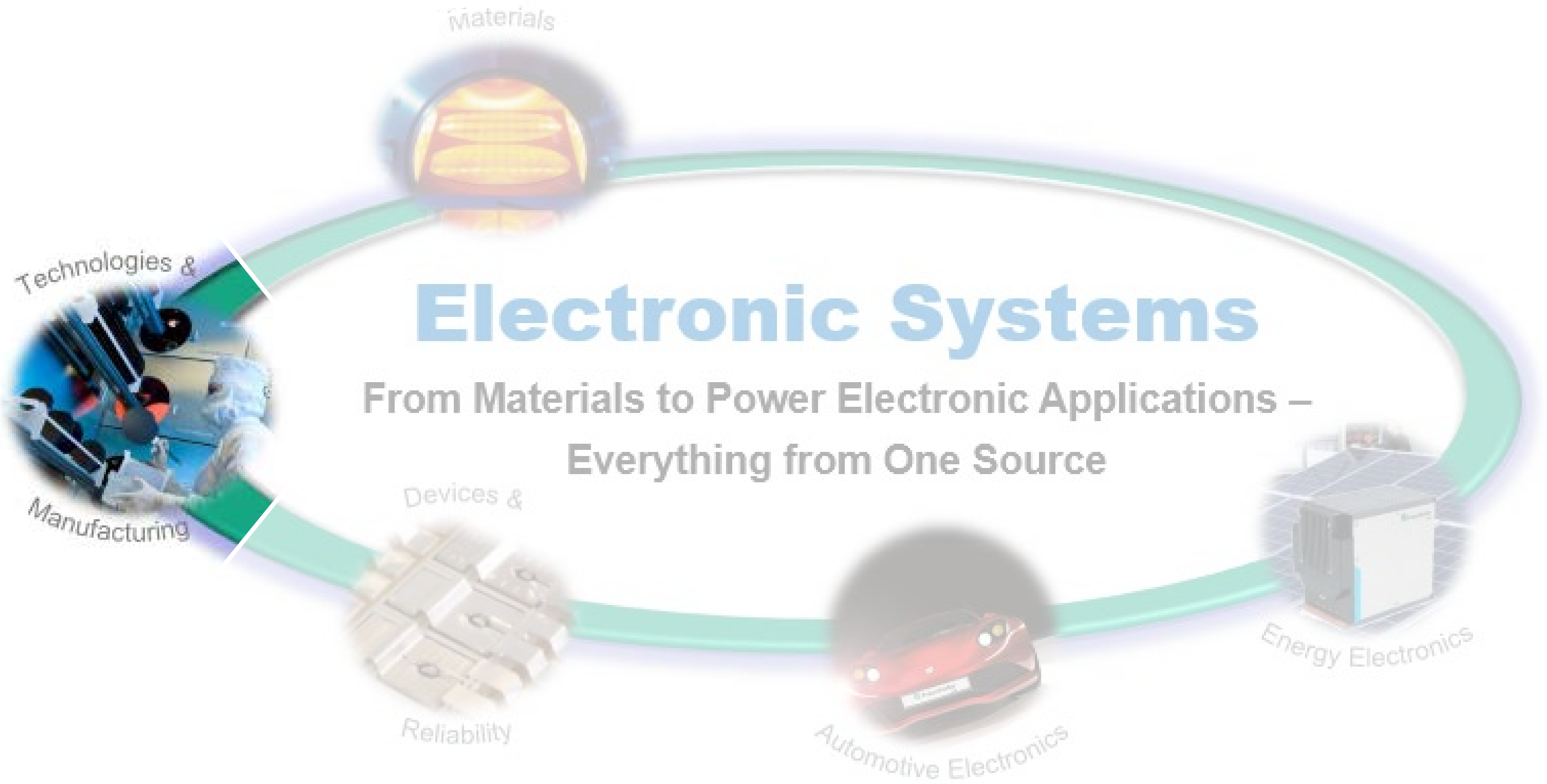
- “Classical” semiconductor technology based capabilities
  - Technologies, structures, devices

- “Non conventional” technologies based capabilities
  - Technologies, structures, devices

Fraunhofer IISB

- Independent, non-profit applied research institute
- Close cooperation of IISB and University of Erlangen-Nuremberg / LEB
- Contract research for customers from industry and academic
- 220 full time equivalent employees
- R&D partner and service provider for semiconductor related processes and device prototyping
- 1000 m² cleanroom (University) / 500 m² cleanroom (IISB): process line for up to 200 mm CMOS and bipolar Si and SiC power devices





Electronic Systems

From Materials to Power Electronic Applications – Everything from One Source

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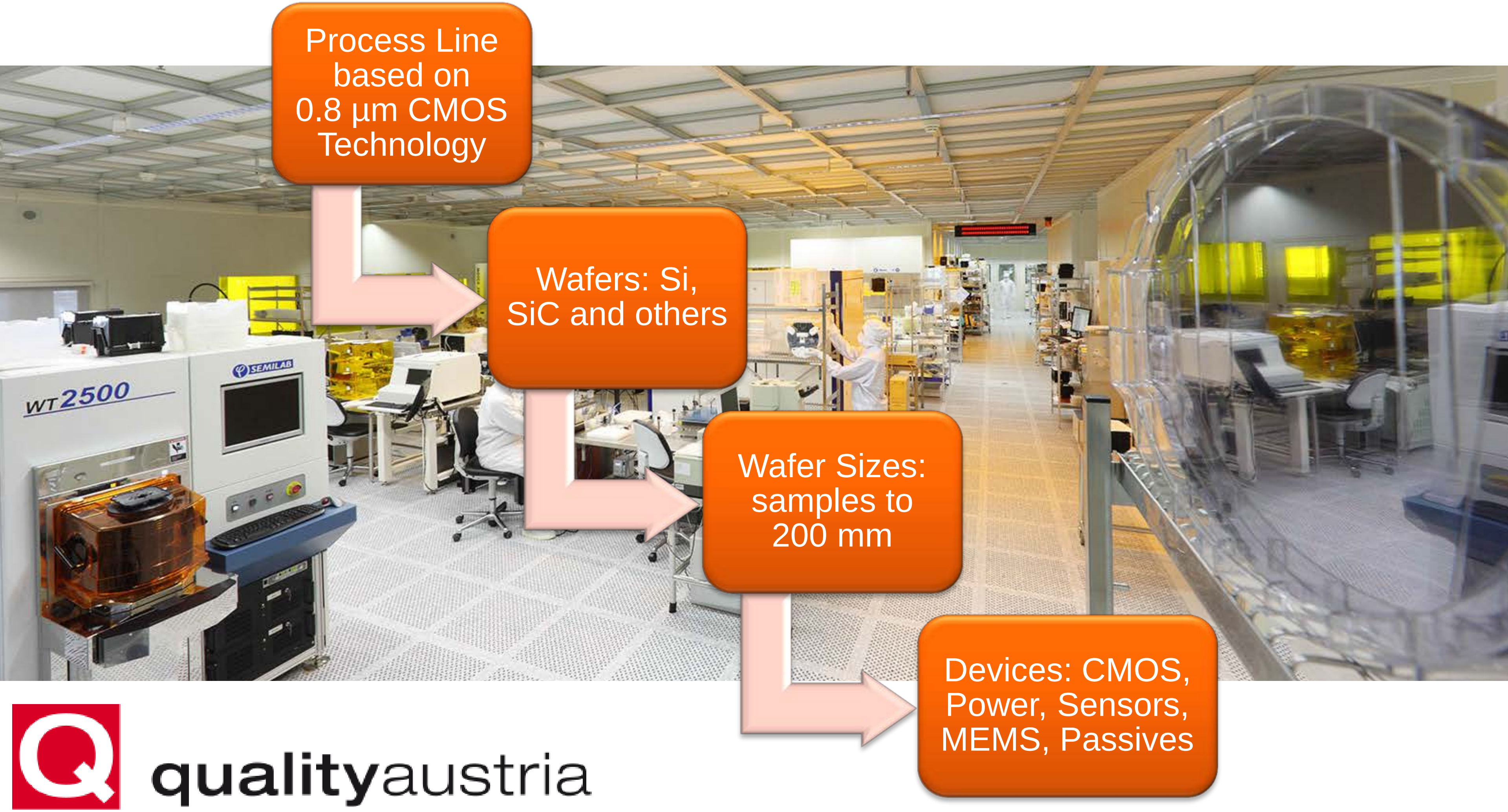
π-Fab

Low Volume Prototype Fabrication Of **Customized** Electron Devices



Process Line based on 0.8 µm CMOS Technology

Wafers: Si, SiC and others

Wafer Sizes: samples to 200 mm

Devices: CMOS, Power, Sensors, MEMS, Passives

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SYSTEM CERTIFIED
ISO 9001:2008 No.16300/0

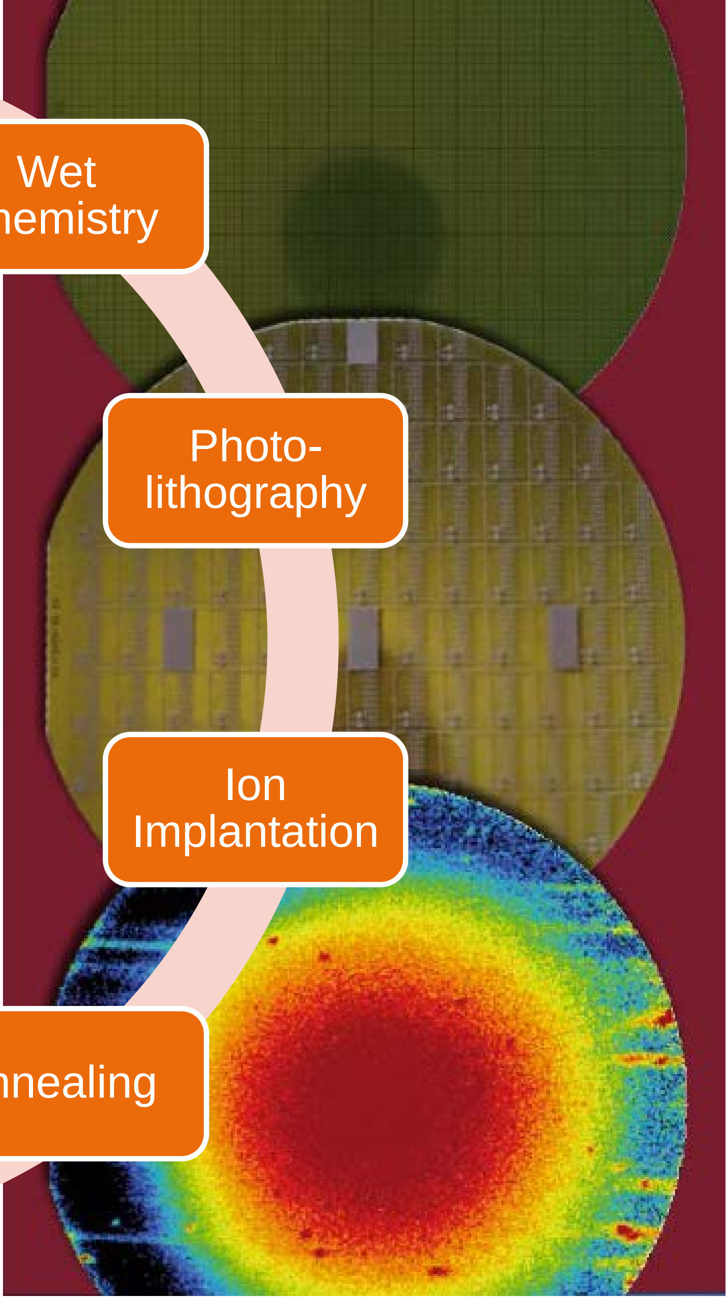
Fraunhofer
IISB

Process Line

- Epitaxy
- Wet Chemistry
- Photo-lithography
- Ion Implantation
- Annealing
- Oxidation
- CVD / ALD
- Dry Etching
- Metallization
- PECVD

CMOS Si Technology

SiC: Process or Equipment Changes



Why SiC / Si?

- Silicon
  - + THE material for microelectronics
  - + very well established and advanced technology
  - + substrates of very high quality and diameter available
  - + (relatively) cheap

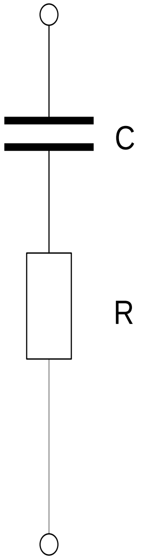
- Silicon carbide (4H-SiC)
  - + higher bandgap (~3.26 eV compared to 1.12 eV for Si)
    → much higher breakdown field strength
  - + higher thermal conductivity
  - + higher operating temperatures and harsh environments possible
  - – substrates still defect rich → epi layers required
  - – expensive

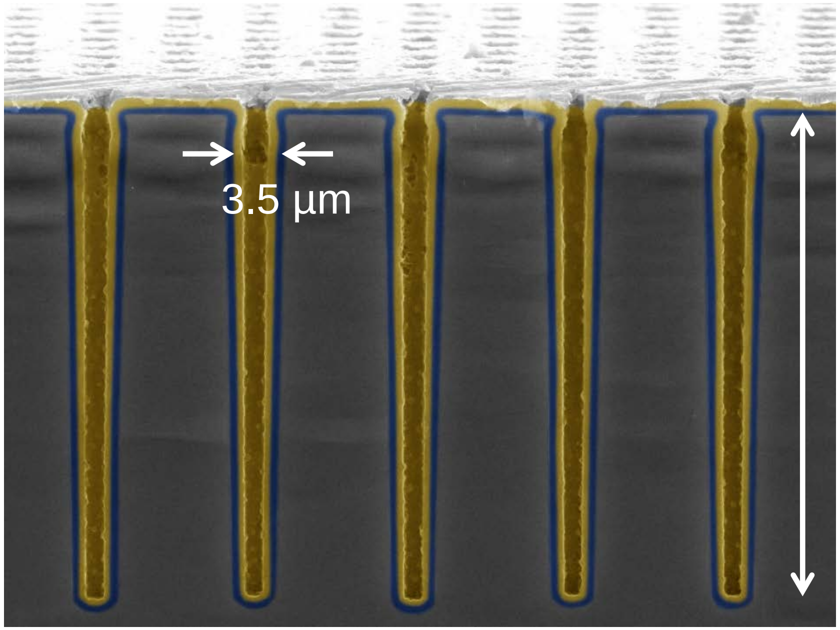
ideal for power devices

Examples – 200 V Si RC Snubber

- Cross-section and function
  - Limitation of voltage rise time
  - Neutralization of switching spikes
  - Enhanced reliability
  - Cancellation of electric arcs
  - Switch mode circuits using inductive loads (e.g. MOS, BJTs)

- **Highly increased surface area**
- **High aspect ratio structures**





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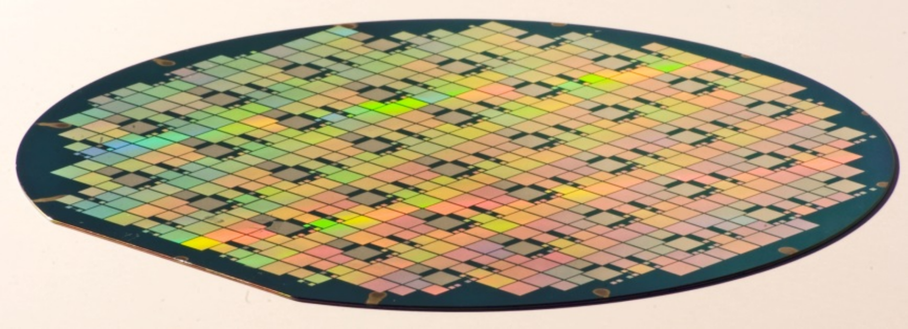
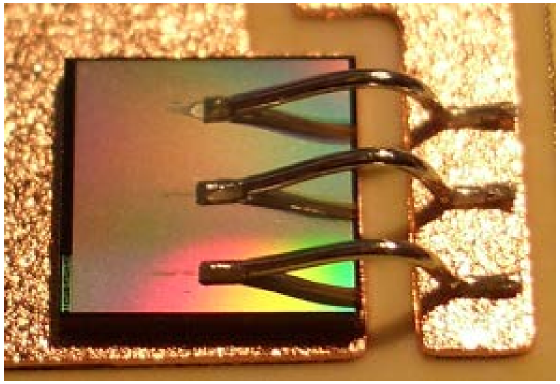


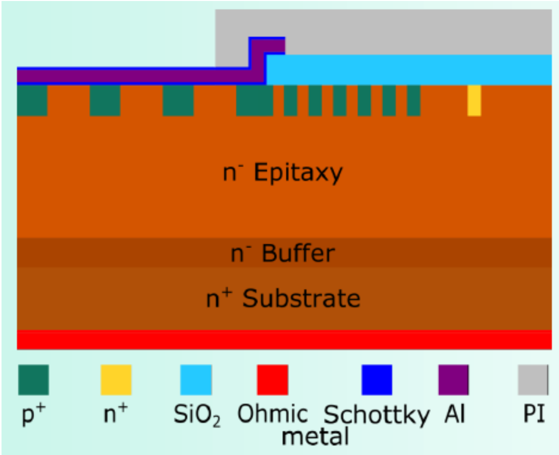
Silicon wafer with integrated RC snubbers



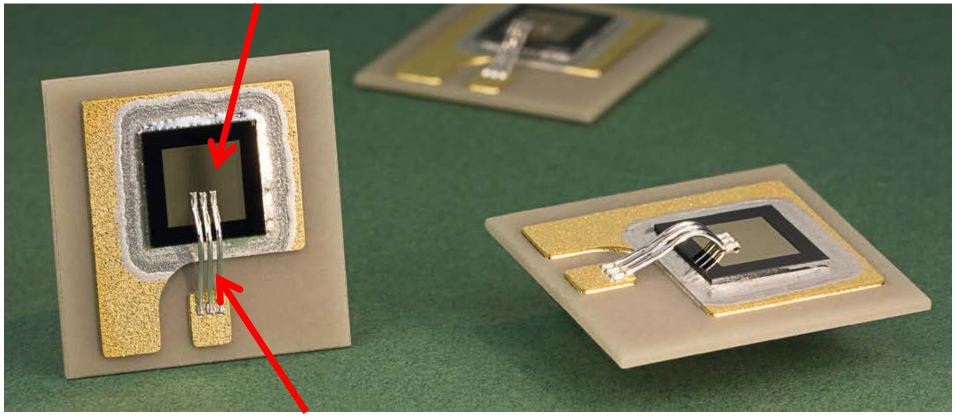
DCB mounted RC snubber

Examples – 3.3 kV SiC JBS Diode

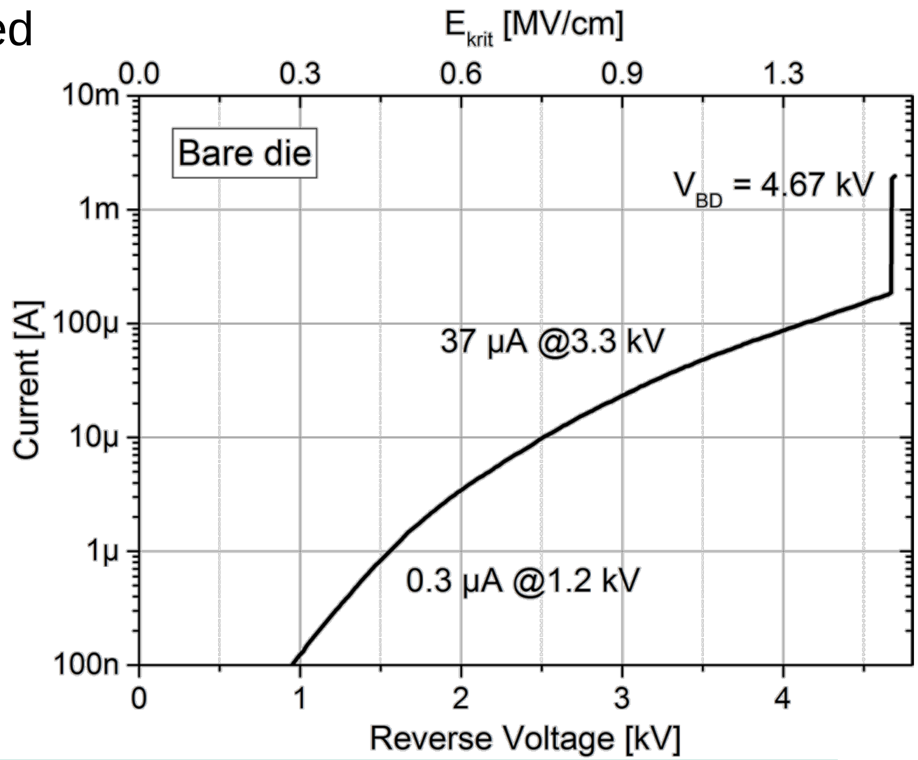
- JBS – Junction Barrier Schottky
  - Schottky → lower loss in forward direction
  - “pn junction” → lower loss in reverse direction
  - breakdown voltage of 4.6 kV achieved
  - proper simulation and design is key



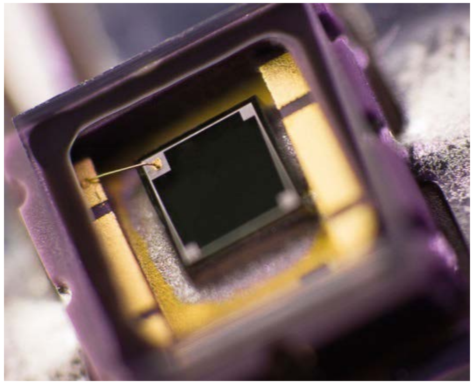
semiconductor device



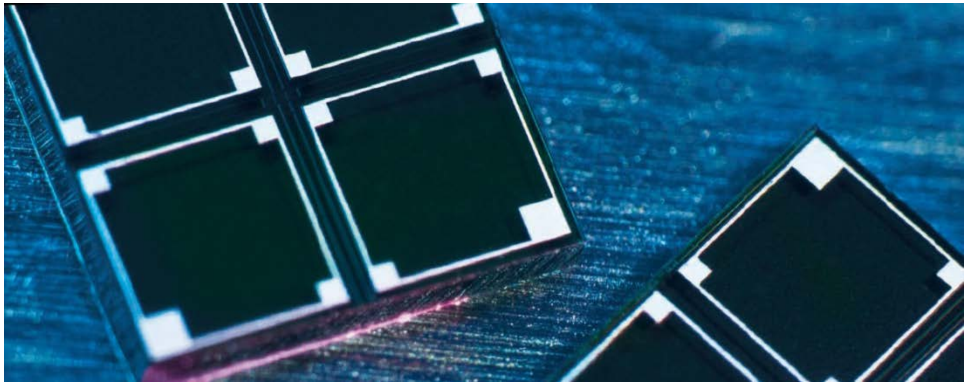
device integration and module fabrication

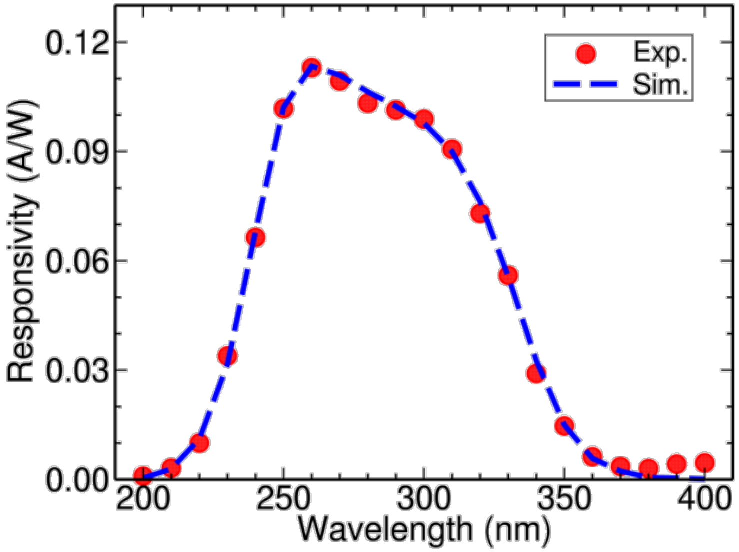


Examples – SiC UV sensor (photodiode)



- SiC photodiode vs. Si
  - visible-blind → no optical filters required
  - high sensitivity without cooling
  - less intrinsic noise





Numerical TCAD model

A. Burenkov, C. D. Matthus, T. Erlbacher, "Optimization of 4H-SiC UV Photodiode Performance Using Numerical Process and Device Simulation," *IEEE Sensors Journal* **16**, 4246-4252 (2016)

Outline

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- “Non conventional” technologies based / added capabilities
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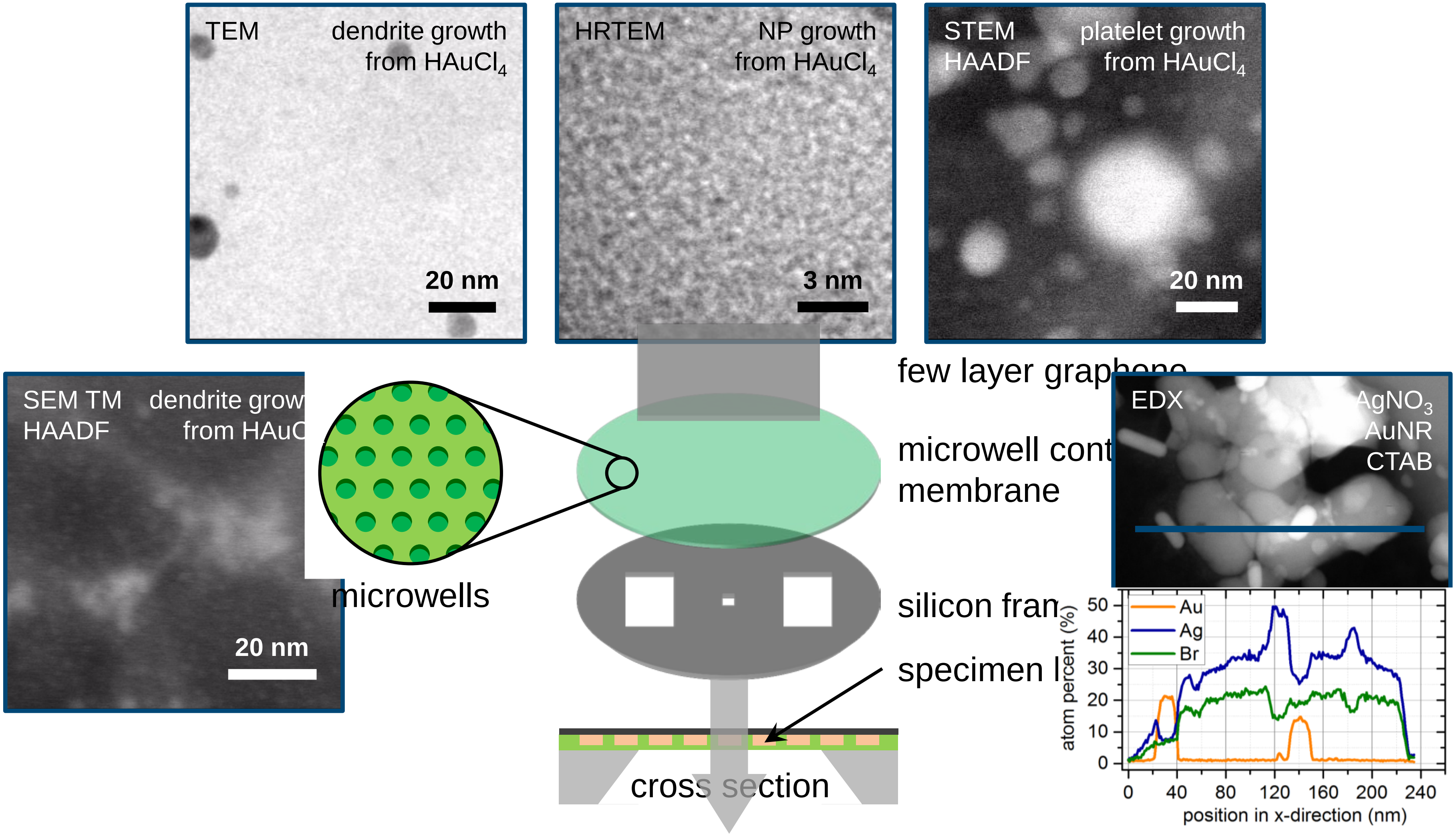
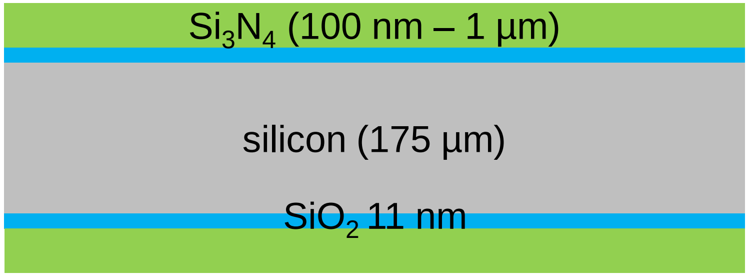
Examples – Liquid cell for TEM analyses (LCTEM)

- Graphene supported Microwell Liquid Cell for TEM
  - in situ investigations into dynamic processes under realistic conditions
  - performance of the electron microscope is often limited by the liquid cell
  - advanced liquid cell design for high performance EM techniques realized

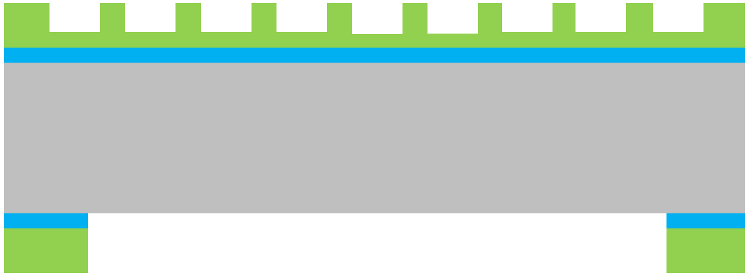
Examples – Graphene supported Microwell LCTEM



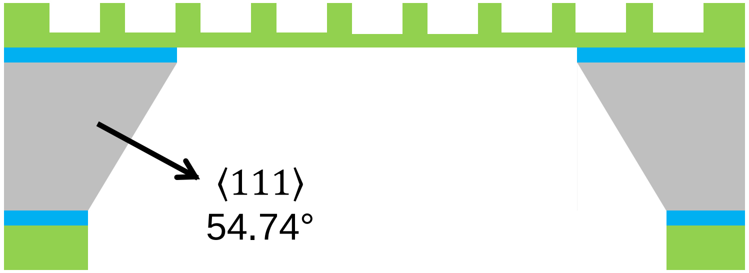
Examples – Graphene supported Microwell LCTEM



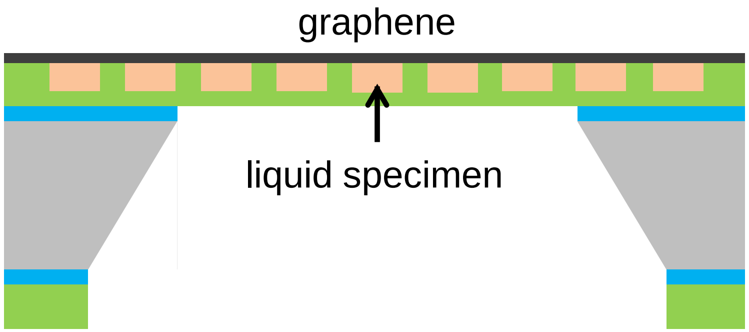
1.) thermal oxide + silicon nitride LPCVD



2.) front side structuring
+ SiN LPCVD 30 nm (membrane)
+ back side structuring



3.) bulk micromachining (KOH) of silicon



4.) filling + graphene transfer

⬜ silicon
🟩 silicon nitride
🟦 fluid specimen
🟦 silicon oxide
⬛ graphene

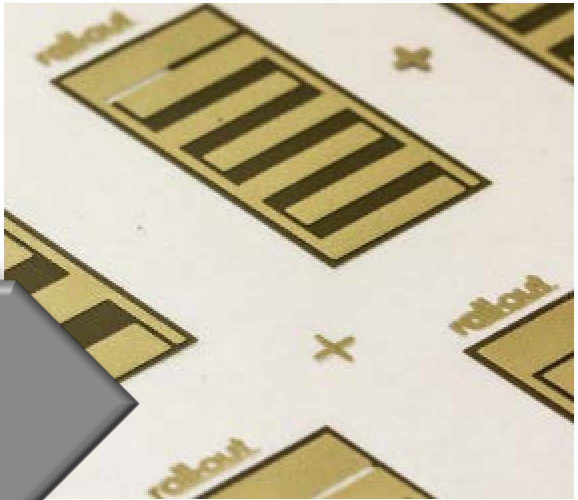
Fraunhofer IISB – Thin Film Systems

- Complementing traditional semiconductor technologies
- “More than Moore”
- Use of flexible substrates / foils
- Facile, cost-effective and scalable processing

Functional Materials

- Materials Synthesis
- Deposition/Coating
- Transformation

Sensors and Systems



- Materials Integration
- Devices
- Application

Examples – Printed Ion-Selective Sensors

- Measurement of NH_4^+
  - Content of NH_4^+ in sweat correlates with overload
  - Monitoring of training level / “fitness”

Test setup with sensor readout and wireless transmission via BluetoothTM low-energy (4.0)

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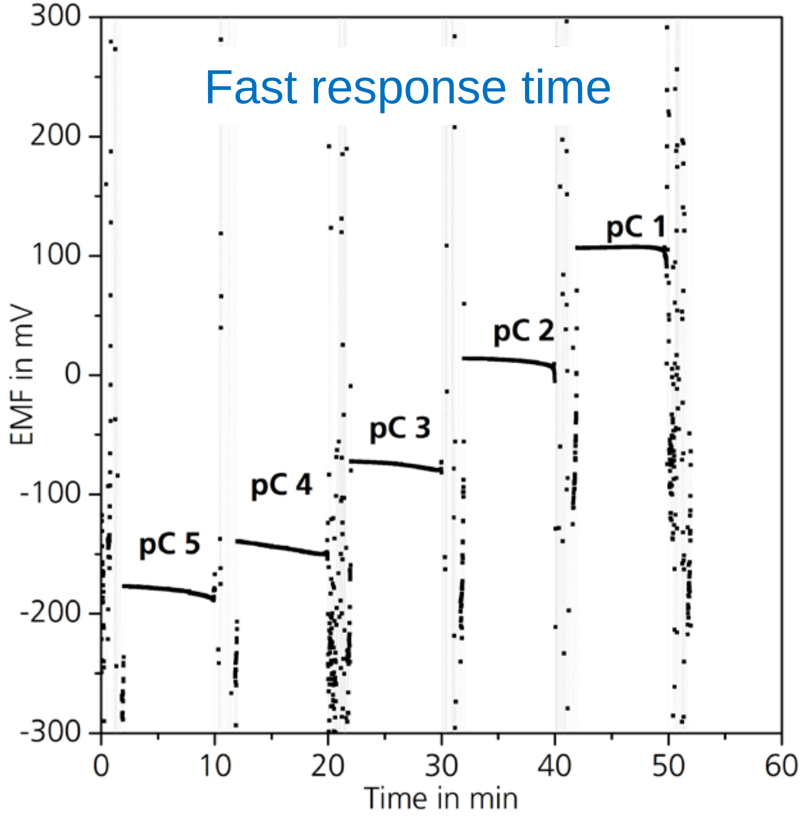
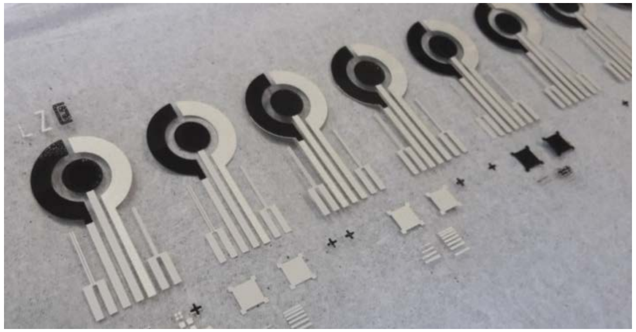


Test setup with sensor readout and wireless transmission via BluetoothTM low-energy (4.0)

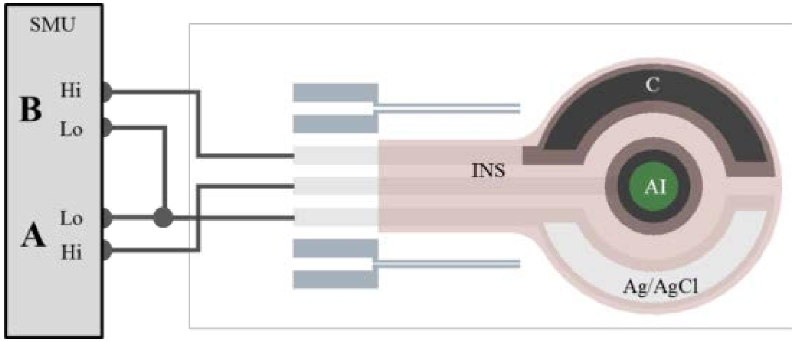
Examples – Printed Ion-Selective Sensors

- Printed electrodes:
  - Working electrode: Ag and C
  - Ion-selective membrane: Ionophores in carrier matrix
  - Reference electrode: Ag / AgCl



Printed sensor electrodes, Van der Pauw test structures

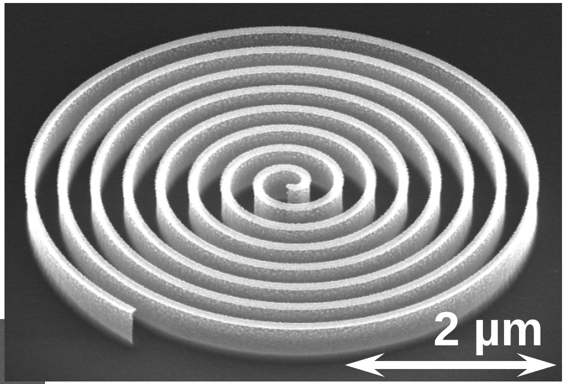
- Electromotive Force (EMF)
  - Potential difference depends on ion concentration
  - Potentiometric measurements

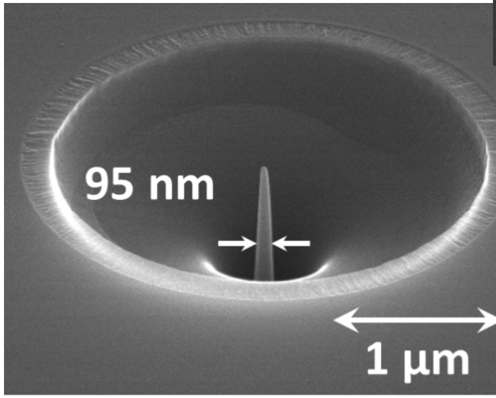


Circuit for potentiometric measurement

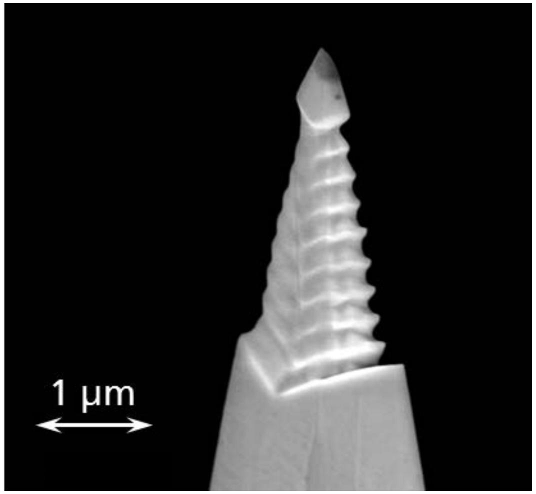
Nanopatterning capabilities

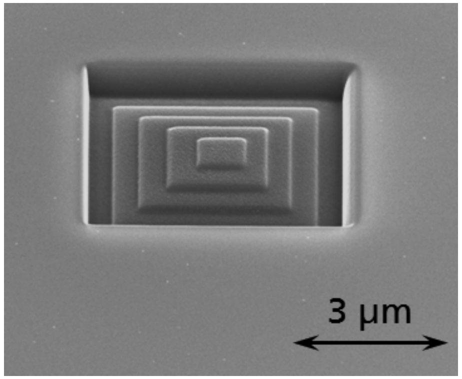
- Focused ion beam (FIB) 2D/3D structures
  - very flexible patterning down to sub 50 nm
  - only rather small area addressable

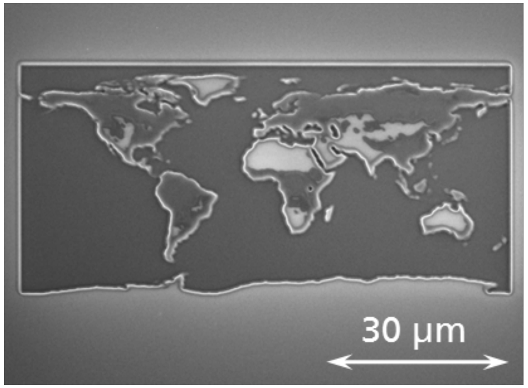




Gold







J.D. Jambreck et al., Proc. SPIE **8105**, 81050G (2011)

M. Rommel et al., Microelectron. Eng. **110**, 177 (2013)

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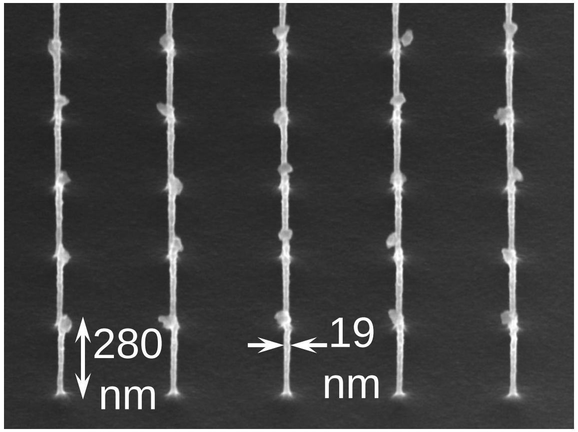

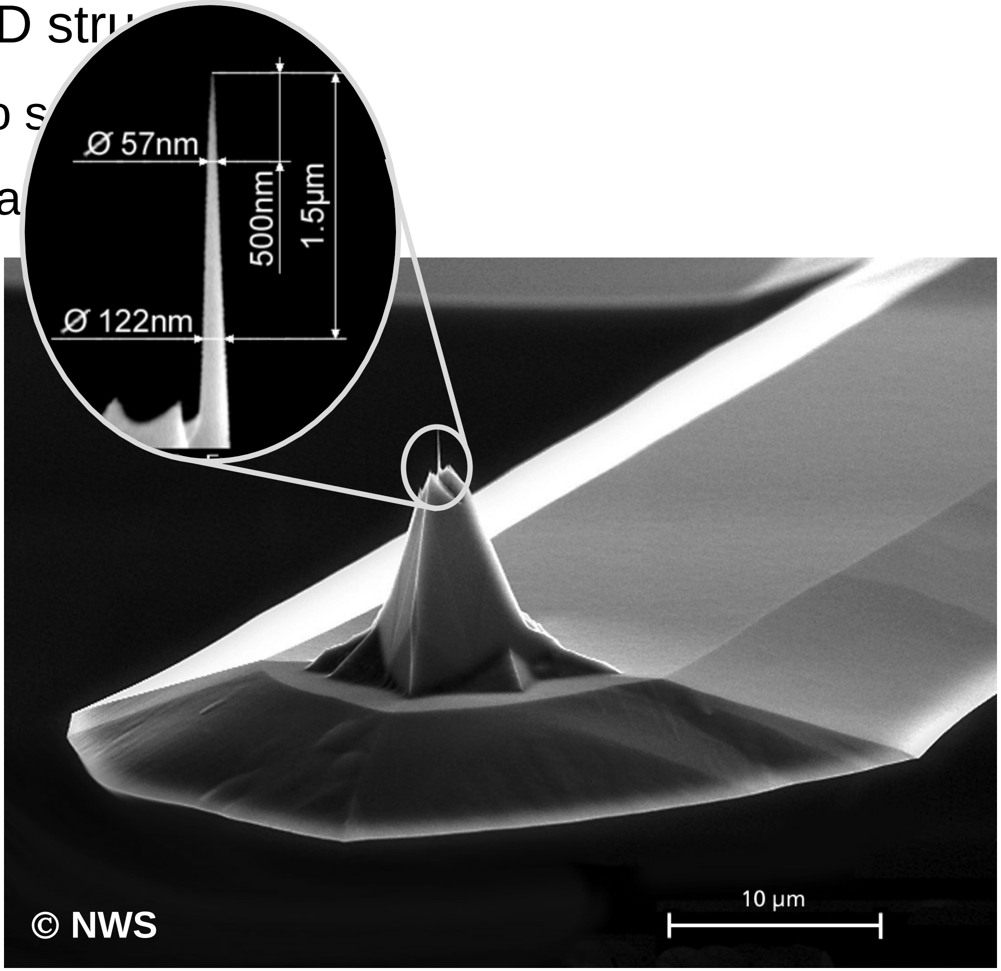

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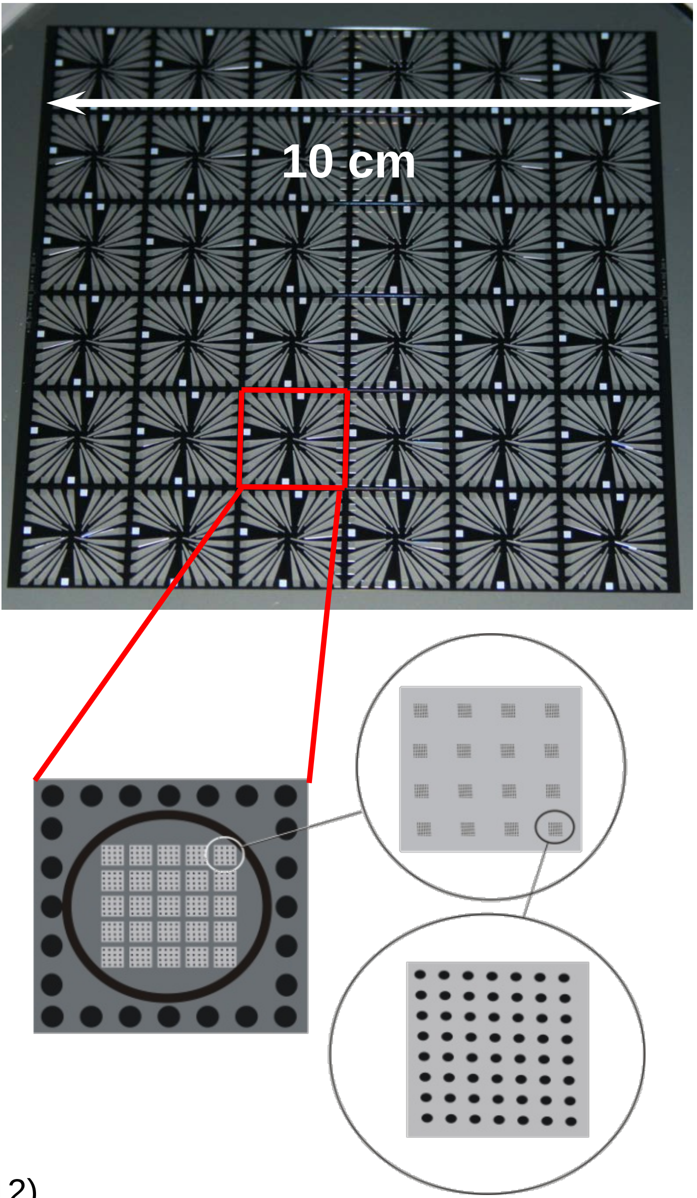
Nanopatterning capabilities

- FIB 2D/3D structures by ion milling
  - automation allows larger area patterning



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Fraunhofer IISB

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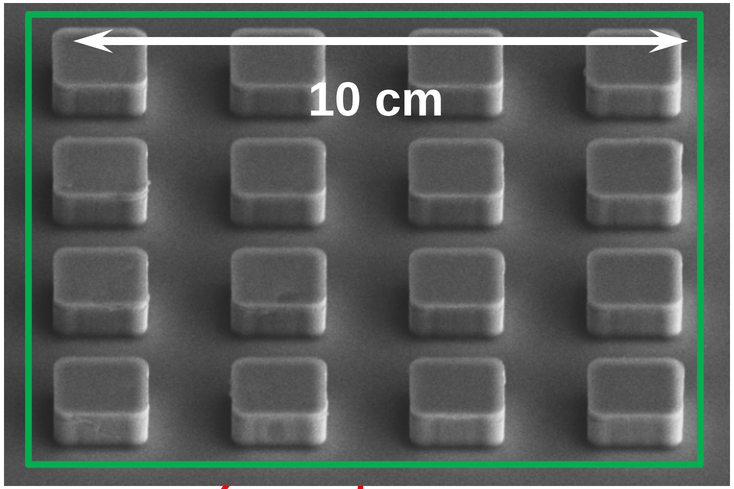

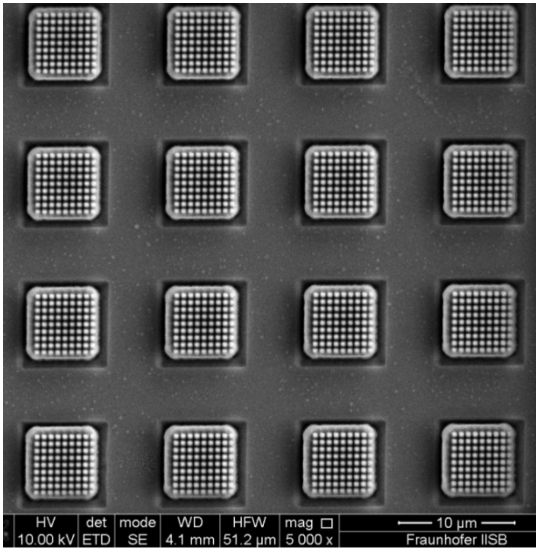

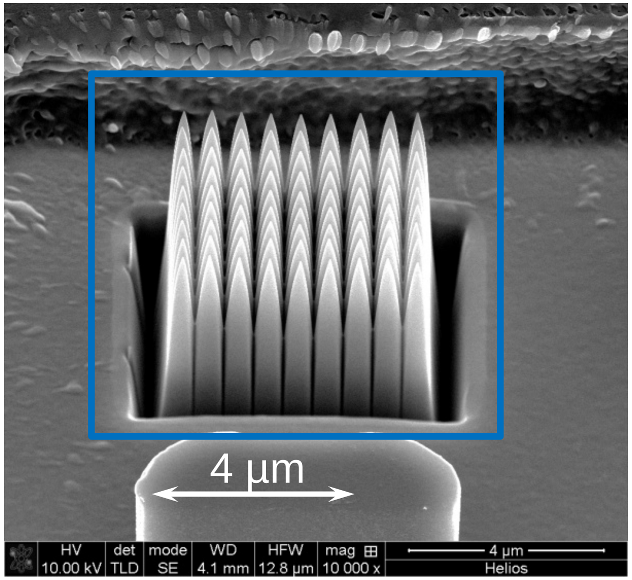

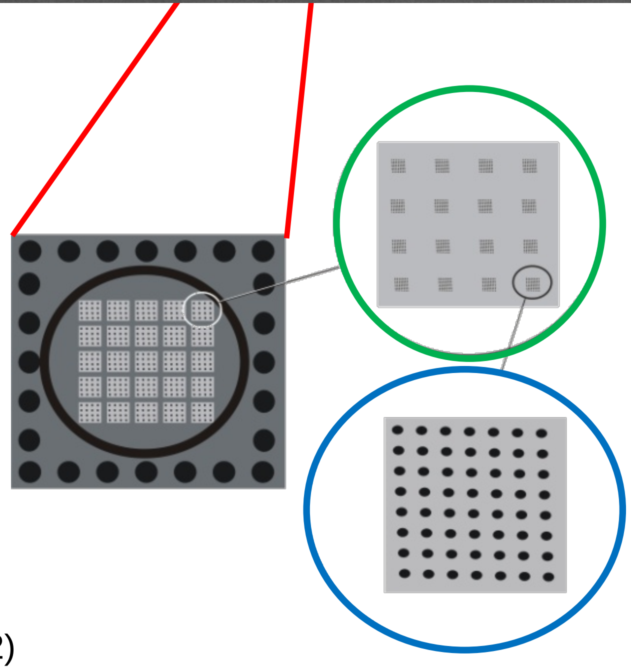

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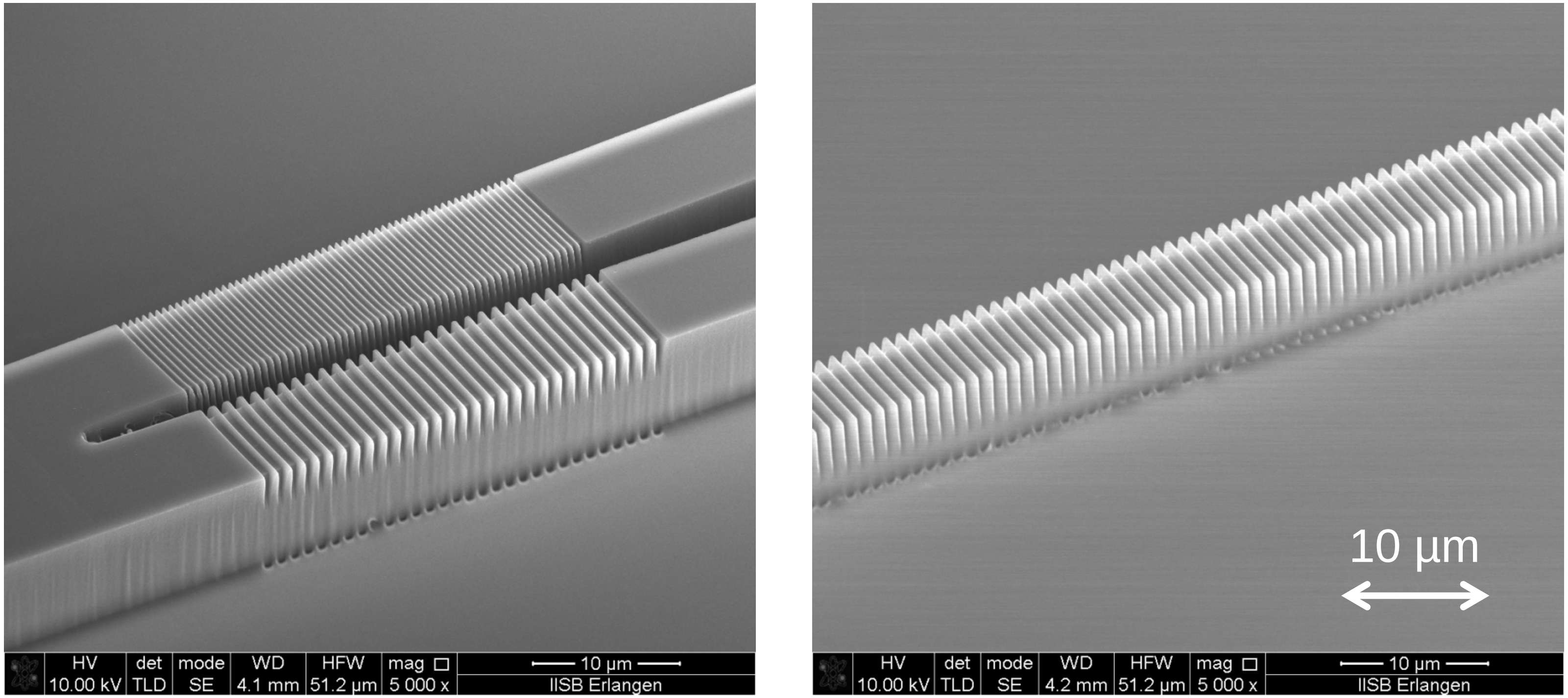
Nanopatterning capabilities

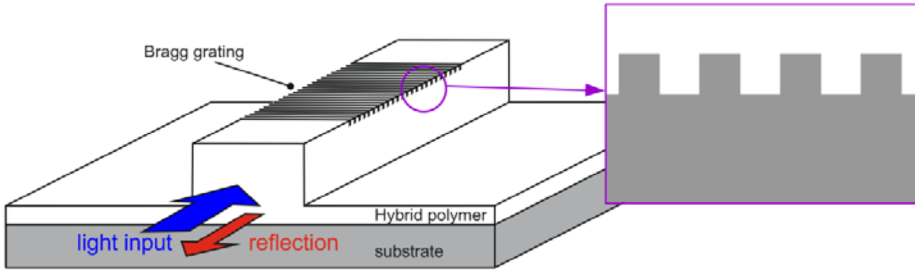
- Waveguides with integrated Bragg grating sensor (one process step!)



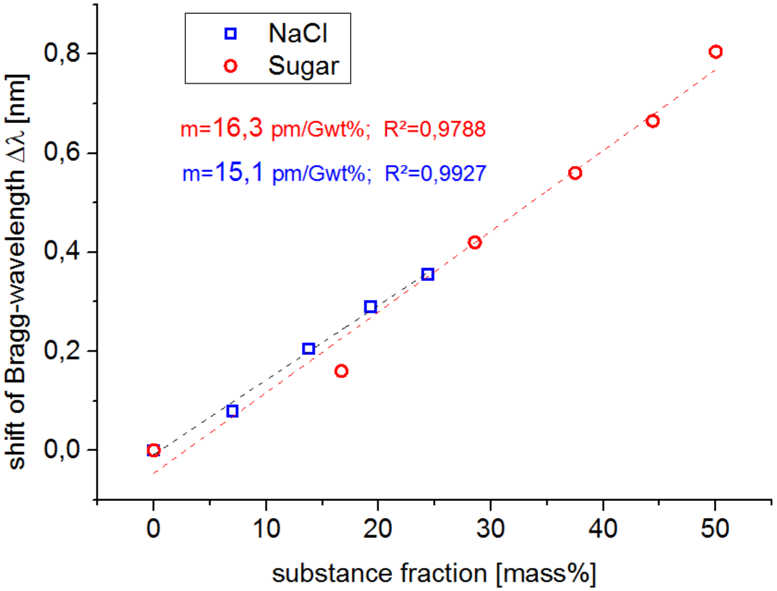
SEM images of Bragg gratings on planar waveguides imprinted into OrmoComp®; waveguide splitter with two different gratings (left) and excerpt from a 1mm long grating used for reflection measurements (right)

M. Förthner et al., 14th International Conference on Nanoimprint & Nanoprint Technology 2015, Napa, USA

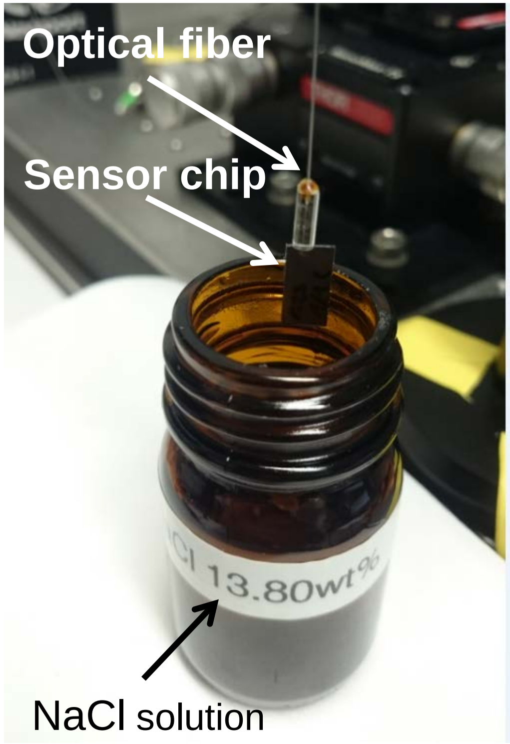
Nanopatterning capabilities



- Waveguides with integrated Bragg grating sensor
  - Temperature and refractive index sensing



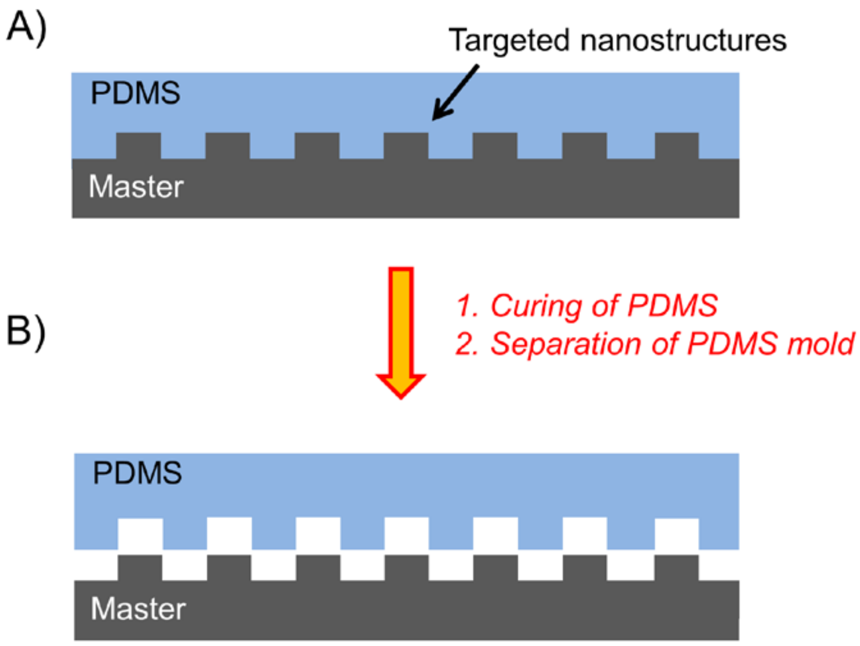
Wavelength shift of Bragg grating due to refractive index change of surrounding medium



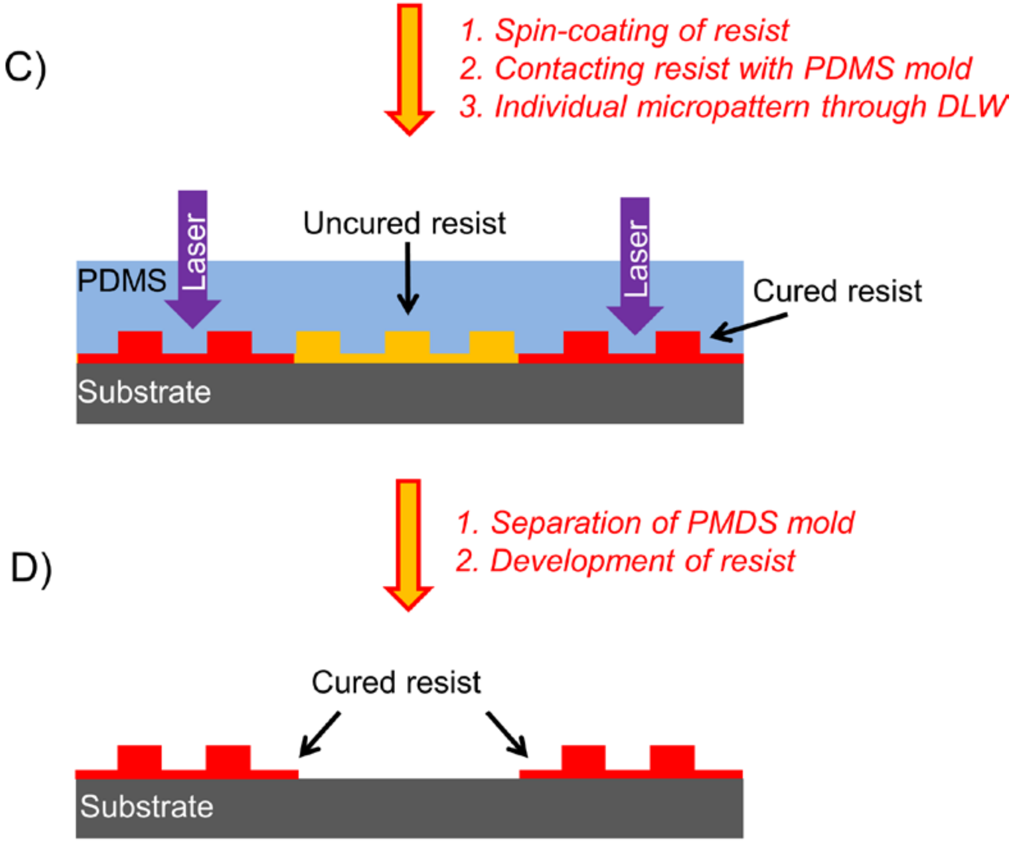
Nanopatterning capabilities

Direct laser writing through transparent mould

- Single step fabrication of hierarchical structures with micro and nano features



1. *Curing of PDMS*
2. *Separation of PDMS mold*



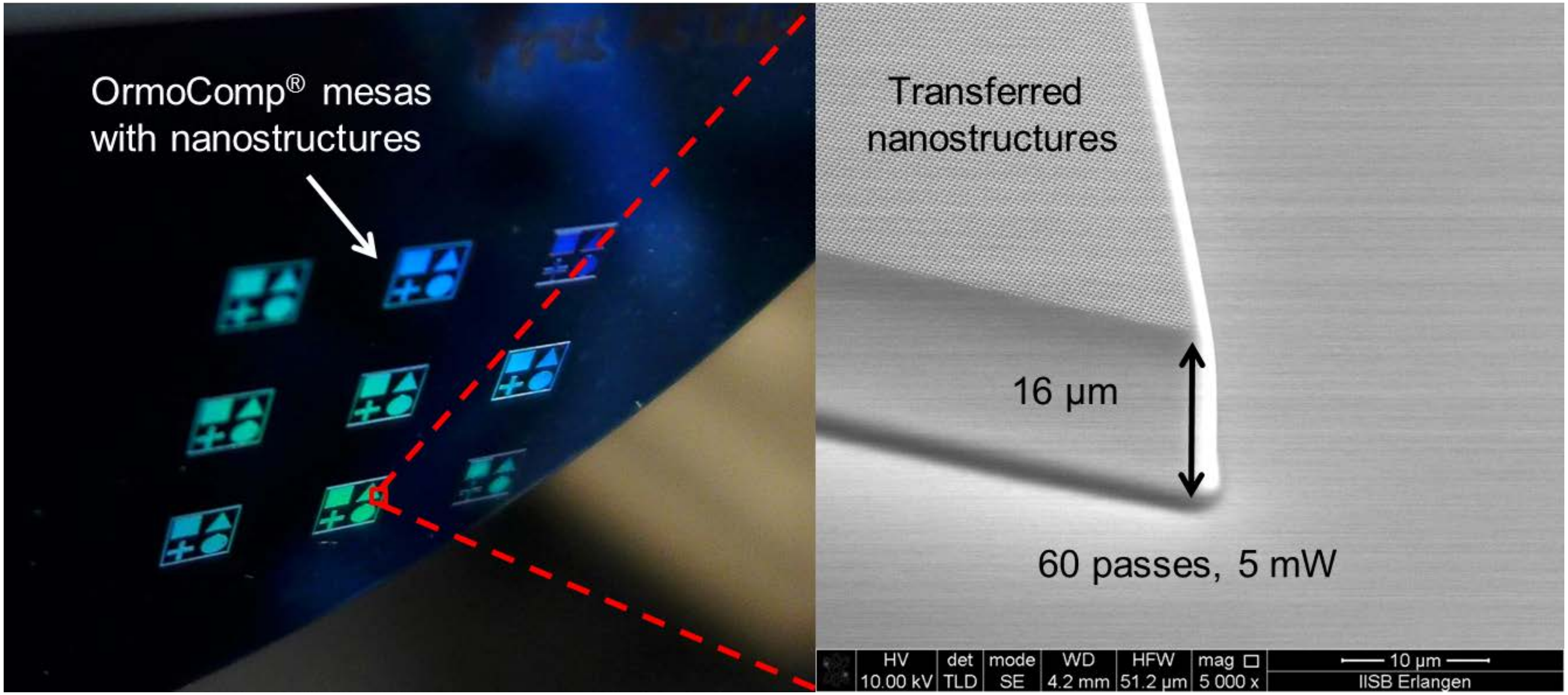
1. *Spin-coating of resist*
2. *Contacting resist with PDMS mold*
3. *Individual micropattern through DLW*

1. *Separation of PMDS mold*
2. *Development of resist*

Individual micropatterns with integrated nanostructures

Nanopatterning capabilities

- Single step hierarchical structures



M. Rumler et al., NNT 2015

Nanopatterning capabilities

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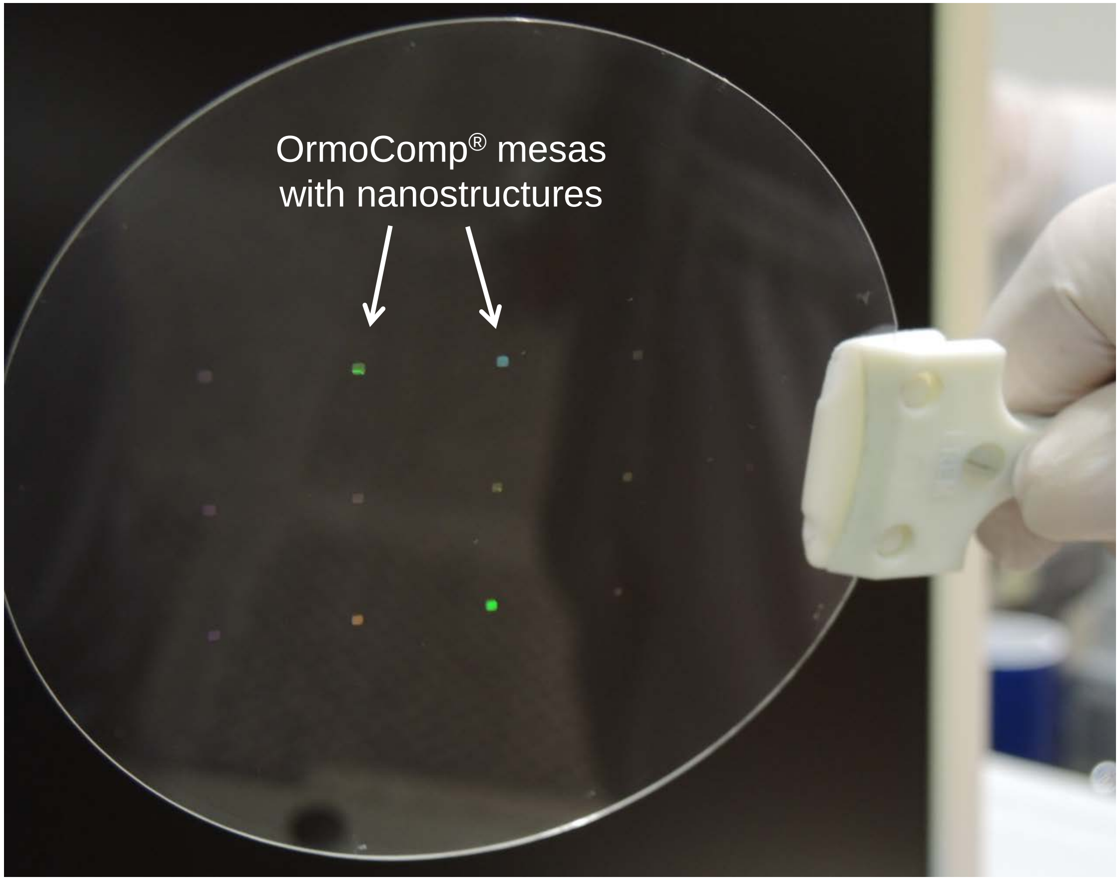
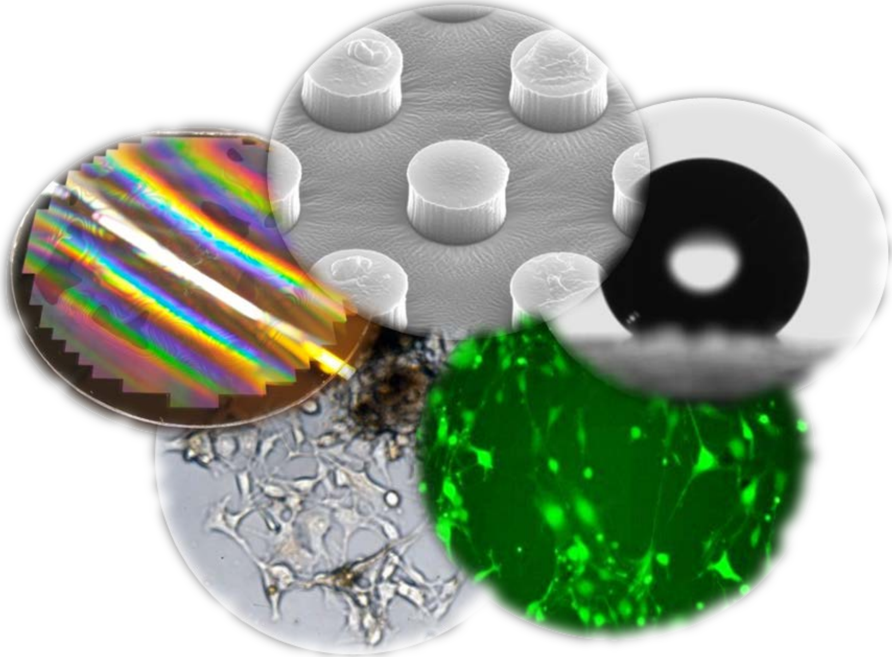


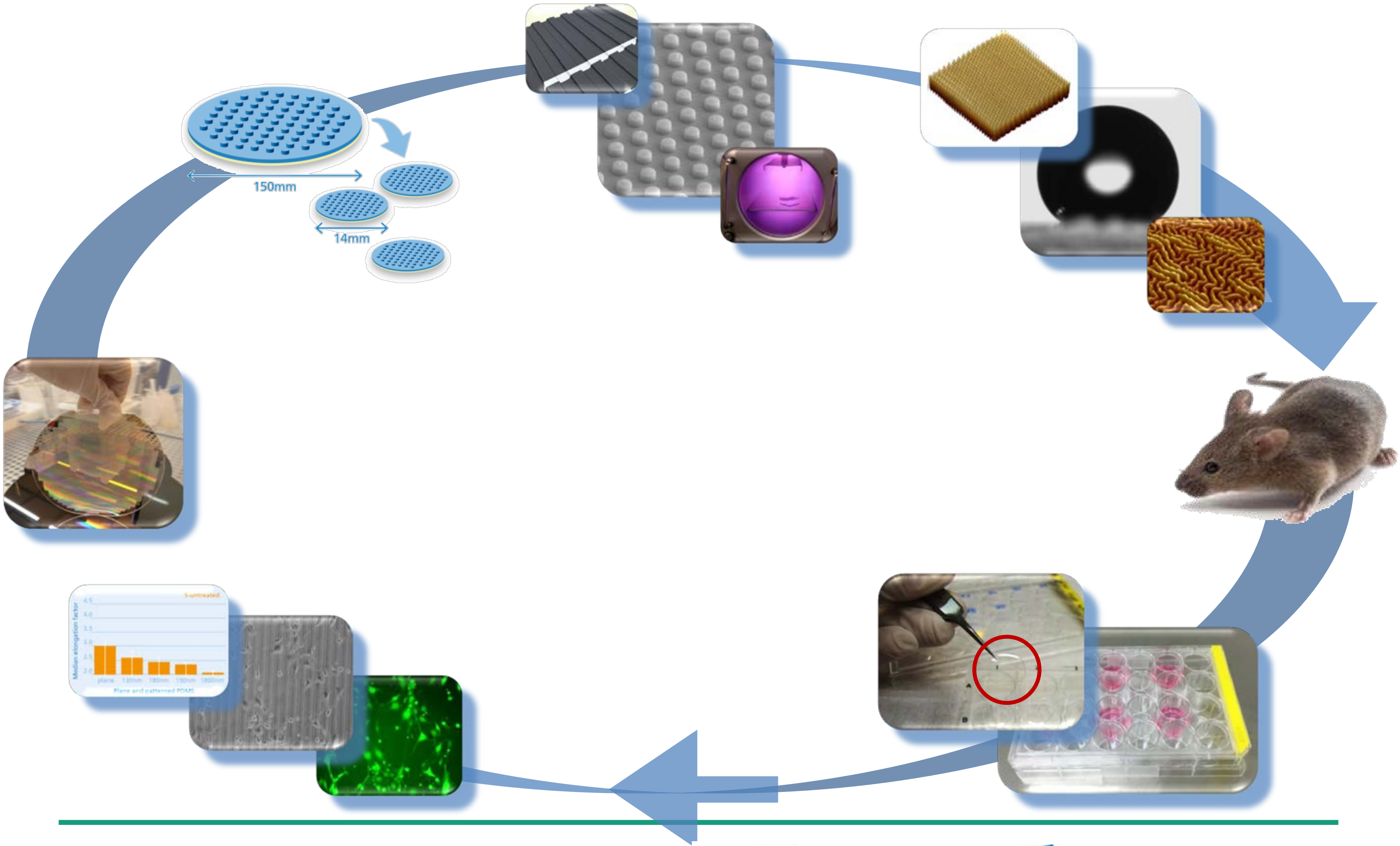
M. Rumler et al., NNT 2015

Nanopatterning capabilities

- **Micro- and Nanopatterned PDMS Thin Films for Bio Templates**
  - PDMS: polydimethylsiloxane
  - Hydrophobic Si-based polymer
  - Biocompatibility, flexibility, optical transparency
  - O_2- und CO_2-permeability
  - Ease of molding into (sub) micrometer features
  - Wettability tunable by proper plasma treatment and storage environment



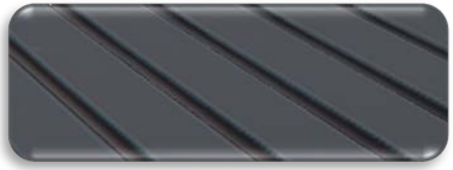
Manufacturing and Characterization of PDMS Thin Films



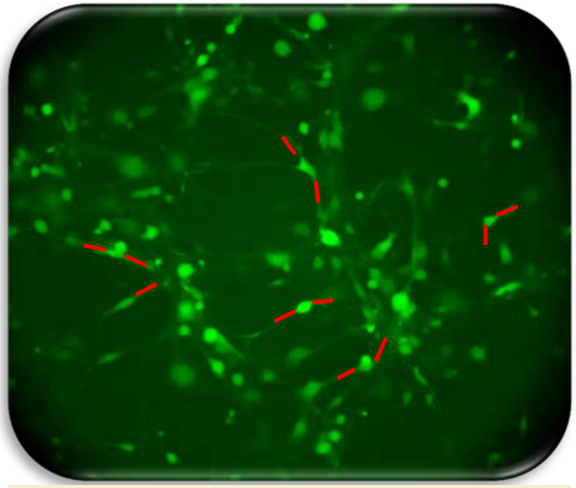
Psychiatric and psychotherapeutic
Clinic, Laboratory for Neurophotonics

Universitätsklinikum
Erlangen

Nanopatterning capabilities – PDMS Templates

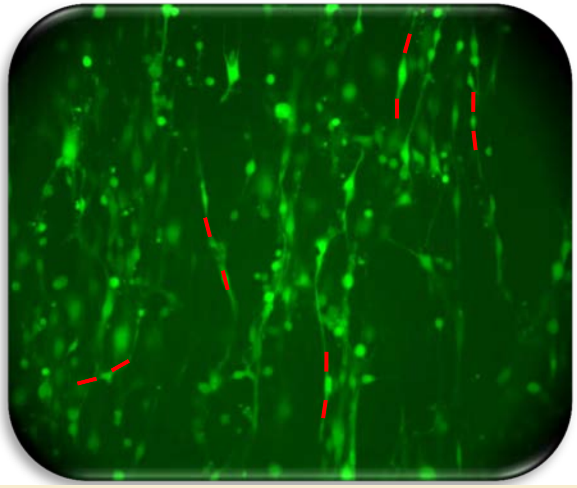


- Influence of groove depth on DRG* neurite growth



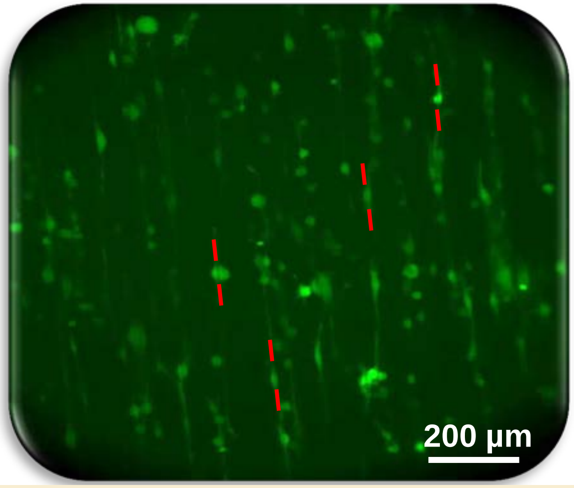
Plane X-PDMS

- Random DRG neuron branching
- No neurites orientation



Patterned X-PDMS, 3µm depth

- Less DRG neuron branching
- Neurites grow along the grooves, but with connection to other cells



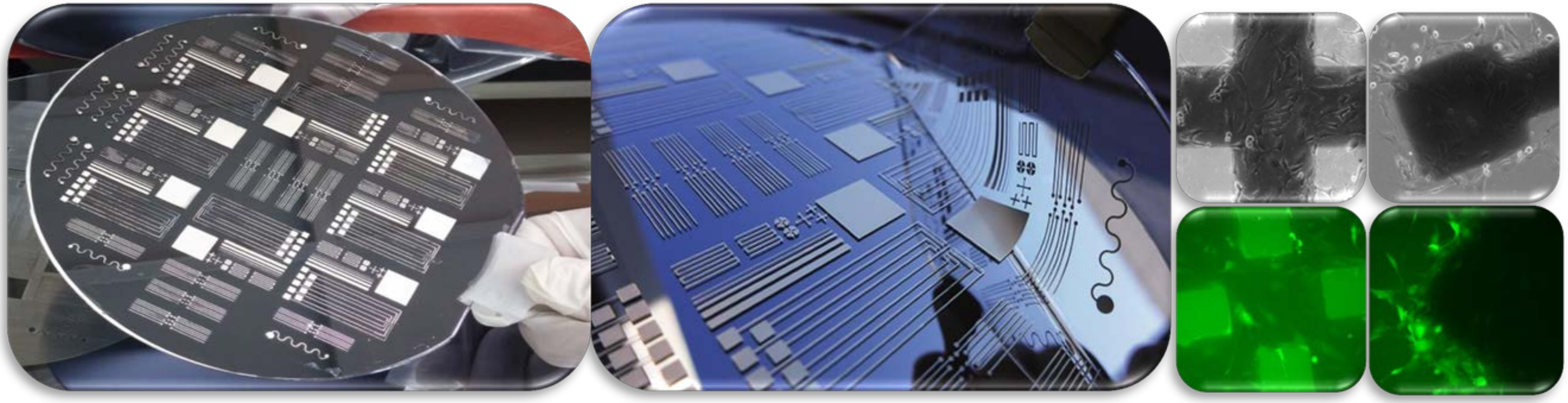
Patterned X-PDMS, 10µm depth

- Neurites grow exactly along the grooves
  - → Neurite length increases
  - → No connection to neighbour neurite
  - → Cell count decreases

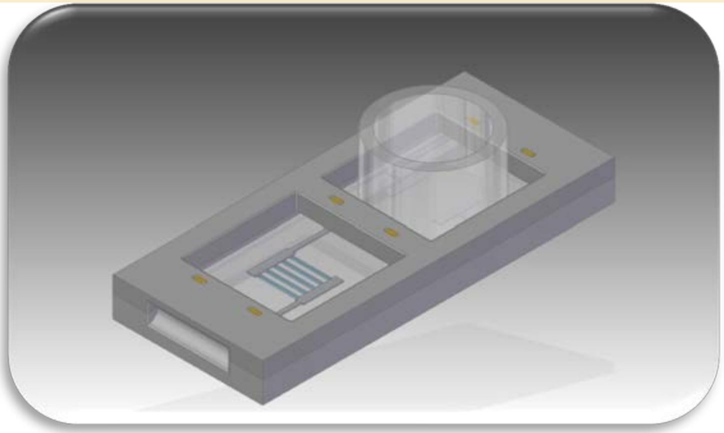
* Mouse Embryonic Dorsal Root Ganglion

Nanopatterning capabilities – PDMS Templates

- PDMS with Ti electrodes for cell adhesion and stimulation investigations



Flexible Ti electrode test patterns on X-PDMS substrate for stimulation of DRG neurons



Cell culture chamber with Ti electrodes on X-PDMS

Thank you for your attention!