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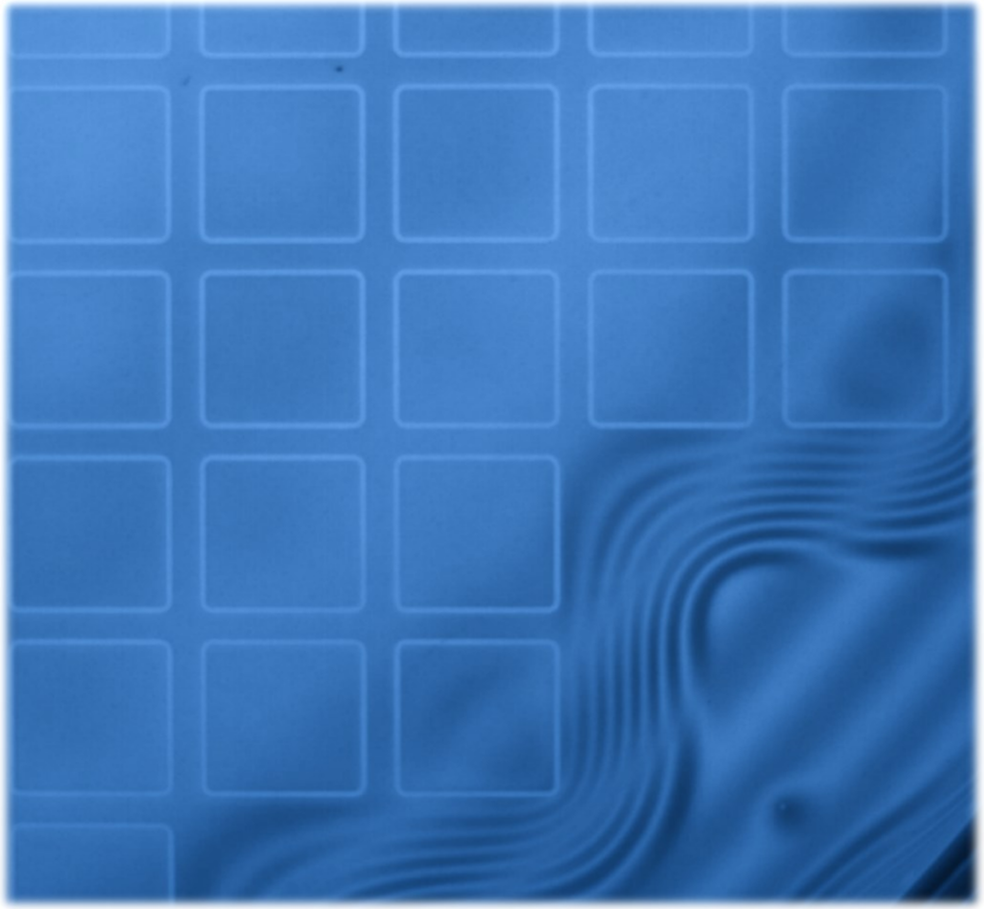
Parylene for Health Care: From Biocompatible Encapsulation and Bonding to Ultra-thin Wearables

Franz Selbmann, <u>Frank Roscher</u>, Martin Kühn, Florian Glauche, Maik Wiemer

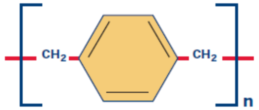
Outline

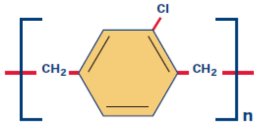
- Introduction
- Parylene for biocompatible encapsulation
- Biocompatible Parylene adhesive bonding
- Parylene based ultra-thin flexible electronics for wearables
- Conclusion
- Outlook

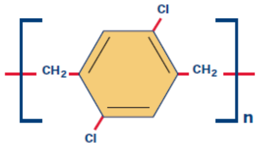


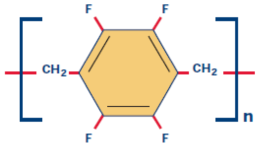
Introduction - Parylene

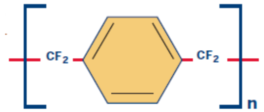
Parylene layers are thin, pinhole and defect free polymer coatings with a high conformity for a variety of different applications.


Parylene N


Parylene C


Parylene D

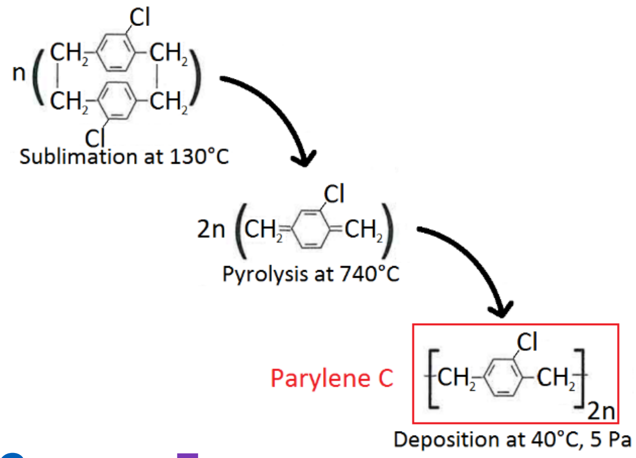

Parylene F


Parylene AF

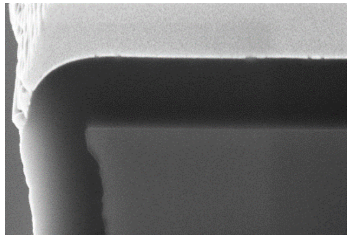
Properties:

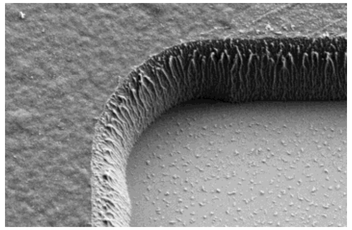
- Biocompatible / biostable (ISO 10993)
- Dielectric
- Chemically inert
- Hydrophobic
- Barrier against moisture and chemicals
- Optically transparent
- Thermally stable
- Low friction coefficient

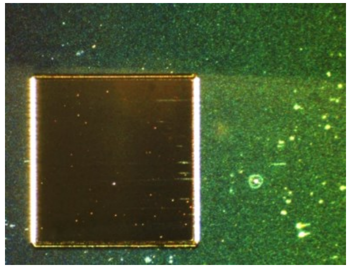
- Gas phase deposition (CVD)

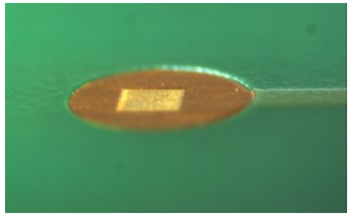


	N	C	F
Melting point [°C]	410	290	> 460
Young‘s modulus [MPa]	2400	3200	2500
Tensile strength [MPa]	45	69	52
Strain to rupture [%]	250	200	200
Refractive index	1.661	1.639	1.559


3D conformity of Parylene


Patterned Parylene via lithography and O_2-plasma etching




Patterned Parylene via laser

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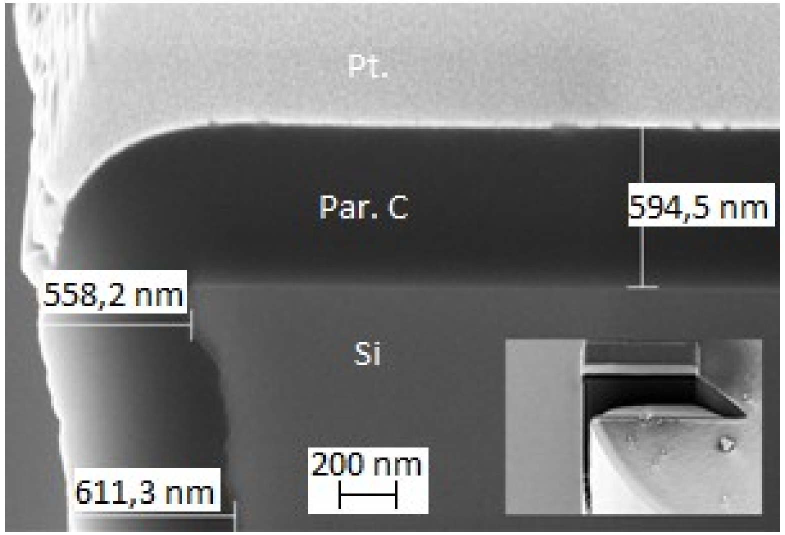
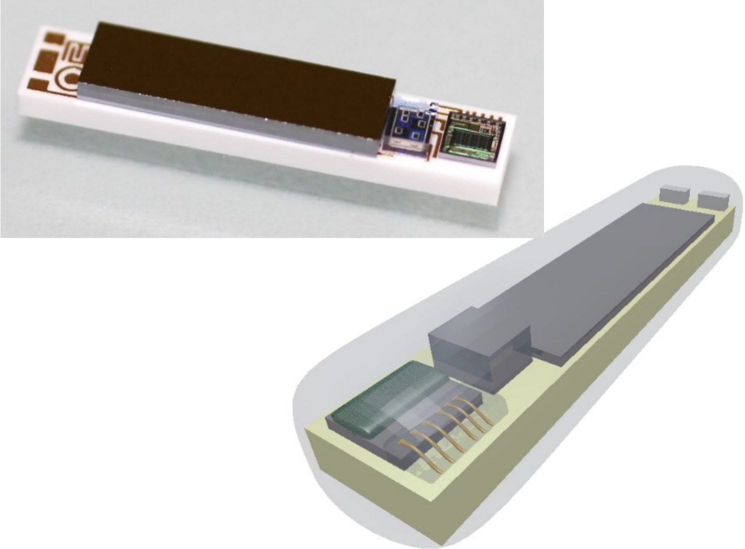
Parylene for biocompatible encapsulation

- Biocompatible encapsulation of medical implants, electronics, optics, PCB for protection against body fluids, environmental impacts and vice versa release of toxic components into the body
- Highly conformal gas phase deposition
- Dielectric strength 7,16 MV/cm → ca. 2500 V at 5 µm layer thickness

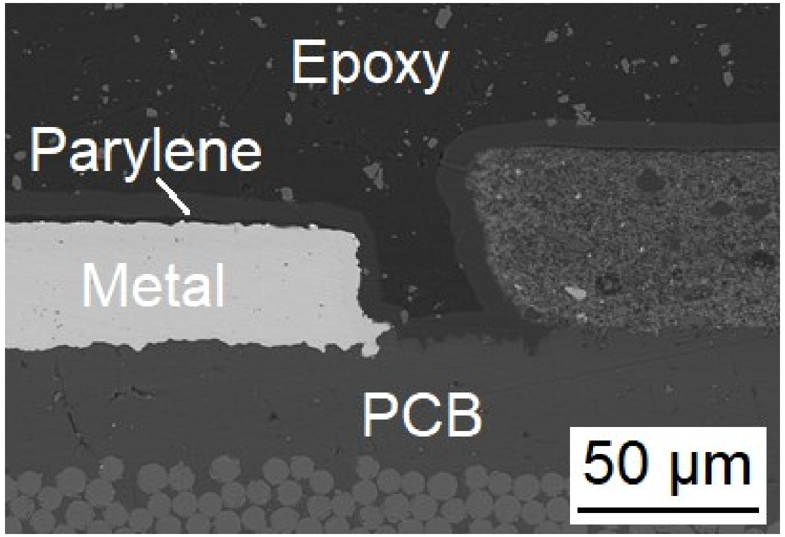


Cross-sectional SEM image of Parylene coated silicon pillar



Parylene encapsulated smart medical implant

PCB with and without 5 µm Parylene C coating soaking for 1 week in 5 m% salt solution

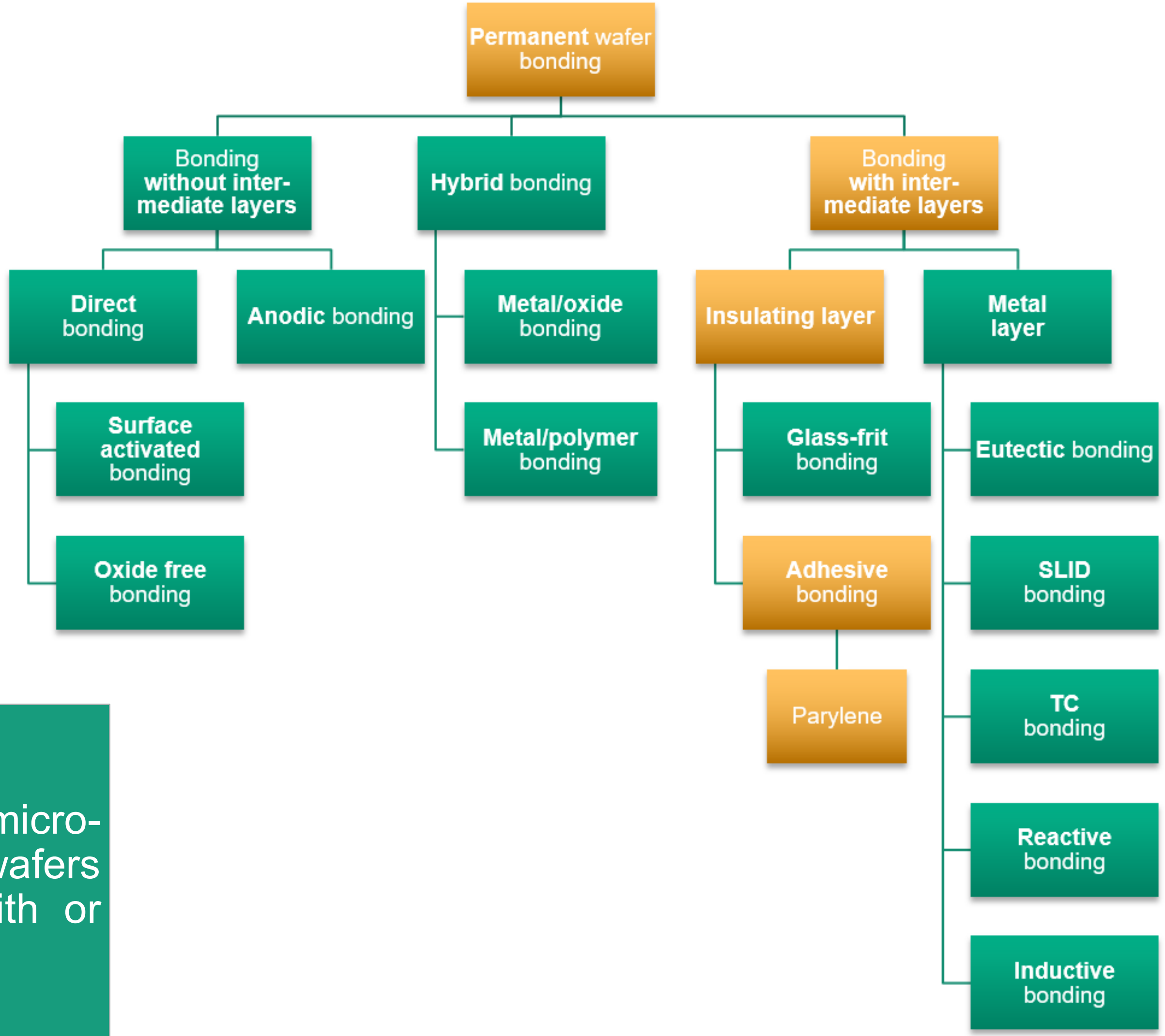


Cross-sectional SEM image of Parylene coated PCB

Biocompatible Parylene adhesive bonding

General requirements

- Low temperatures (< 400 °C)
- Material compatibility
- Mechanical stability
- Most cases: hermetic sealing
- Minimized bonding frame width



Permanent wafer and chip bonding

Wafer and chip bonding techniques are used in micro-electronics and micro-mechanics to join thin, polished wafers or chips made of different materials together – with or without additional intermediate layers.

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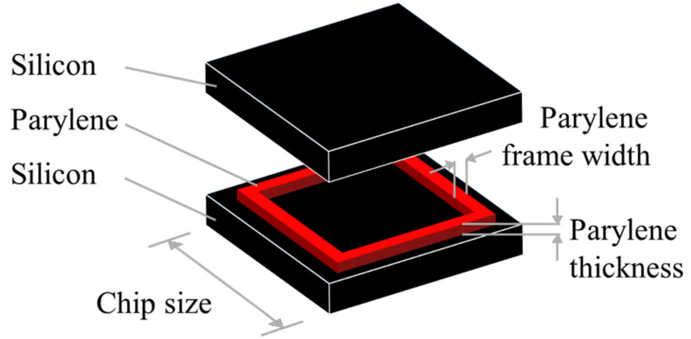
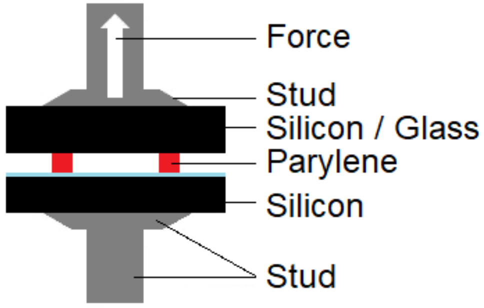
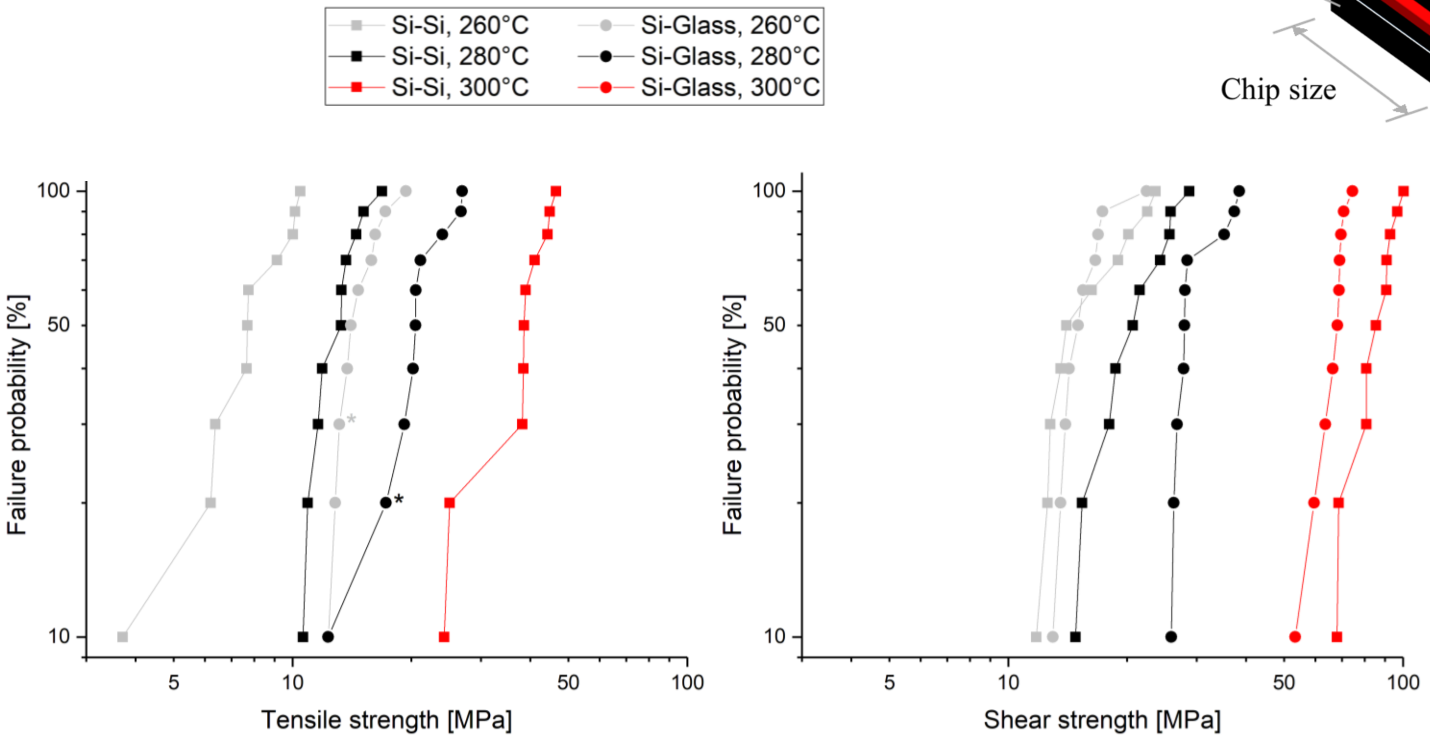
Parylene C wafer bonding





Tensile test



Bonding parameters:

- 2 bar contact pressure
- 10 min bonding time
- 0.5 … 10 µm Parylene thickness
- 50 µm Parylene frame width to unpatterned Parylene

Results:

- Max. average tensile strength: 38 MPa
- Max. average shear strength: 85 MPa

→ Strong dependency of the mechanical strength on the bonding temperature, but only minor dependency on bonding time and contact pressure as well as Parylene frame width and Parylene thickness

*glue failure

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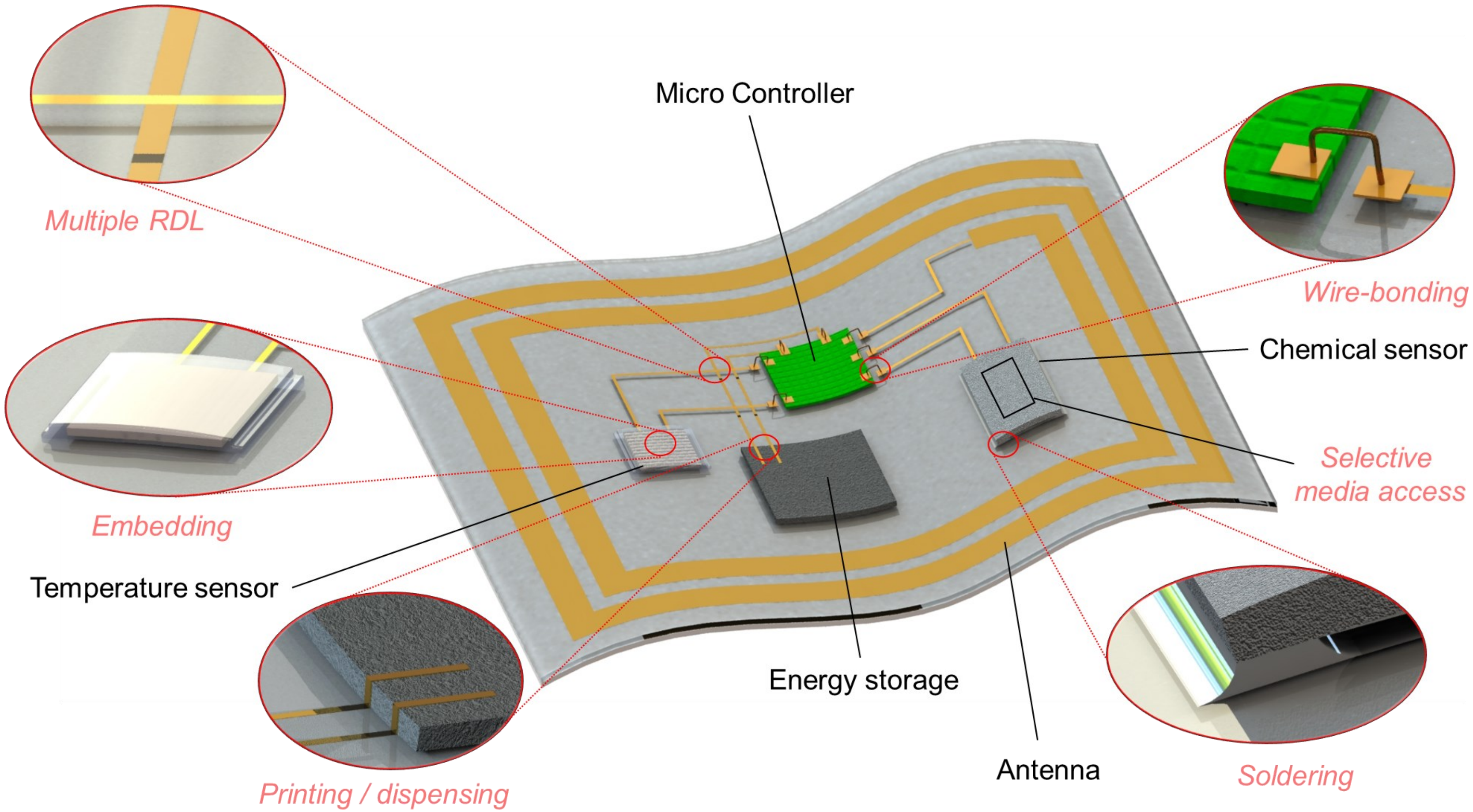
Biocompatible Parylene adhesive bonding
Conclusion

- Parylene C adhesive bonding successfully demonstrated on 150 mm and 200 mm wafers for different material combinations → max. average tensile / shear strength: 38 MPa / 85 MPa
- Investigation of the influence of different bonding parameters
  - Bonding temperature → highest influence → different mechanical stability
  - Bonding time, Parylene thickness, Parylene frame width → minor influence
- Bonding conditions do not change Parylene C chemically but increase its crystallinity
- Process variations:
  - Bonding at increased pressure leads to comparable bonding strengths as for vacuum
  - Bonding with Parylene N and Parylene F at 420 °C and 430 °C / 440 °C, respectively, lead to comparable comparable bonding strengths as for Parylene C → realization of triple stacks
- Parylene C chip bonding sucessfully demonstrated with comparable bonding strengths as for Parylene C wafer bonding

Parylene based ultra-thin flexible electronics for wearables

Motivation



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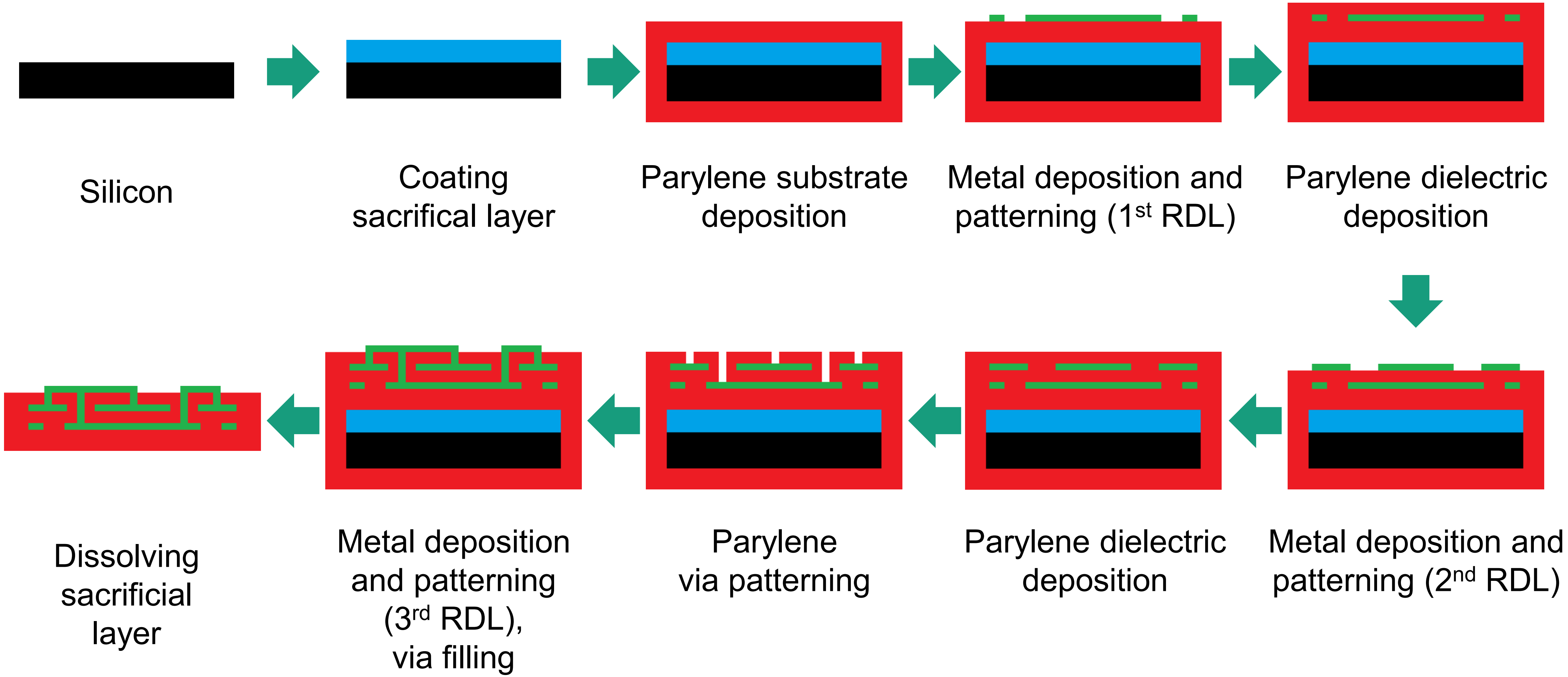
Parylene based ultra-thin flexible electronics for wearables

Process sequence



Parylene based ultra-thin flexible electronics for wearables

Metallization

Parylene can be metallized with different metals and technologies:

- PVD and ECD:

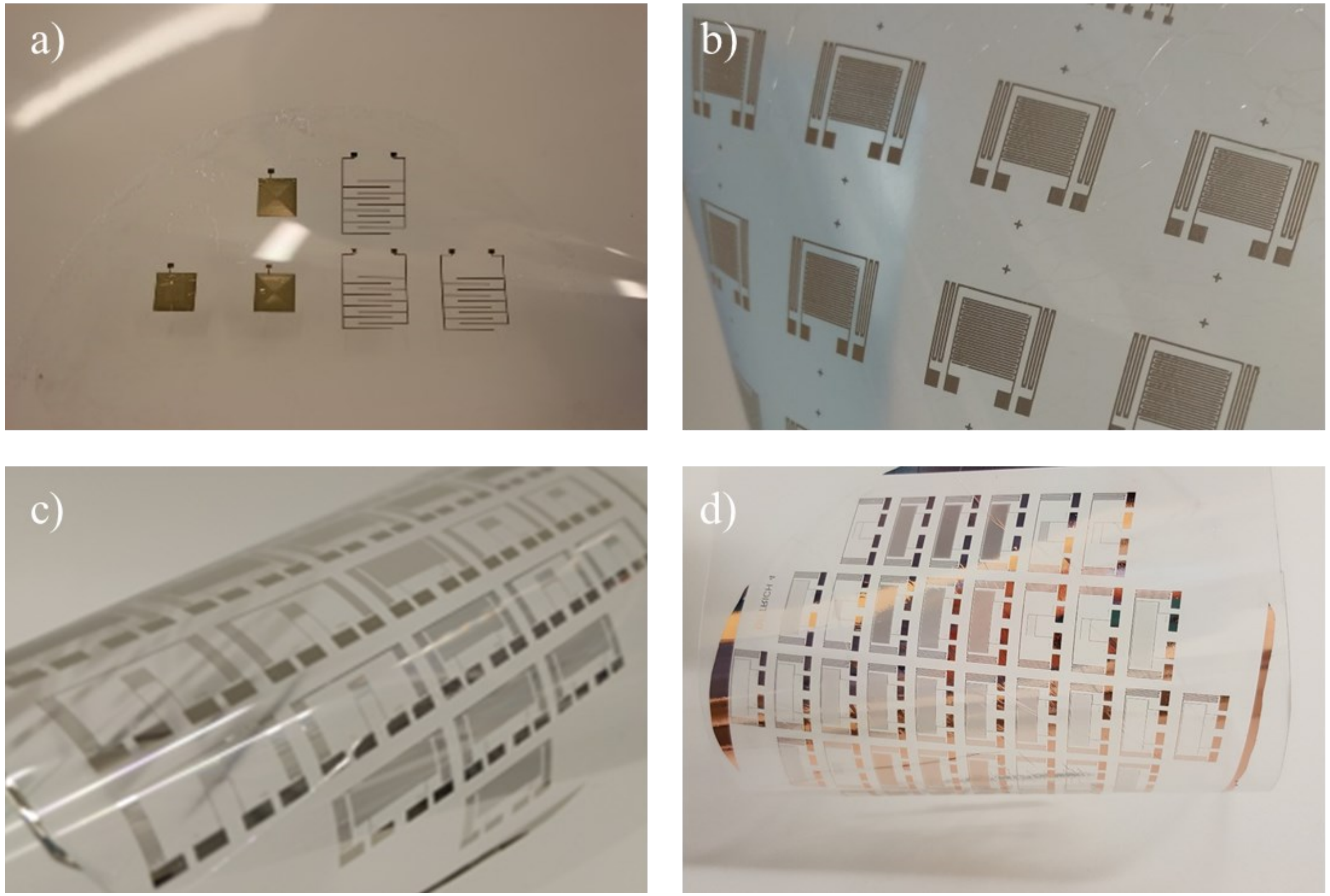
  Au, Al, Cu, Ti, Cr, Pt, Pd

- Aerosol-Jet printing:

  Ag, Au, …

- Screen printing

  Ag, Ag/AgCl



Parylene metallized by Aerosol-Jet printed silver (a), screen printed silver (b), sputtered and wet-chemically etched Alumunum (c) and copper (d), respectively.

Parylene based ultra-thin flexible electronics for wearables

Via Formation

- Realization of ultra-thin flexible Parylene PCBs was successfully demonstrated for boards with two and three RDLs based on gold
- Parylene vias show a „natural“ slope enabling contact two RDLs by sputtering
- Parylene via filling demonstrated by electro-chemical deposition of Aluminum and Copper.

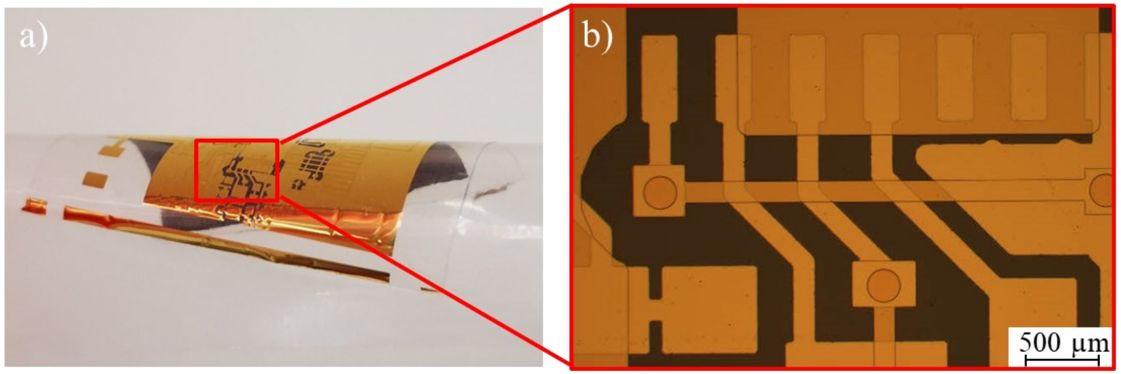
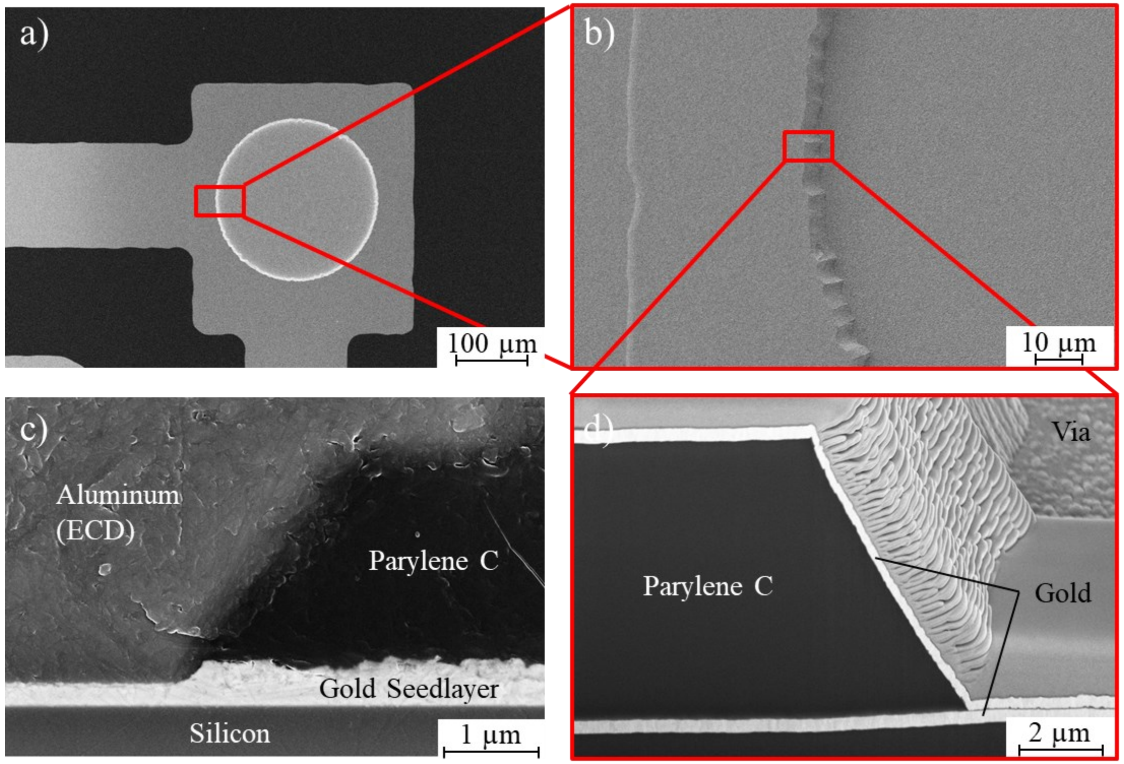


Photo and light microscopic image of the fabricated ultra-thin flexible Parylene PCB with two RDLs for stimulation of wound healing.

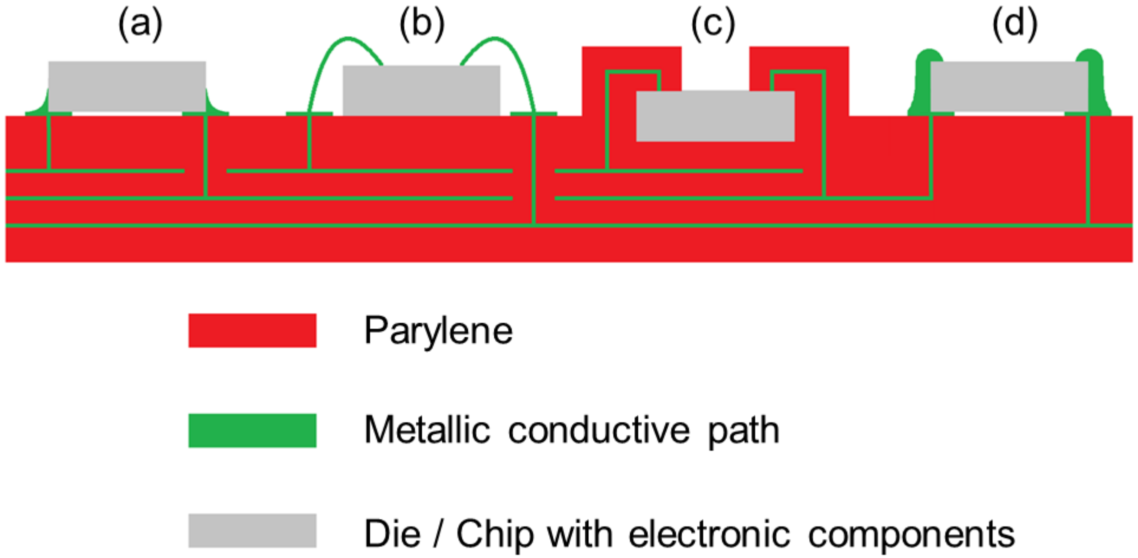


SEM images of the FIB cut through a metallized Parylene via (a), (b), (d), as well as of a cross-section of a Parylene via villed with electrochemically deposited aluminum (c)

Parylene based ultra-thin flexible electronics for wearables

Integration

- Integration technology:
  - Soldering (a)
  - Wire bonding (b)
  - Embedding with selective media access (c)
  - Dispensing / Printing (d)



Parylene based ultra-thin flexible electronics for wearables

Integration

- Integration technology:
  - **Soldering (a)**
  - Wire bonding (b)
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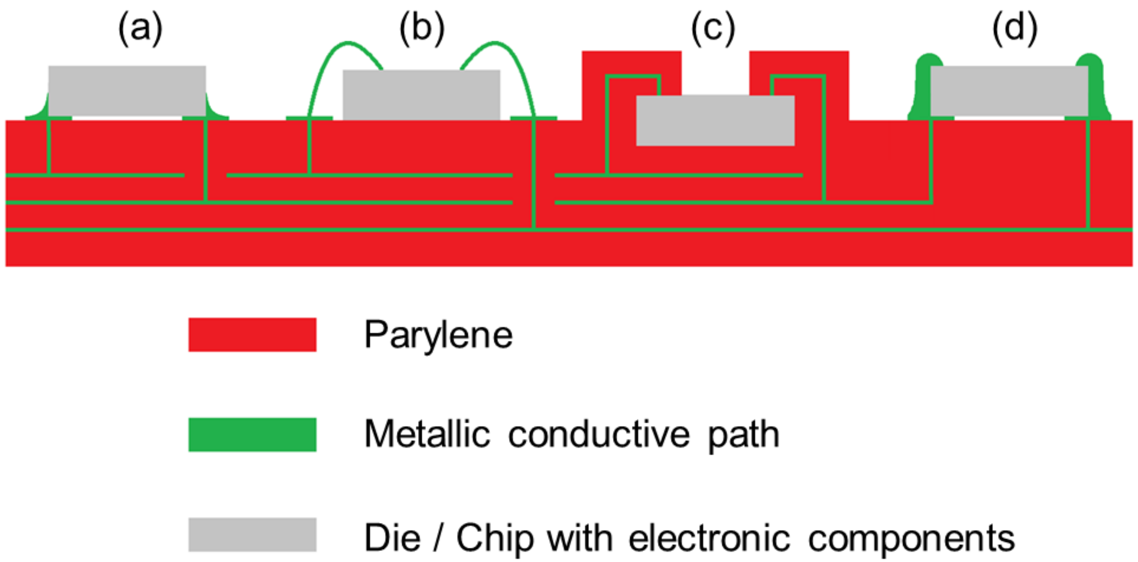
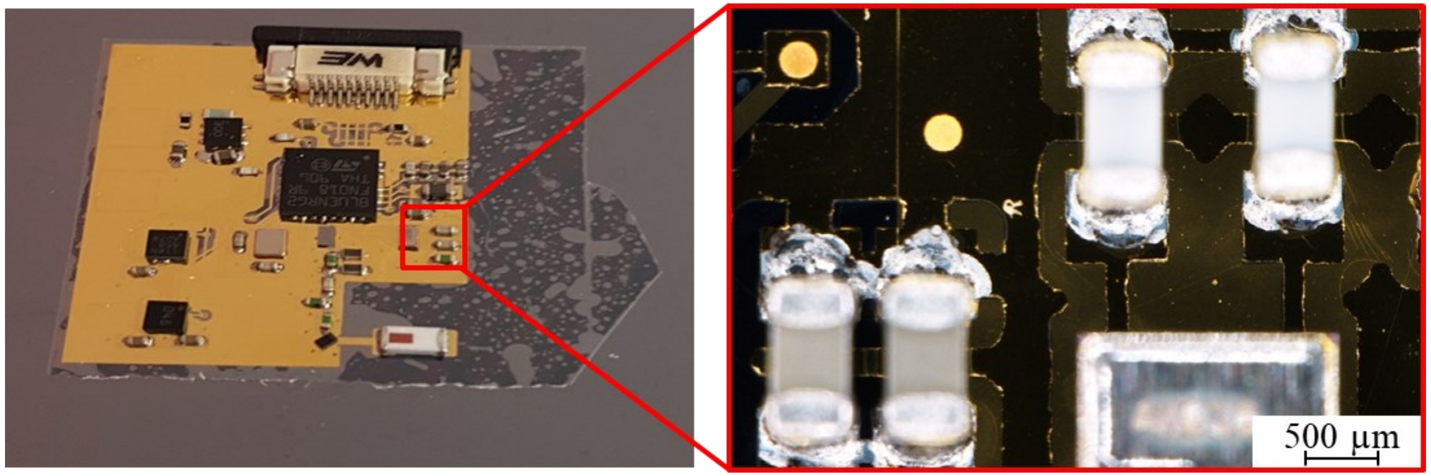


- First tests for soldering electronic components using a low temperature solder ($Sn_{42}Bi_{58}$) demonstrate feasibility.
- Soldering using standard solders feasible using highly temperature stable Parylene



Soldered electronic components on a Parylene flexible PCB

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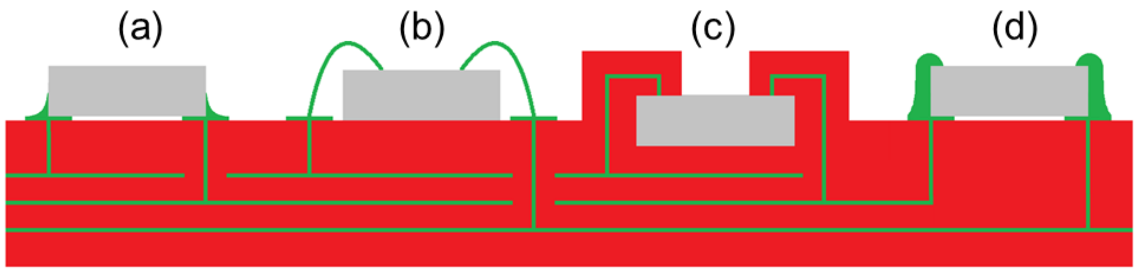
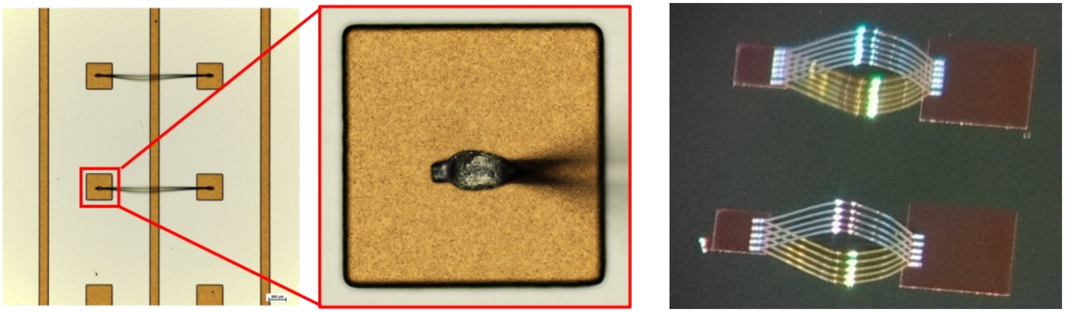
Integration

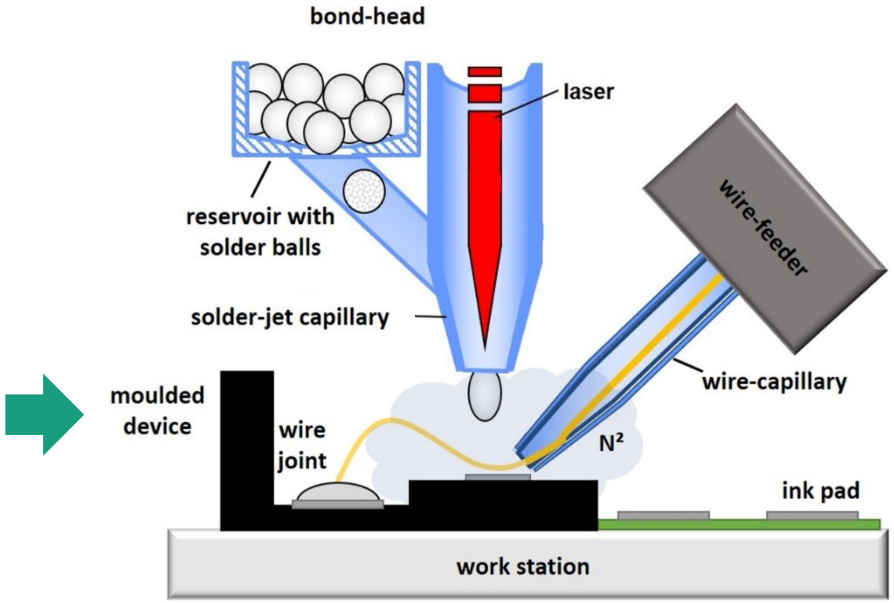


- Integration technology:
  - Soldering (a)
  - **Wire bonding (b)**
  - Embedding with selective media access (c)
  - Dispensing / Printing (d)
- Wire bonding is possible for thick pad metallization
- Thin pad metallization requires more advanced wire bonding



25 µm Al wire bonds on copper pads on Parylene PCB

→ Failure at 10,2 g ± 1,2 g



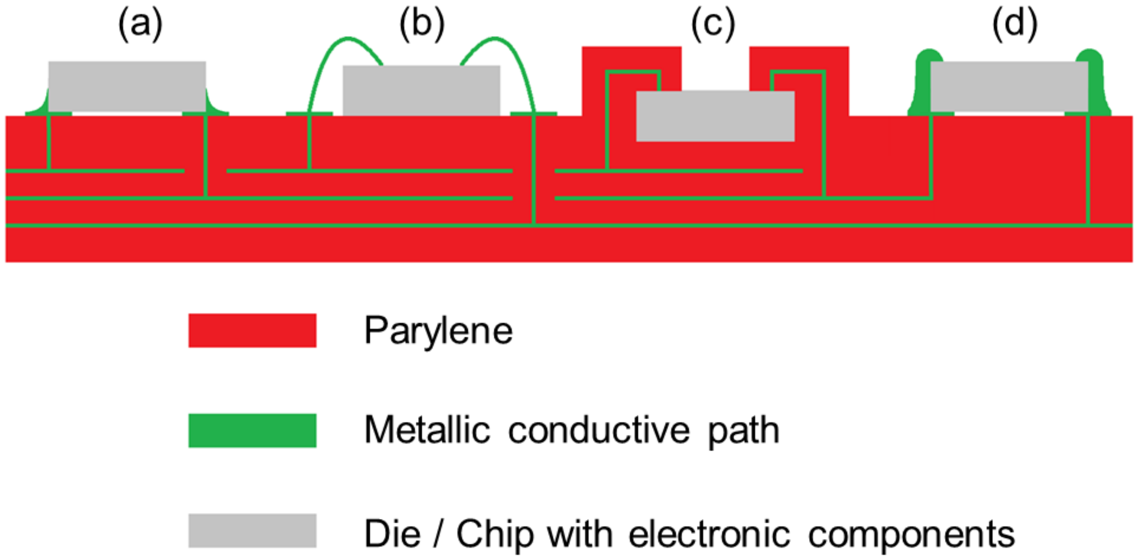
Principle of solder jetted supported wire bonding

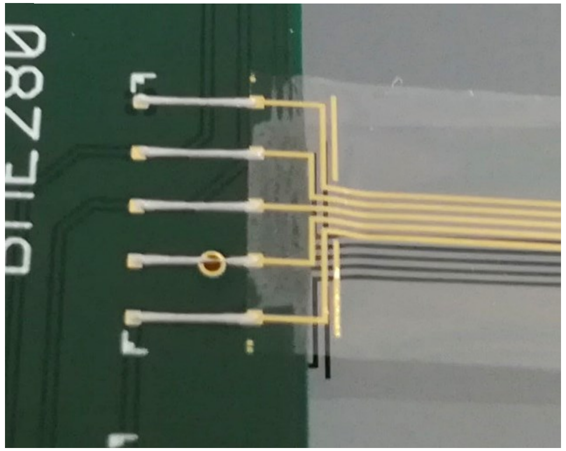
Parylene based ultra-thin flexible electronics for wearables

Integration

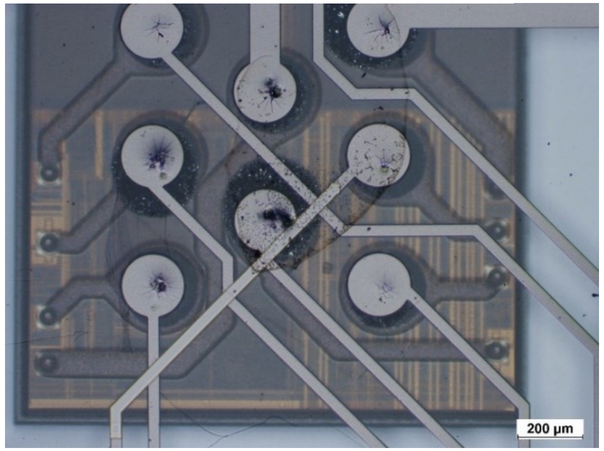
- Integration technology:
  - Soldering (a)
  - Wire bonding (b)
  - Embedding with selective media access (c)
  - **Dispensing / Printing (d)**

- Dispensing of conductive glue provides excellent results. Contacts of SMD components do not penetrate the ultra-thin Parylene PCB





Dispensed conductive glue based contacts



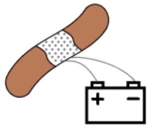
Backside view of a SMD component

Parylene based ultra-thin flexible electronics for wearables

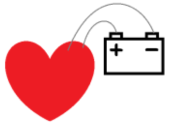
Flexible pH sensor

- Potentiometric pH sensor with two-electrode concept
- Parylene as an ultra-thin, flexible substrate
- Iridiumoxide as pH sensitive layer
- Chemical inertness of all materials in acids and bases
- Realization by only biocompatible materials possible
- High pH sensitivity of 66 mV/pH in the range of pH 2 to pH 11.5
- Good signal stability with low drift of < 1 mV/h
- Good performance for flat and bent conditions

→ pH monitoring for various applications



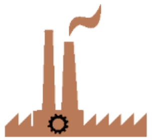
Wearables



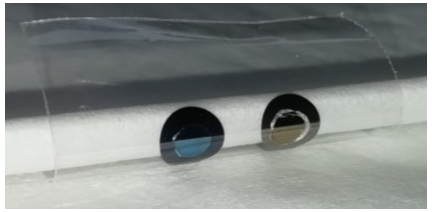
Implants

Environmental

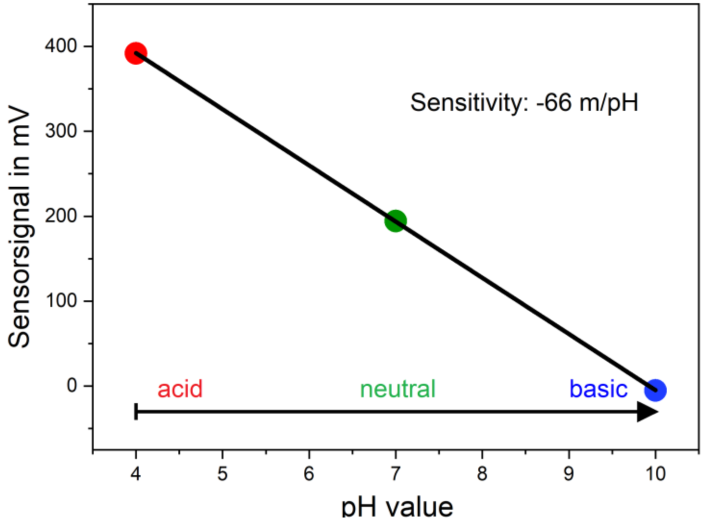
Water / Ressources



Industry 4.0



Fabricated sensor

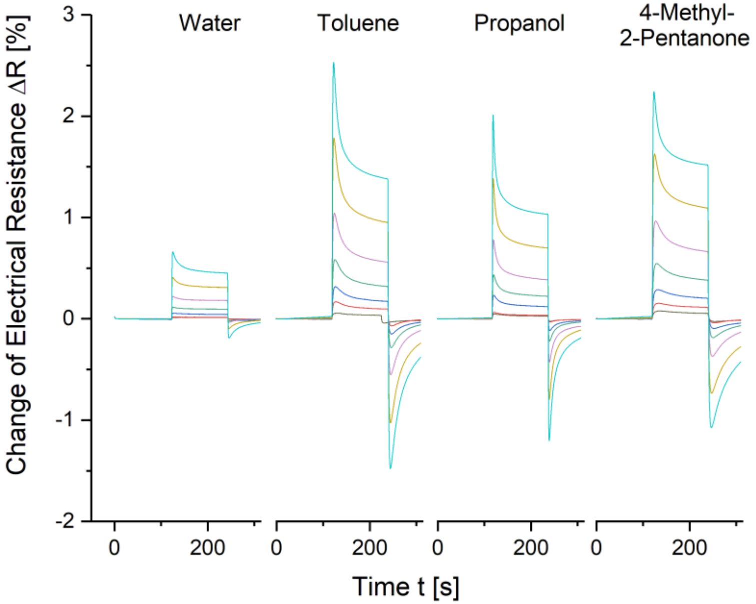


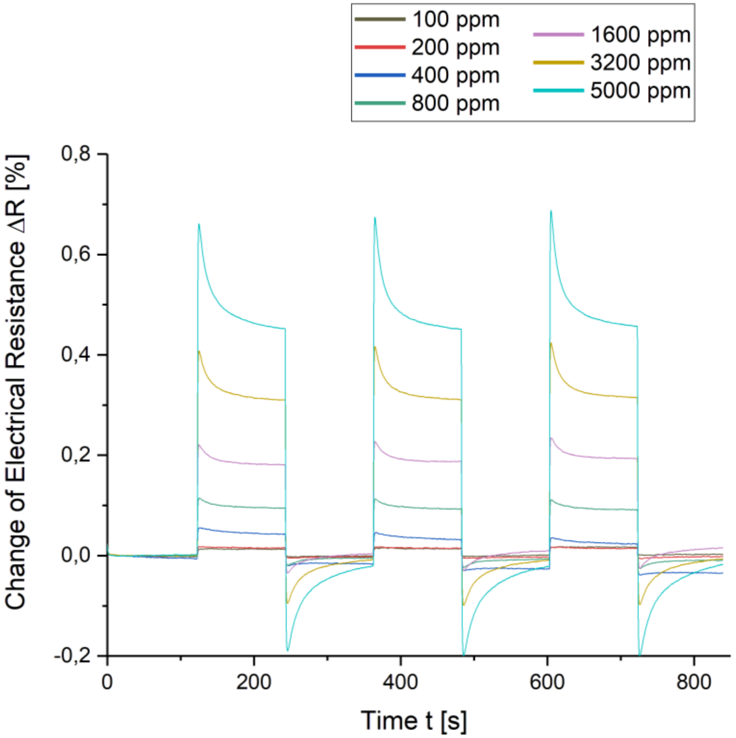
Sensor signal

Parylene based ultra-thin flexible electronics for wearables

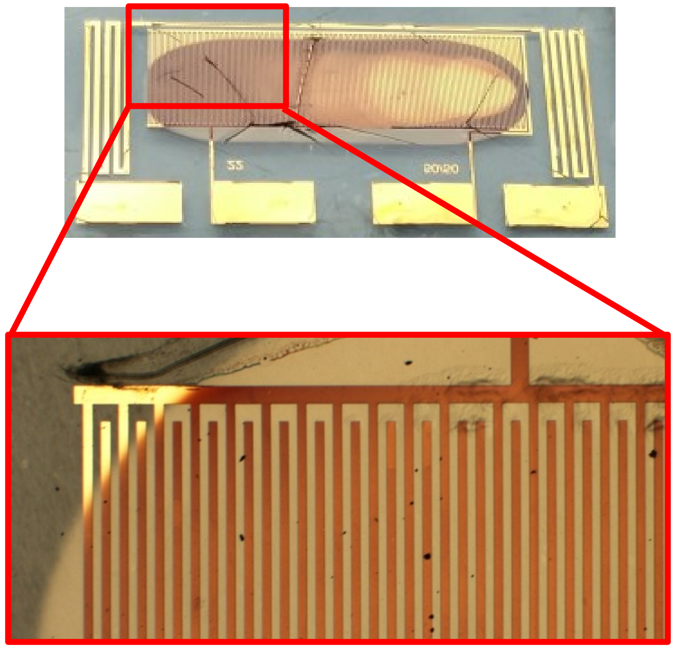
Flexible sensor for VOC

- Resistive flexible sensor for volatile organic componounds such as propanol, toluene, 4M2P or water
- Gold electrodes coated with self-assembled layers of interlinked noble metal nanoparticle networks as sensitive layer





Sensor signal

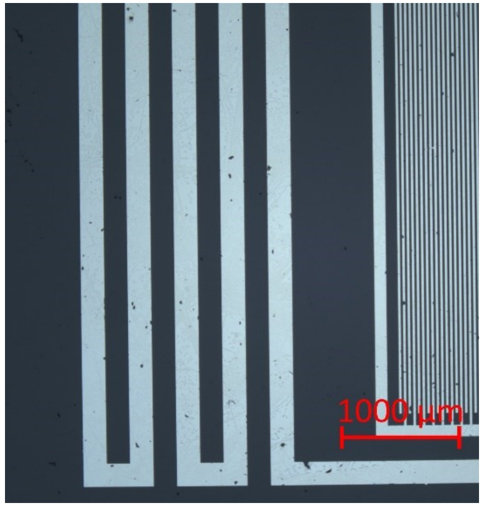


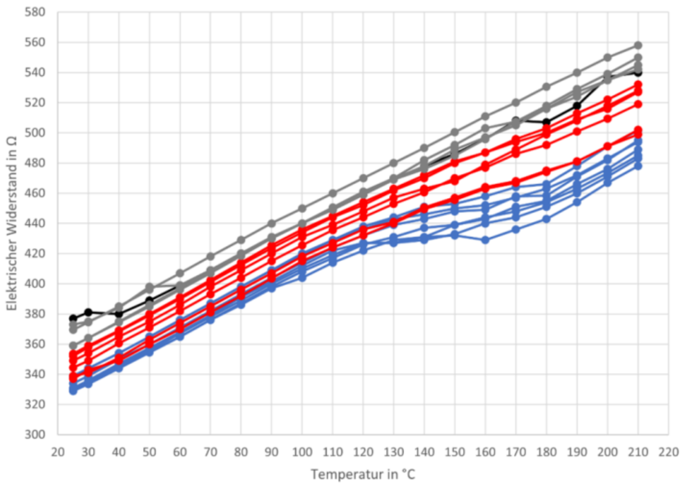
Fabricated sensor

Parylene based ultra-thin flexible electronics for wearables

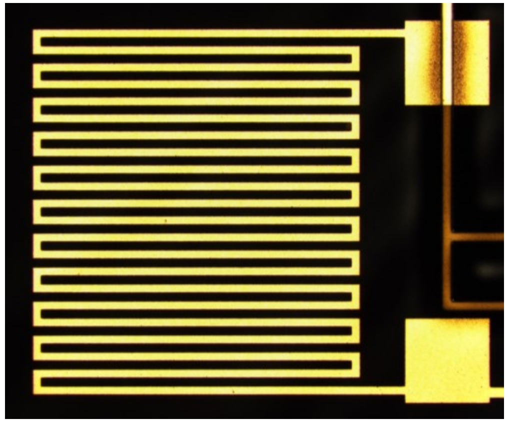
Temperature sensor

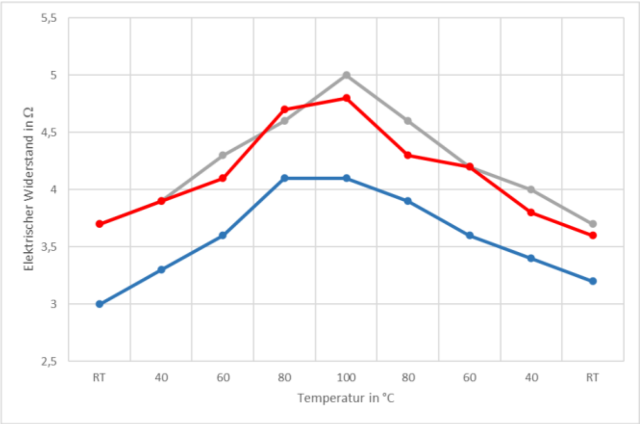
- Thermo resistive sensor principle, i.e. increase of electrical resistance by increase of temperature
- Fabrication directly on Parylene PCB and integration into RDL
- Demonstrated for gold, platinum, copper and nickel → demonstrated for biocompatible materials but also established metals for PCB technology
- Sensor characterization for ambient temperature to 100 °C





Metal meander on ultra-thin flexible Parylene substrate as well as sensor response for temperature measurements



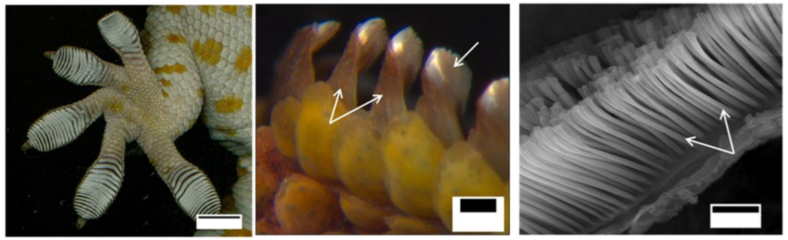


Parylene based ultra-thin flexible electronics for wearables

Integration of smart micro structures

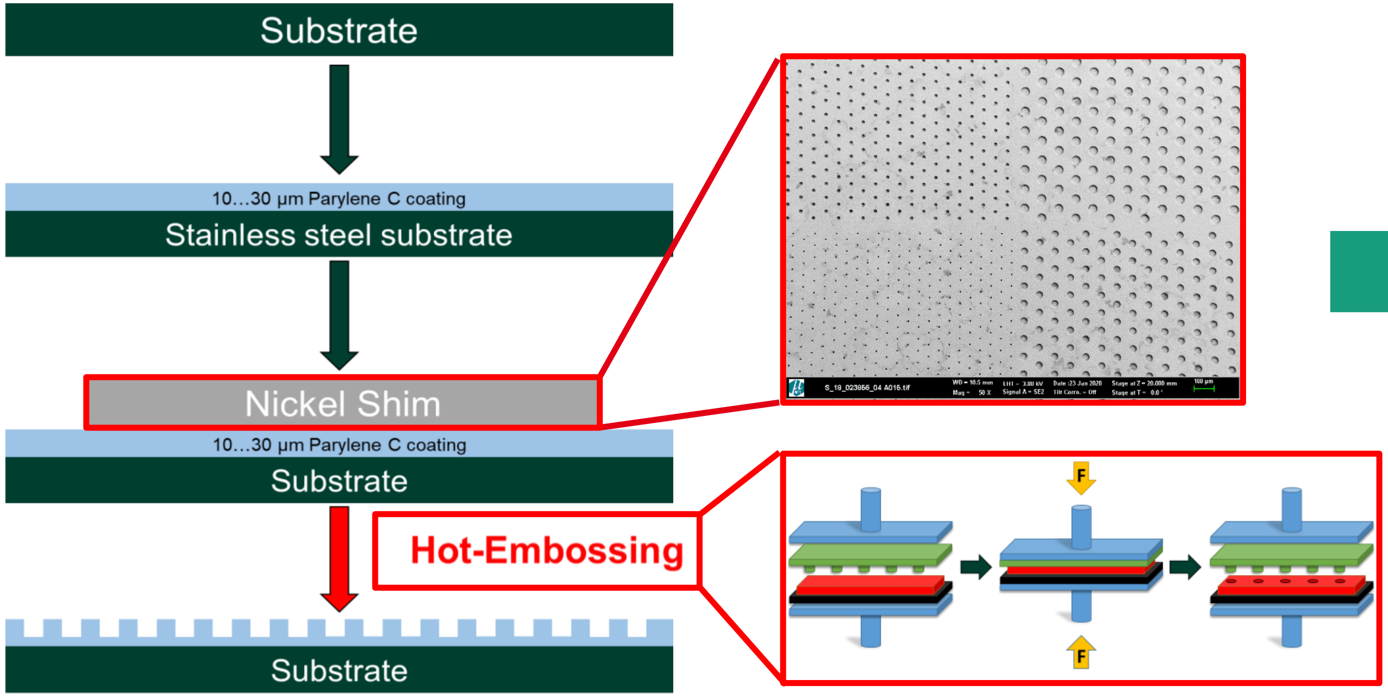
- Self-sticking ultra-thin wearables
- Avoiding Medical Adhesive-Related Skin Injuries

Teachers from nature - Gecko toe pad

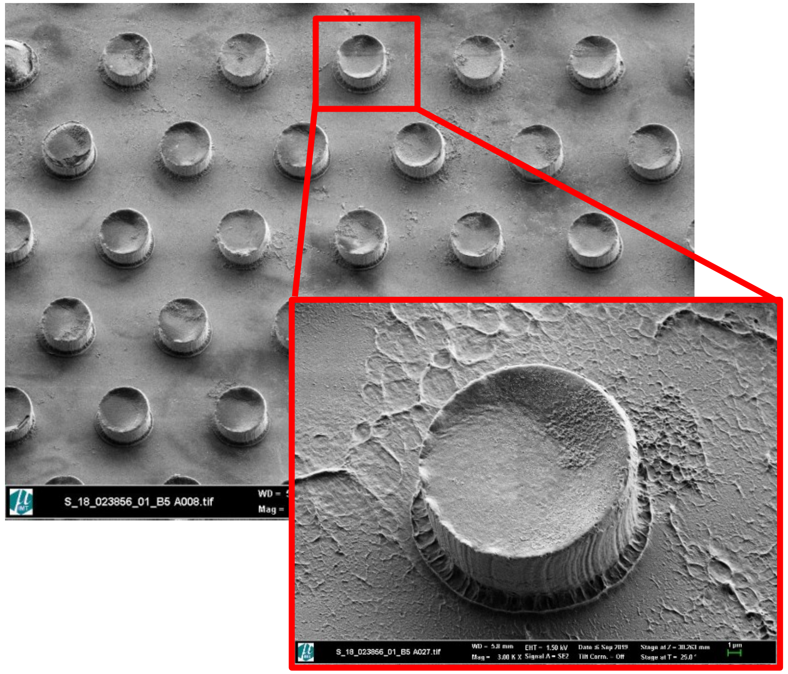


toe pad **lamellae** **setae (hair-like structures)**

Images: Stark et al, 2016, Phil. Trans. R. Soc. A 374



Process flow for hot-embossing Parylene

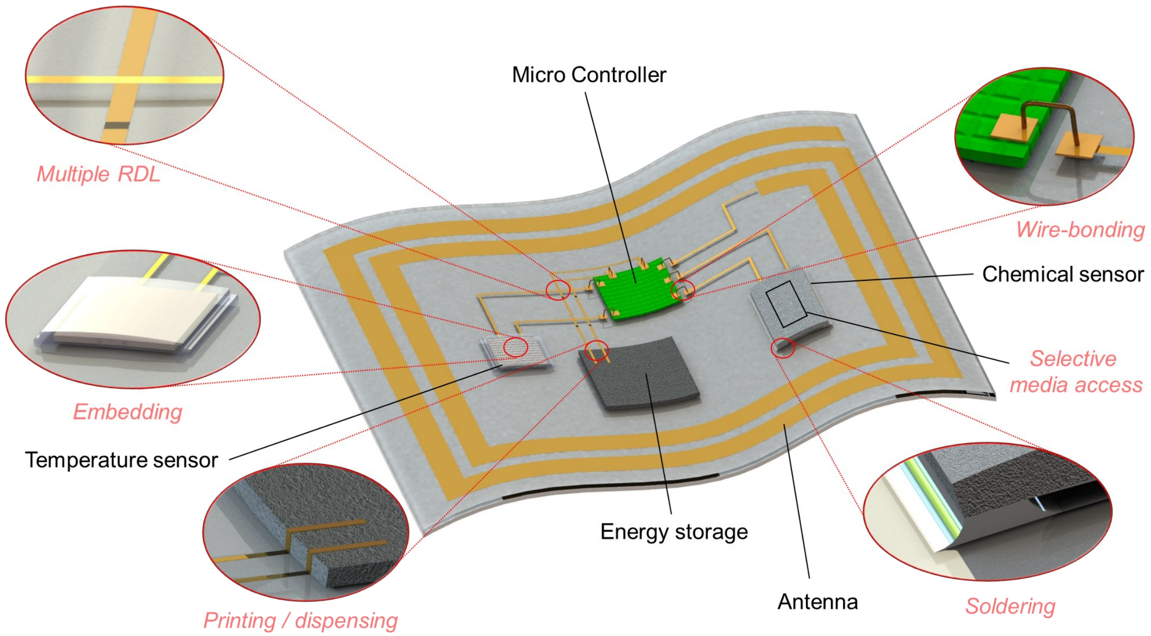


SEM images of hot-embossed Parylene

Parylene based ultra-thin flexible electronics for wearables

Conclusion

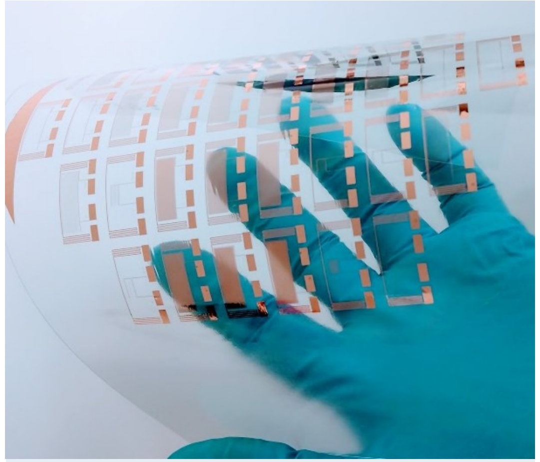
- Fabrication of an ultra-thin Parylene flexible PCB successfully demonstrated
- Fully biocompatible
- Parylene as a substrate, dielectric and encapsulation
- Total thickness < 20 µm
- Multiple RDL
- Different metallization techniques
- Vias with low depth < 10 µm
- Good electrical performance verified
- Direct fabrication of flexible sensors (pH, VOC, T)
- Different approaches for integration for components (direct integration vs. discrete components



→ Ultra-thin and highly flexible Parylene PCB as a new packaging platform for health care applications

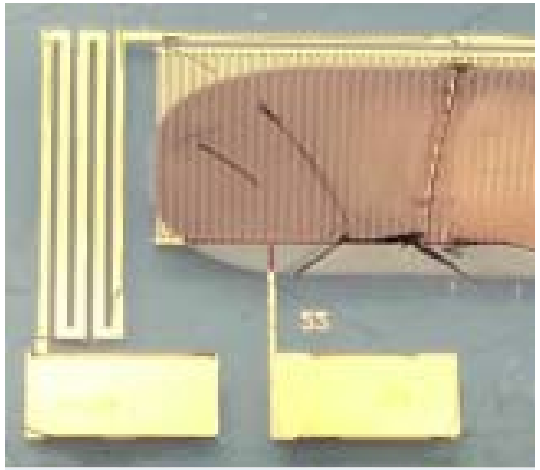
Outlook

Further possibilities



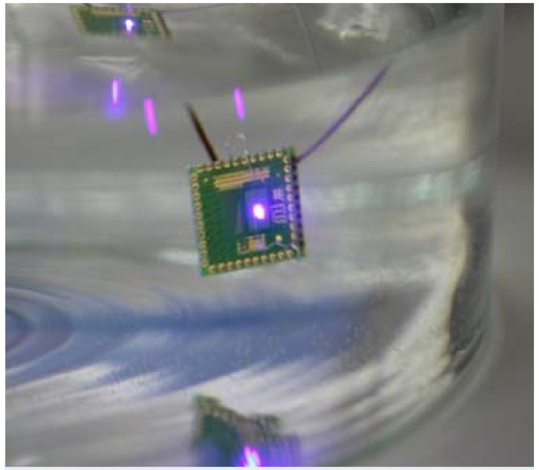
Flexible, Transparent & Self-Sticking Substrate

- Smart plasters
- Optical waveguides
- Heat exchanger



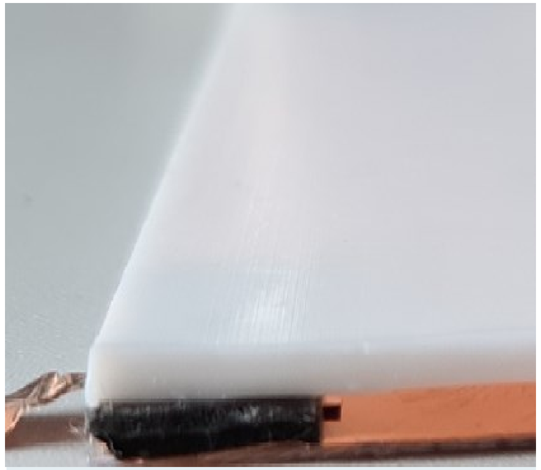
Dielectric Material

- Geometry-adaptive sensors
- Flexible microelectronics



Encapsulation

- Protection from sweat, water, etc.
- Protection against chemicals



Energy Harvesting

- Triboelecric nanogenerators
- Self-sufficient microsystems

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THANK YOU!

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Questions & Answers