

SiME Congress 2026 Darmstadt



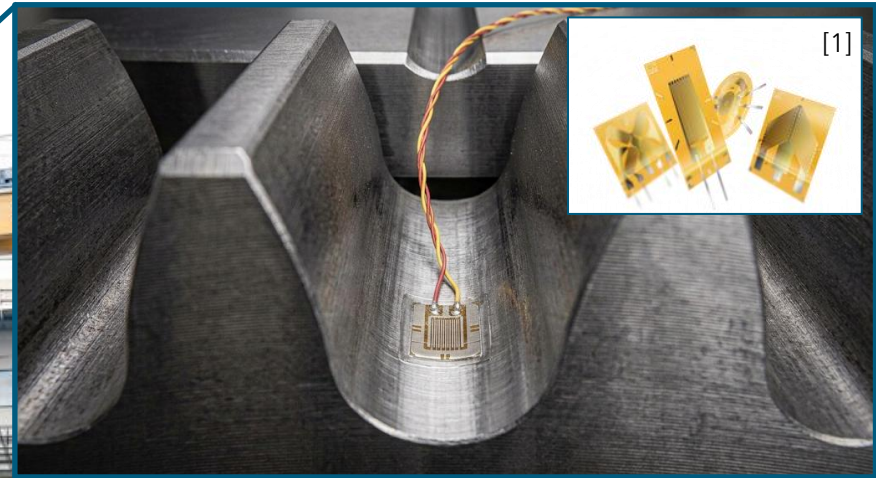
Application and Functionalization of Additively Manufactured Strain Sensors on Drive Train Components

Dr. Samuel Moritz Fink (Fh-ILT), Dr. Ingo Wirth (Fh-IFAM)

Daniel Flaswinkel (Flender GmbH), Tim Rusch (Fh-IFAM), Martin Shulevski (Fh-ILT)

Motivation

Application of Strain Gauges

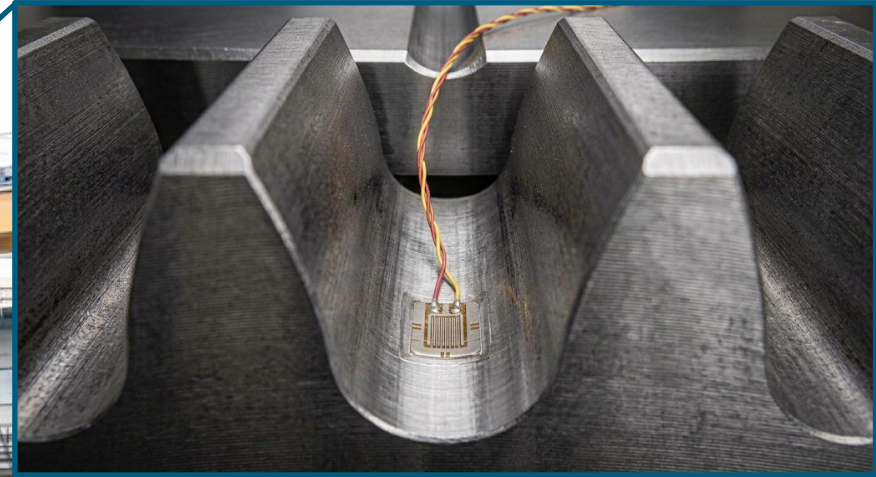


Requirements

- ✓ 2.5D surfaces
- ✓ Reproducible signal
- ✓ Long-term stability
 - Adhesive
 - Electrical connection

Motivation

Application of Strain Gauges – Manual

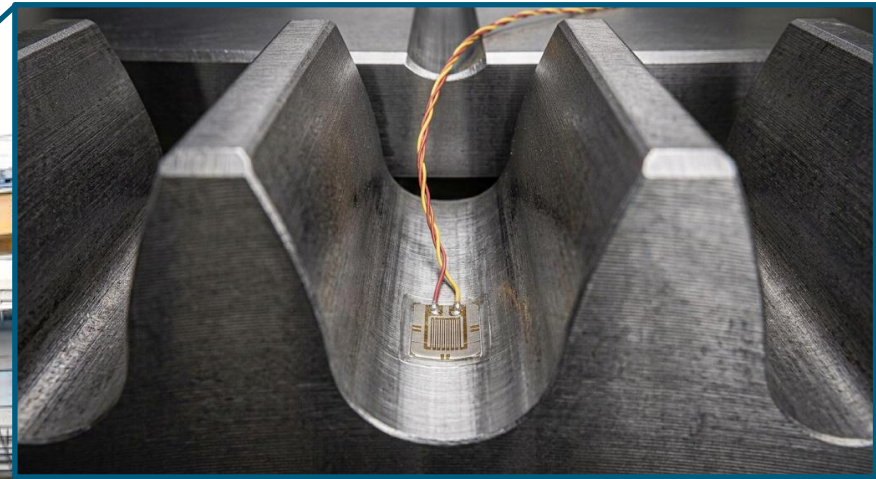


Requirements

- ✓ 2.5D surfaces
- ✓ Reproducible signal
- ✓ Long-term stability
 - Adhesive
 - Electrical connection

Motivation

Application of Strain Gauges – Automated Pick-and-place



Requirements

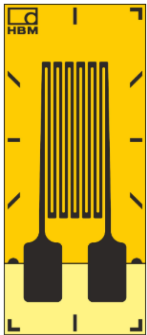
- ✓ 2.5D surfaces
- ✓ Reproducible signal
- ✓ Long-term stability
 - Adhesive
 - Electrical connection

Motivation

Additive Manufacturing of Strain Sensors on Drive Train Components

Manual Application of Foil Strain Gauges

- Reproducible and reliable measurement
- Time consuming and prone to variations due to manual labor

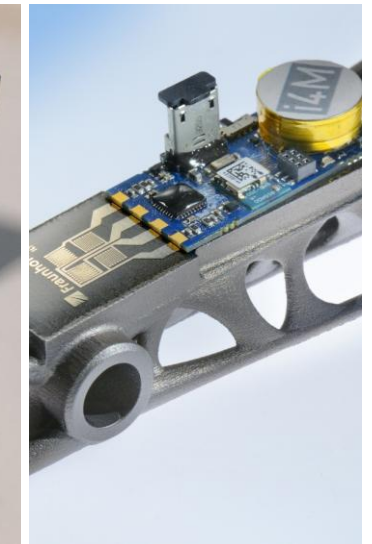


HBK: DMS 6/350
LY15
Quarter bridge
strain gauge



Integrated Sensors in Drive Train components

- ✓ Live-Monitoring of mechanical and thermal stress
- ✓ Structural health monitoring
- ✓ Integration on 3D-surfaces possible
- ✓ High thermal and mechanical coupling between component and sensor



State of the Art

Additively Manufactured Sensors – Components and Effects

Bonding

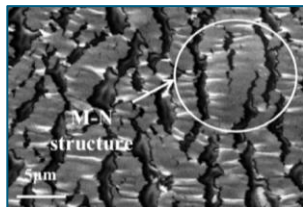
- Conductive adhesive
 - Limited long-term durability
- Soldering
 - Often not possible on printed films

Application methods

- Inkjet [4]
- Aerosoljet [1]
- Laser-induced forward transfer [5]
- Screen printing [3]

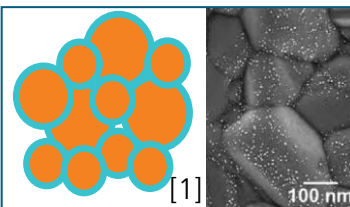
Drift/ S/N-ratio

Crack formation



[2]

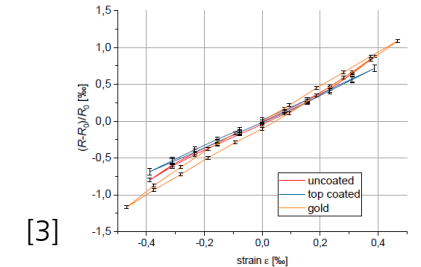
Residual organics



[1]

Material: Isolator

- Polymer Isolation [1, 3]
- Polyimide [4]

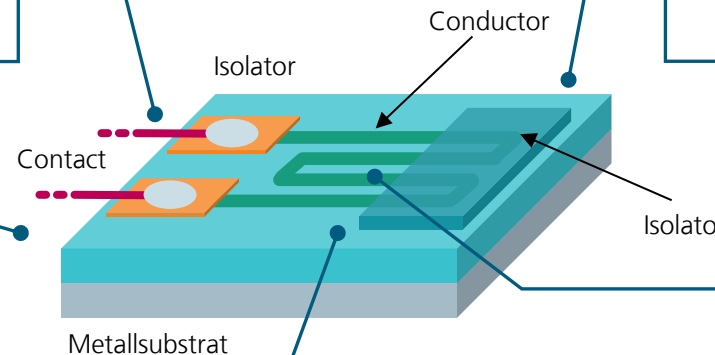
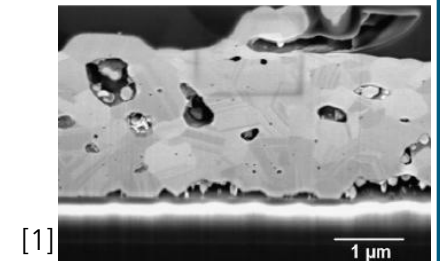


Material: Conductor

- Silver [1, 3, 4]
- Graphene/Carbon Black [3]
- Gold [3]
- Konstantan/CuNi alloys (Konstantan)

Thermal processing

- Oven
- Flash lamp
- Laser

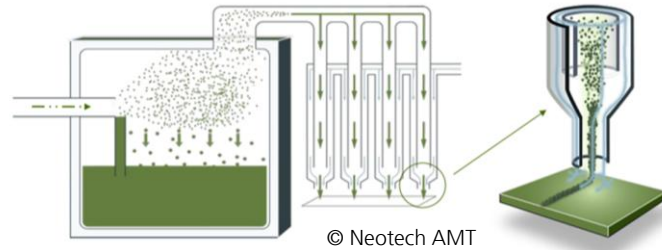


State of the Art

Digital Technologies for Sensor Printing

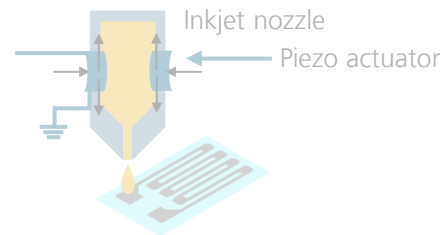
Aerosol-Jet

Transfer of nanoparticle ink through spray nozzle



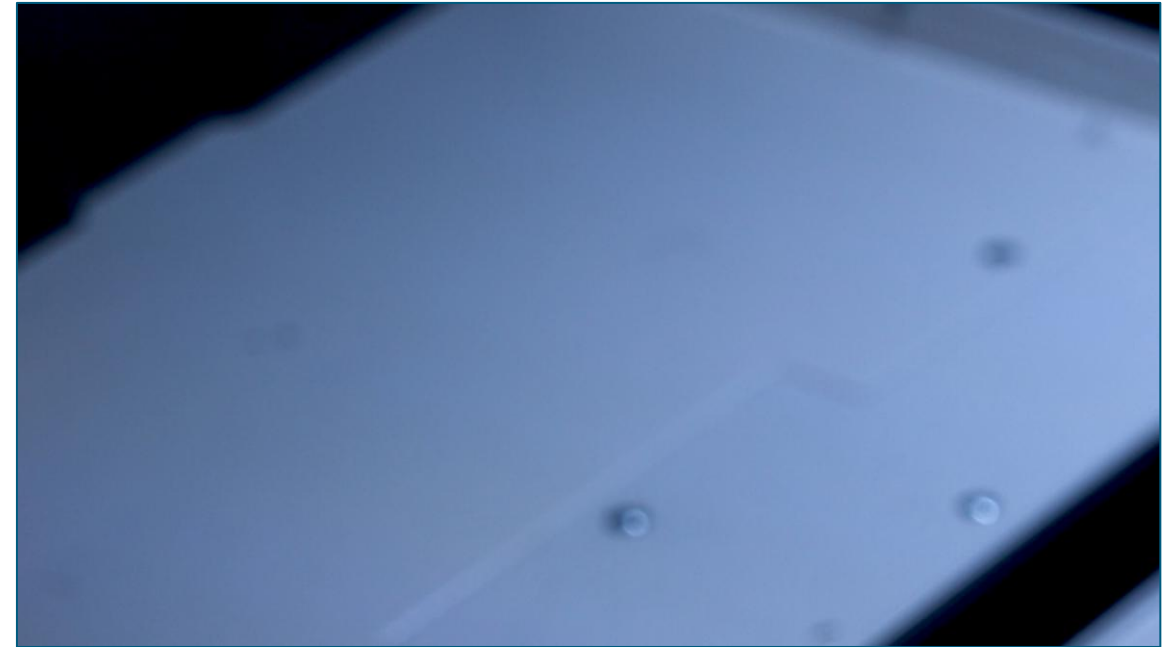
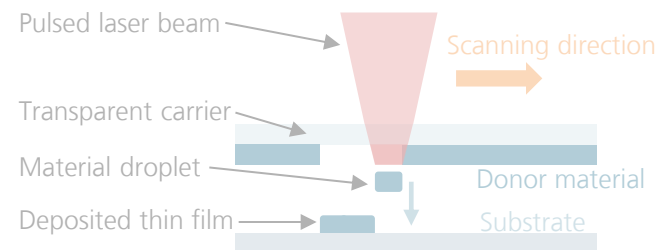
Inkjet

Nanoparticle ink droplet ejection through nozzle



LIFT

Laser-induced forward transfer of melt droplets from donor foil



- 3D capable
- High flexibility
- Broad range of inks



- Low productivity
- Complex equipment

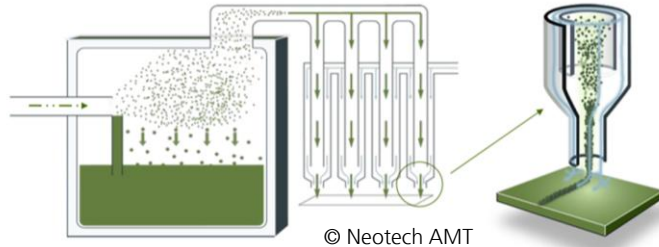


State of the Art

Digital Technologies for Sensor Printing

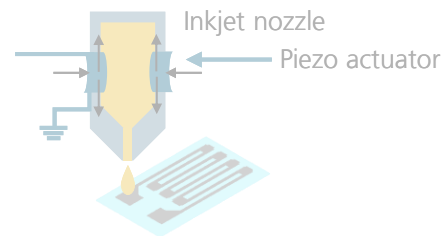
Aerosol-Jet

Transfer of nanoparticle ink through spray nozzle



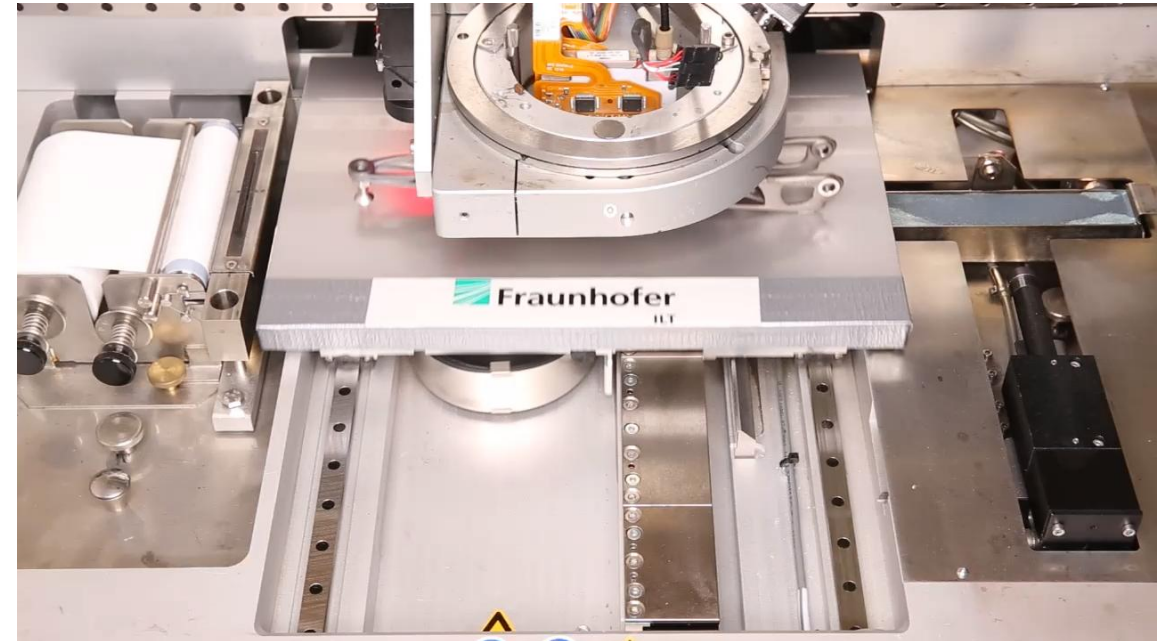
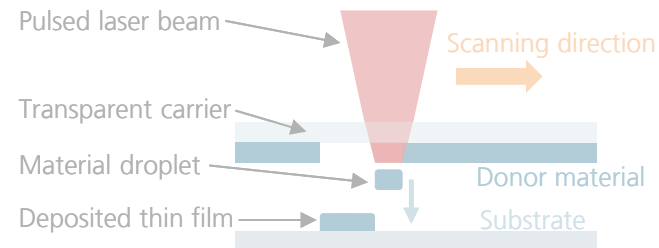
Inkjet

Nanoparticle ink droplet ejection through nozzle



LIFT

Laser-induced forward transfer of melt droplets from donor foil



- High productivity
- Inline capable



- Limited to 2D
- Complex equipment
- Limited ink availability

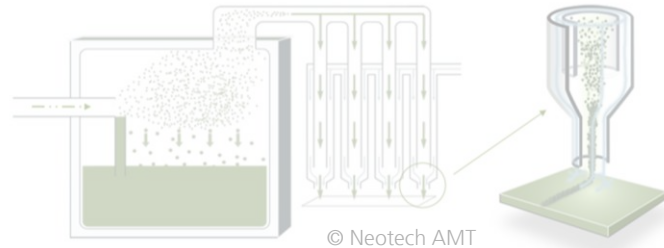


State of the Art

Digital Technologies for Sensor Printing

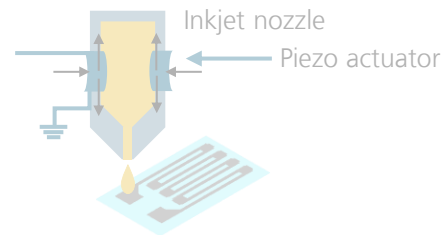
Aerosol-Jet

Transfer of nanoparticle ink through spray nozzle



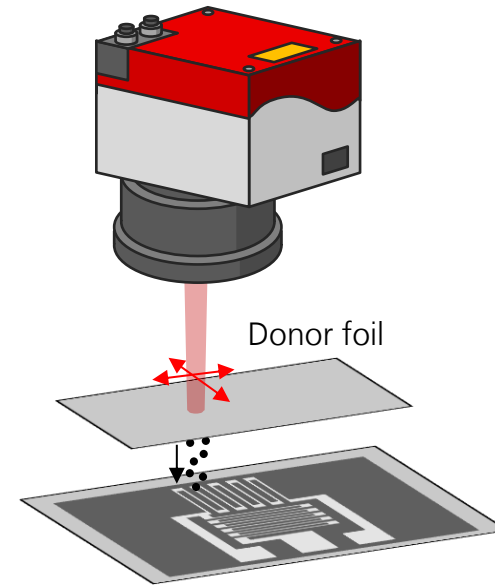
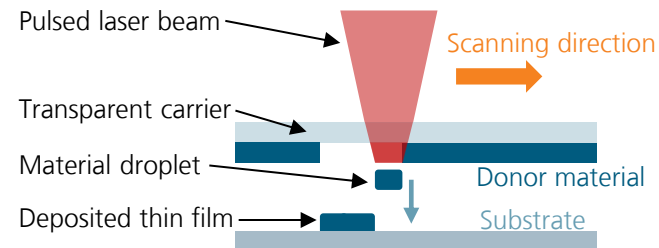
Inkjet

Nanoparticle ink droplet ejection through nozzle



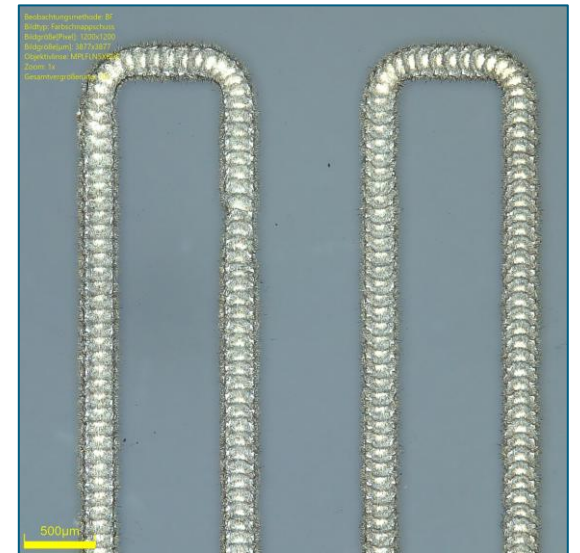
LIFT

Laser-induced forward transfer of melt droplets from donor foil



Schematic of LIFT process

- 2,5D capable
- High flexibility
- No liquid inks
- Wide material range



Silver-LIFT meander structure on glass substrate

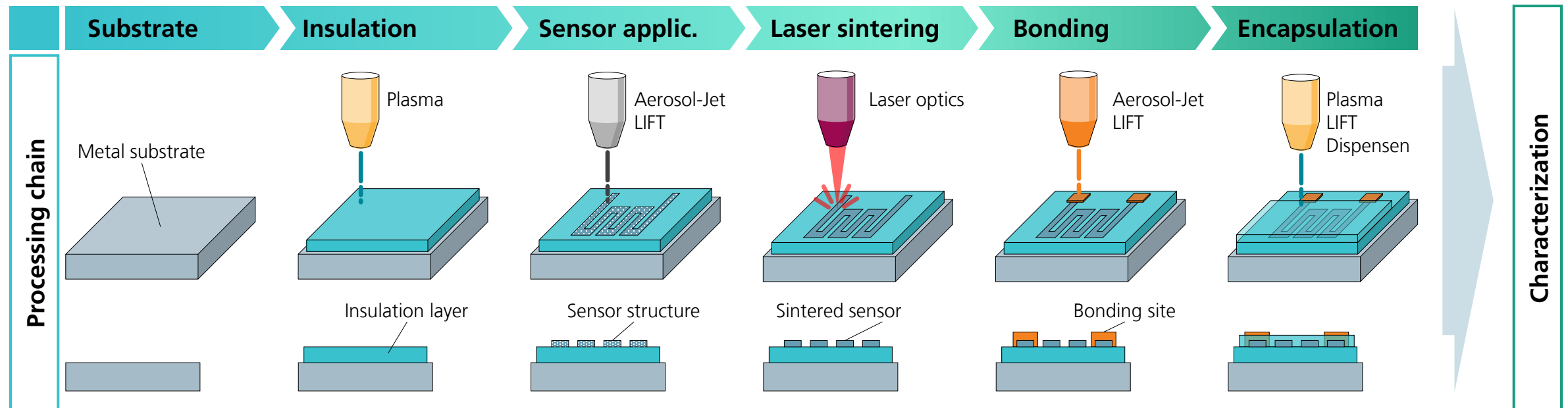
- Sensible process
- Limited compatible substrates



Project „Printed Sensors on Drive Strain Components“ - FVA 937 II

Project Goal and Processing Chain

- **Content:** Experimental study on the maturity of additively manufactured sensor technology, with a focus on interconnection and strain measurement for powertrain technology
- Processing Chain

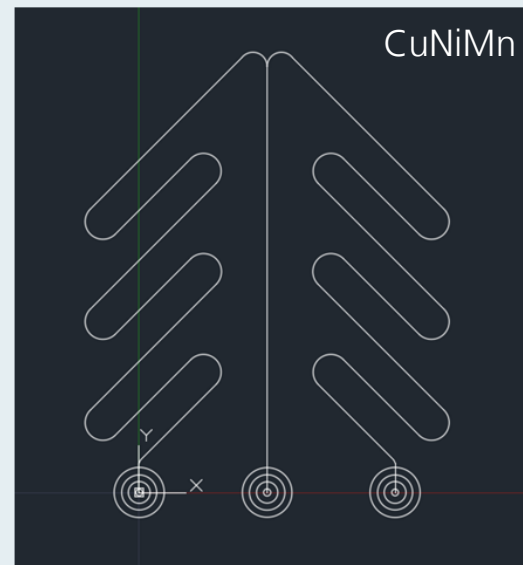
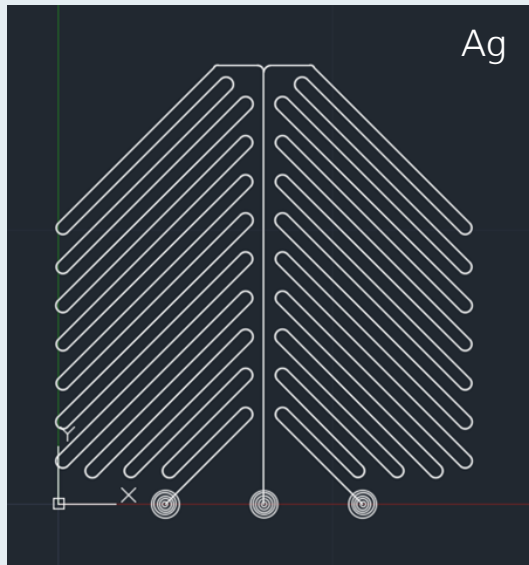


Project „Printed Sensors on Drive Strain Components“ - FVA 937 II

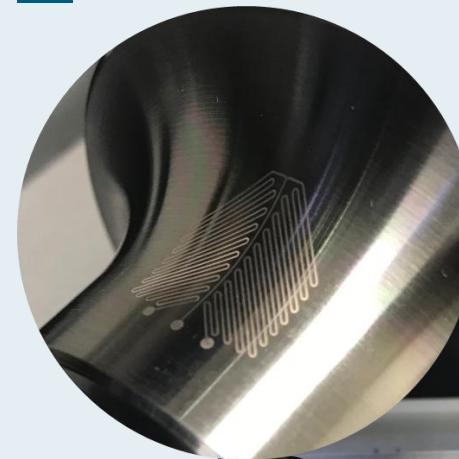
Aerosoljet printing of strain gauges

Strain gauge layout (torque measurement)

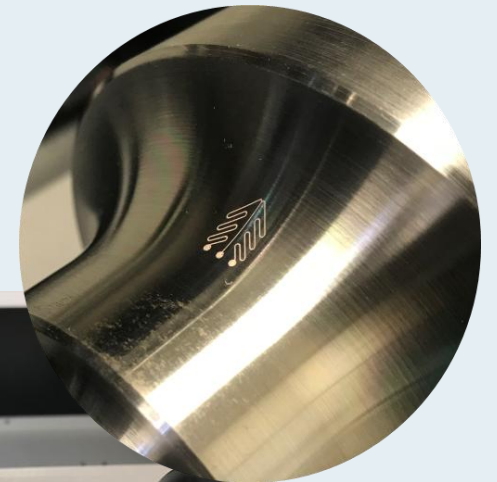
- Adjusted layout for target resistance of 350 Ω



Metal shaft with printed strain gauges



Y-DMS
Ag



Y-DMS
CuNiMn

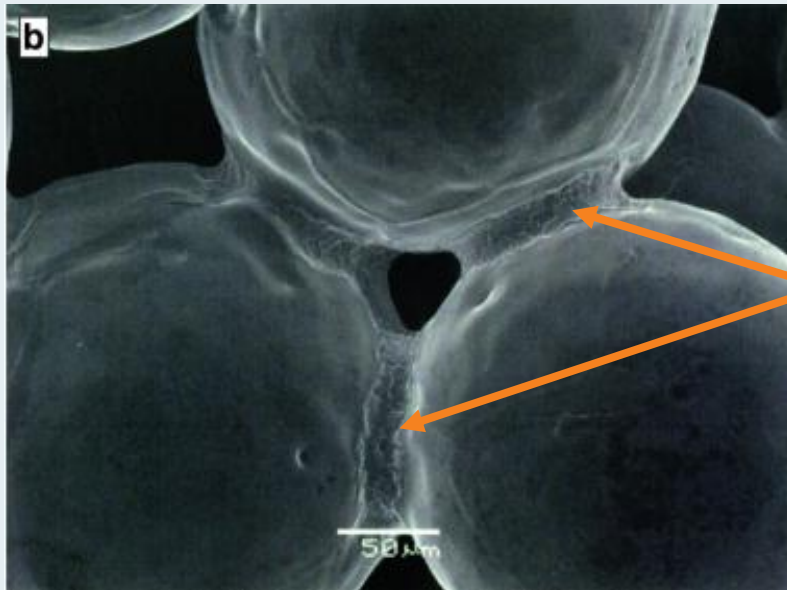


Project „Printed Sensors on Drive Strain Components“ - FVA 937 II

Laser sintering of strain gauges

Sintering process

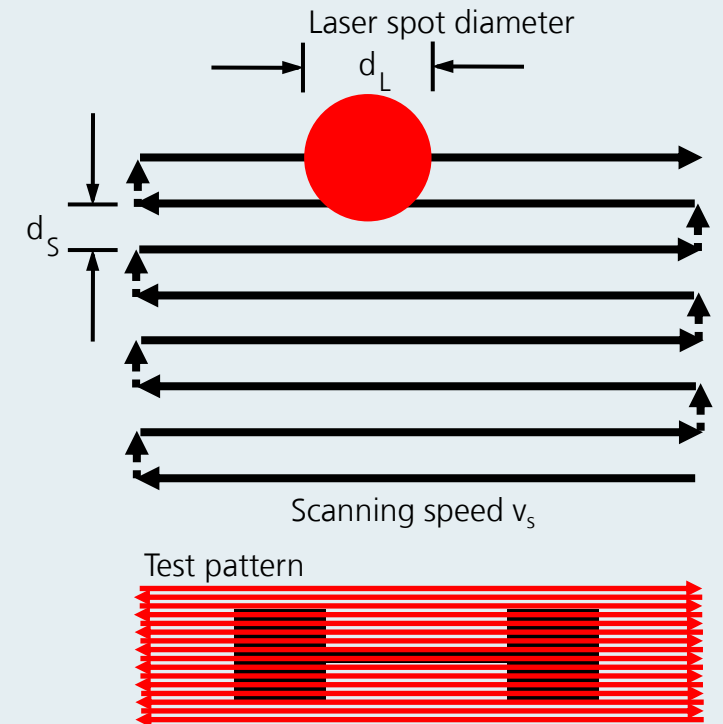
- Enlargement of the contact surface between silver nanoparticles due to laser sintering [1]



Sinter necks

Resistance adjustment using laser radiation

- Variation of
 - Spot diam.
 - Laser power
 - Interaction time
- Adjustment of resistance



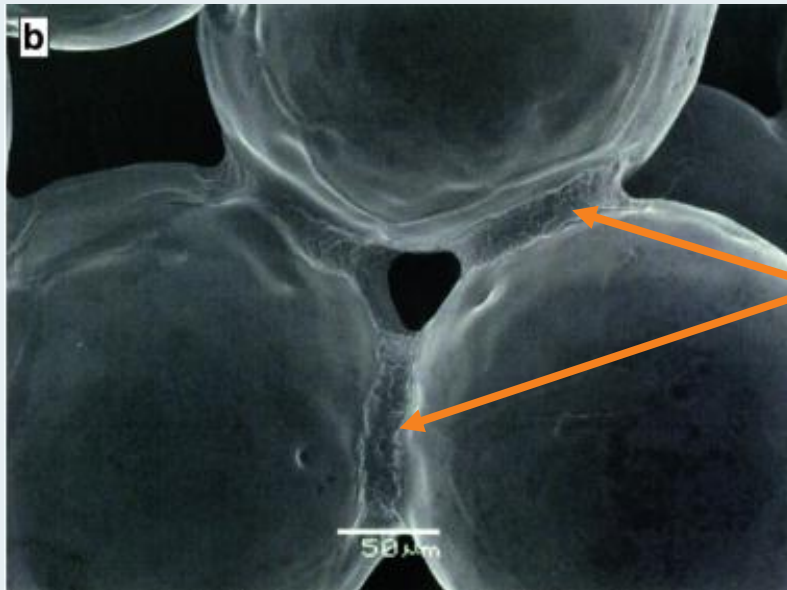
[1] https://link.springer.com/chapter/10.1007/978-3-658-25374-5_99

Project „Printed Sensors on Drive Strain Components“ - FVA 937 II

Laser sintering of strain gauges

Sintering process

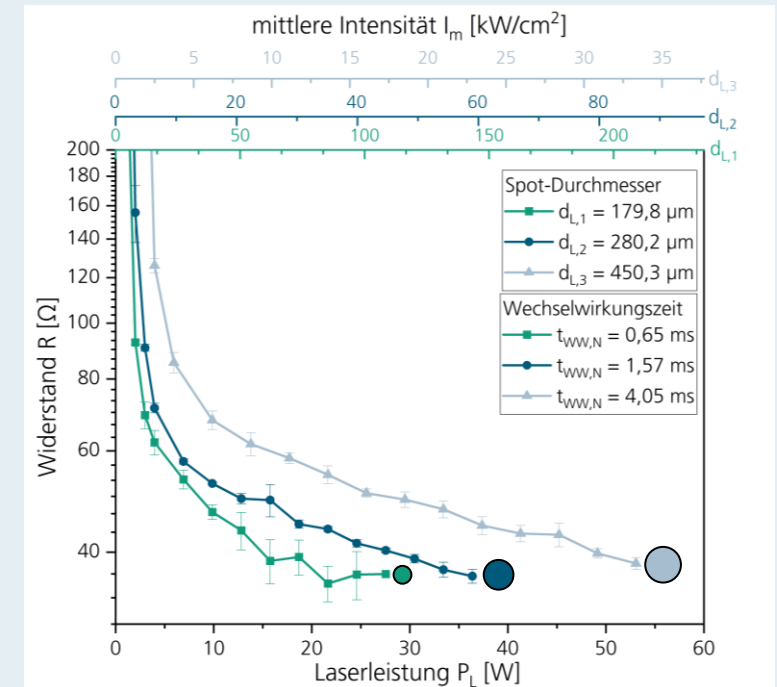
- Enlargement of the contact surface between silver nanoparticles due to laser sintering [1]



Sinter necks

Resistance adjustment using laser radiation

- Variation of
 - Spot diam.
 - Laser power
 - Interaction time
- Adjustment of resistance



[1] https://link.springer.com/chapter/10.1007/978-3-658-25374-5_99

Project „Printed Sensors on Drive Strain Components“ - FVA 937 II

Laser sintering of strain gauges

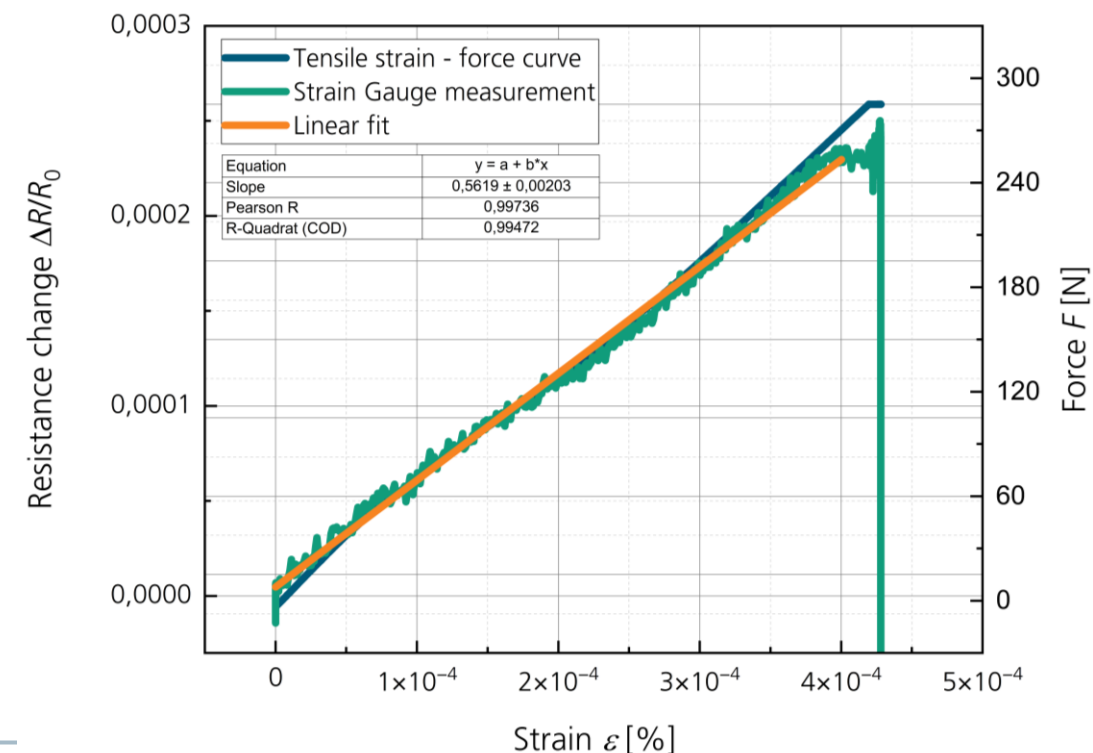
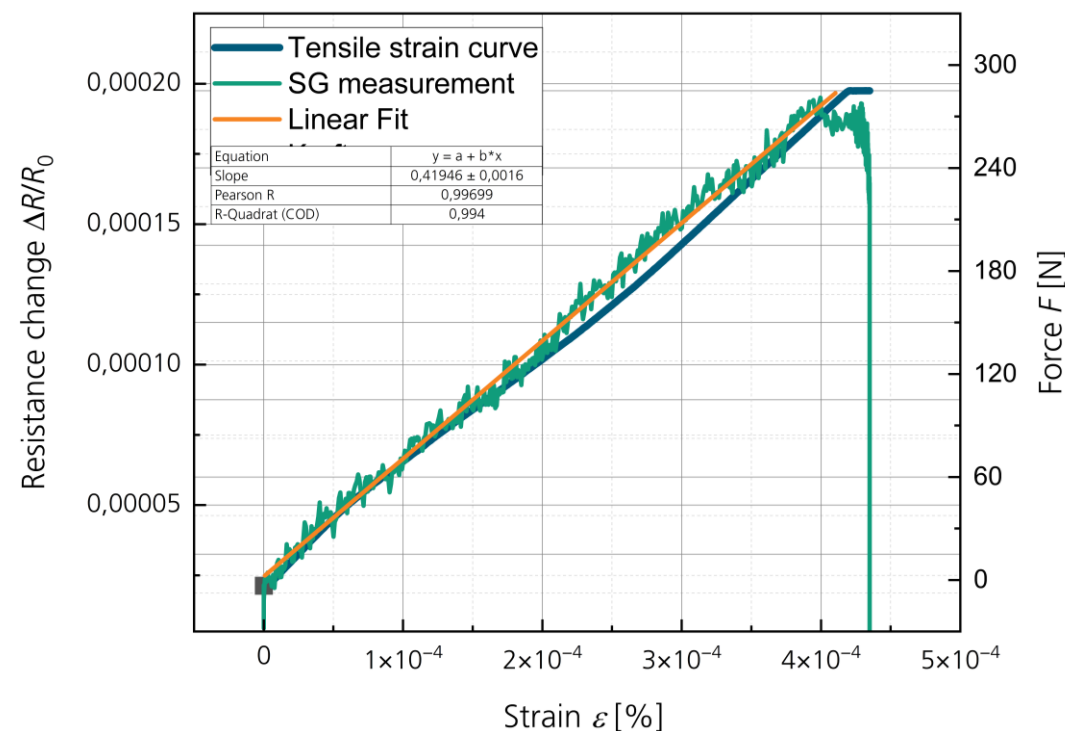
Measurement of strain gauges with following laser sintering parameters:

P_L 40 W, v_{scan} 1750 mm/s, dy 40 μm

SG factor 0,4195; R_0 386 Ω

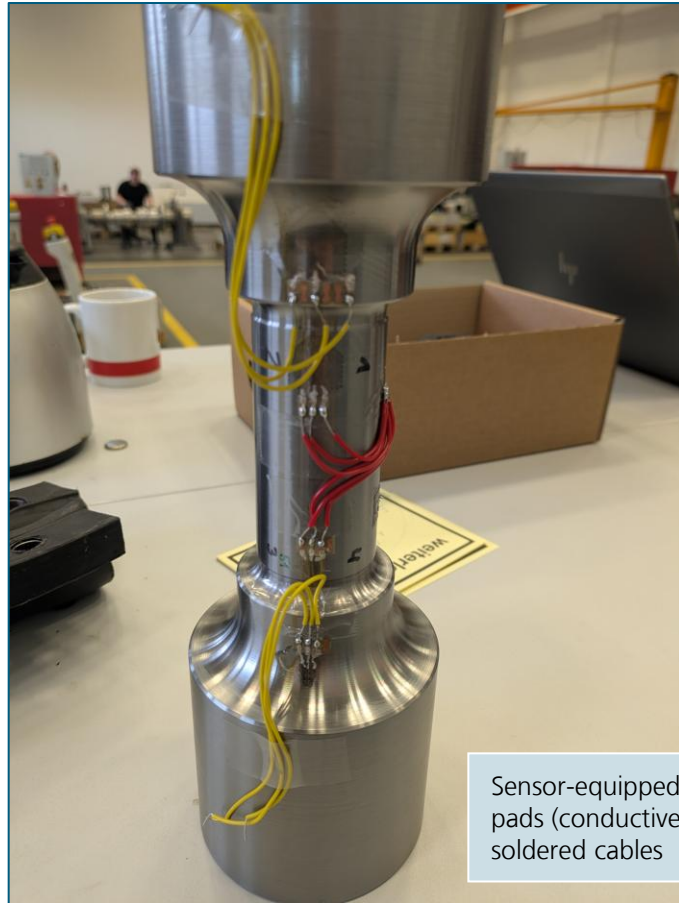
P_L 32 W, v_{scan} 1000 mm/s, dy 40 μm

SG factor 0,5619; R_0 320 Ω

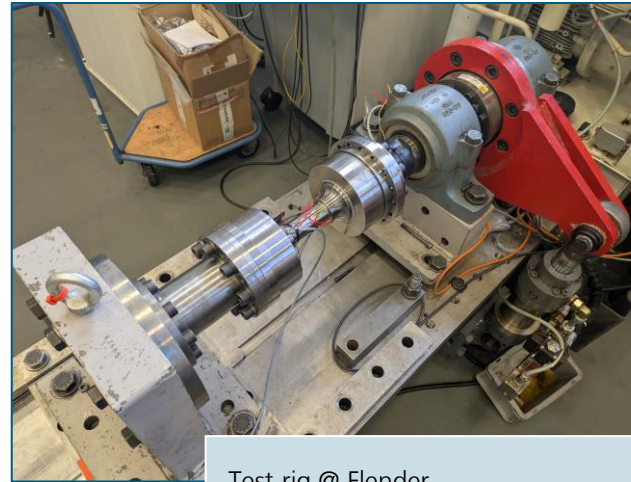


Project „Printed Sensors on Drive Strain Components“ - FVA 937 II

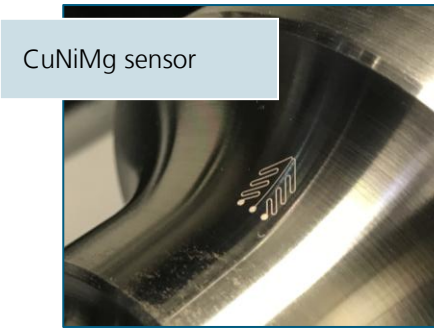
Results – Torque sensor on metal shaft on test rig



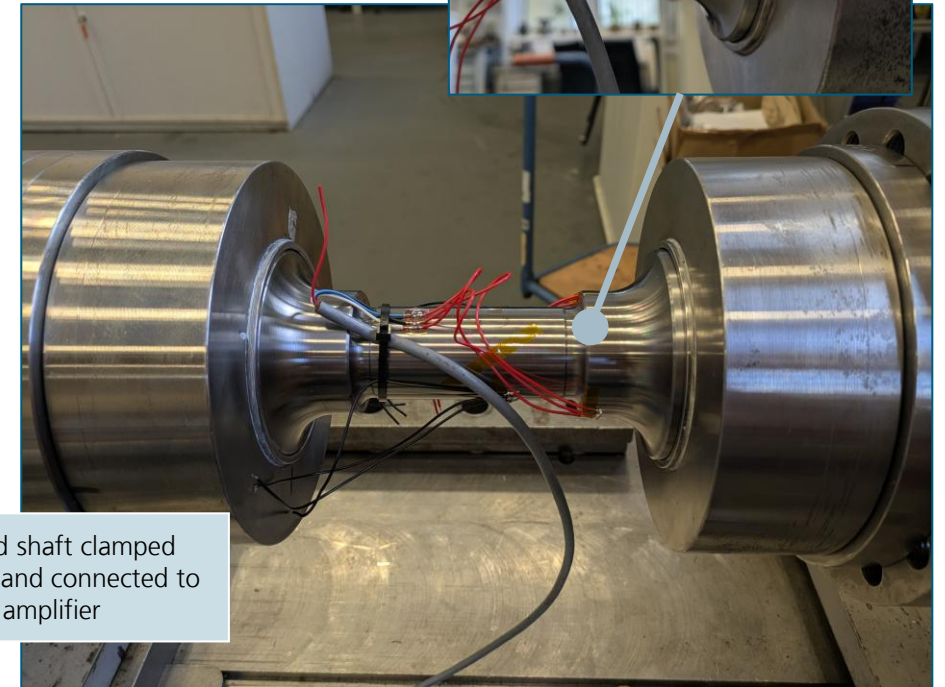
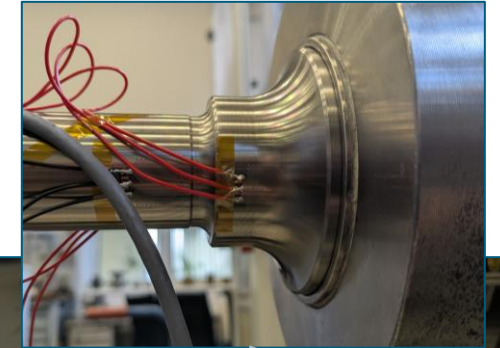
Sensor-equipped shaft with solder pads (conductive adhesive) and soldered cables



Test rig @ Flender



CuNiMg sensor

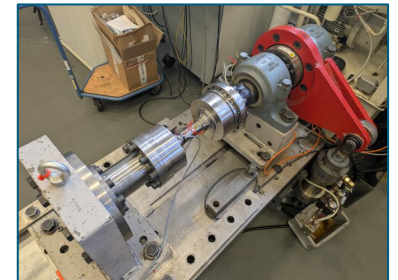
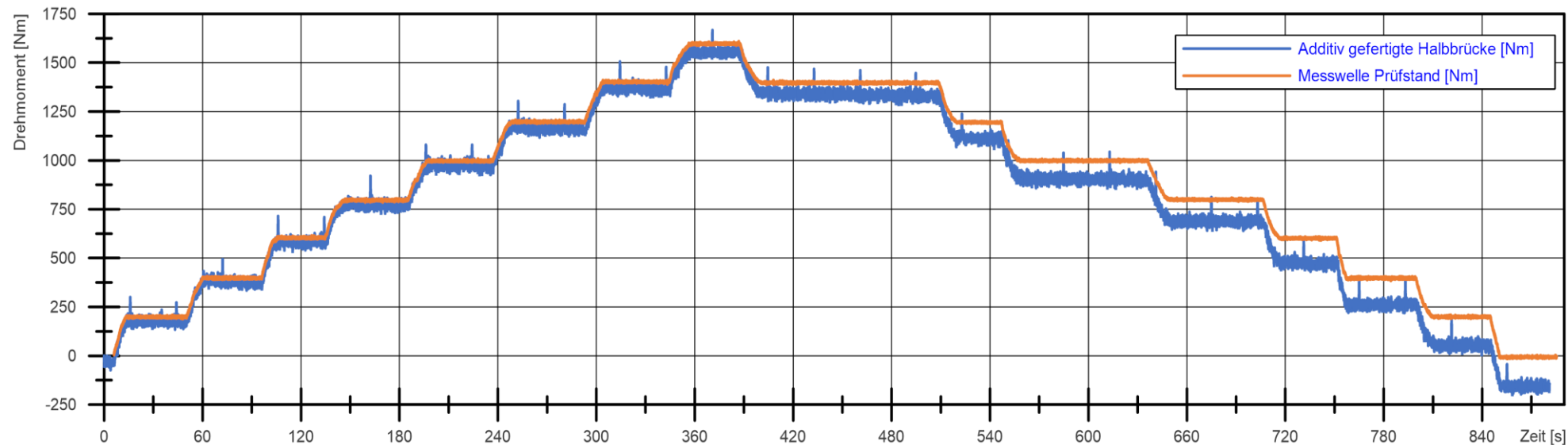


Sensor-equipped shaft clamped into the test rig and connected to a measurement amplifier

Project „Printed Sensors on Drive Strain Components“ - FVA 937 II

Results – Torque sensor on metal shaft on test rig

- **Step-load application** to the shaft on the torsion test rig
- Recording of the sensor signal (half-bridge) → comparison to internal test rig torque sensor
- Subsequent adjustment of offset and scaling



Test rig @ Flender Bocholt

Project „Printed Sensors on Drive Strain Components“ - FVA 937 II

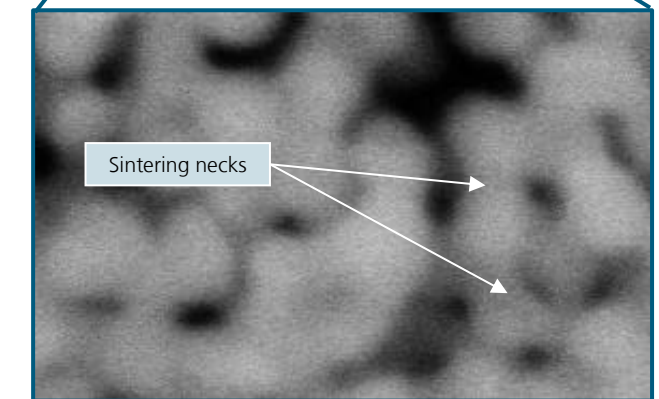
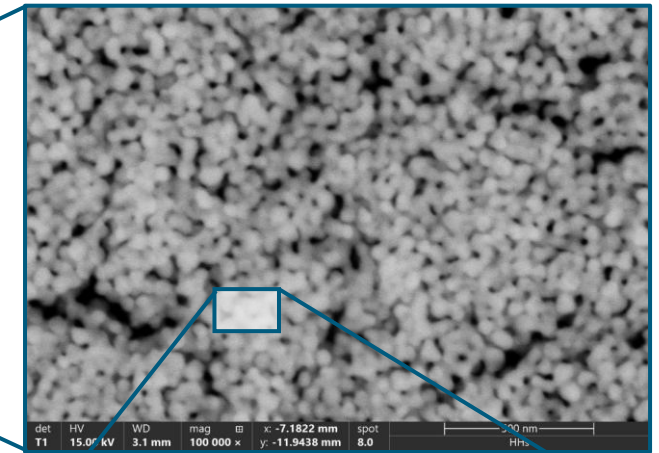
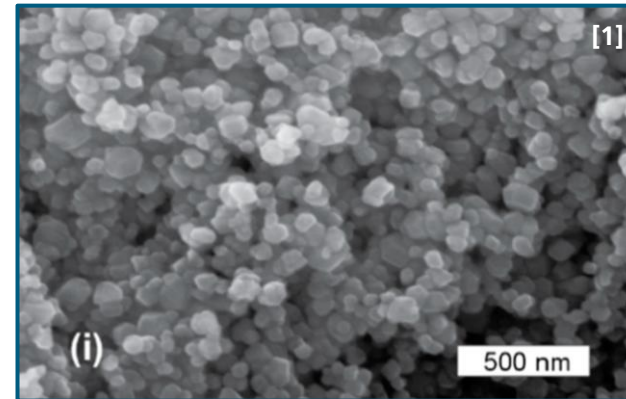
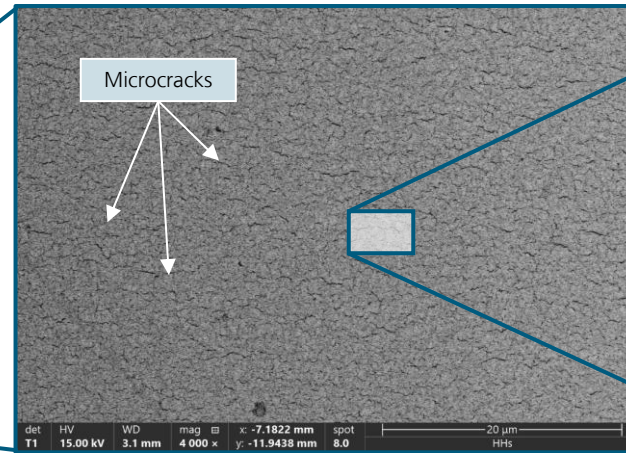
Results – SEM images of laser sintered Ag nanoparticles

- SEM analysis of printed sensors show
 - Microscale cracks
 - Porous sintering structure
- Structure is prone to crack propagation



Inkjet-printed full-bridge design

- Porous nanostructure poses challenge for functional strain gauges
- Optimization of sintering process necessary



Conclusion

Advantages of additive sensor manufacturing

- Automatable
- Freedom of design
- Potential for long-term stability



Principle functionality was shown in the project

- Additively manufactured sensor using different printing technologies
- Characterization in test rig on drive component



What we still need to figure out

- Mobile application platform
- Deeper understanding of sintering process
- Holistic approach to sensor system (including isolation, contacting and packaging under real-life conditions)



Appendix

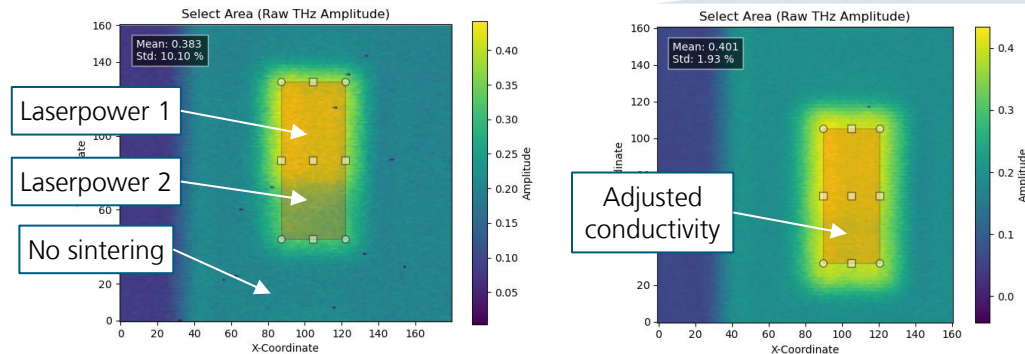
THz-based Quality Control and Laser-based Error Correction

Applied for Conductive Structures in Printed Electronics and Semiconductors

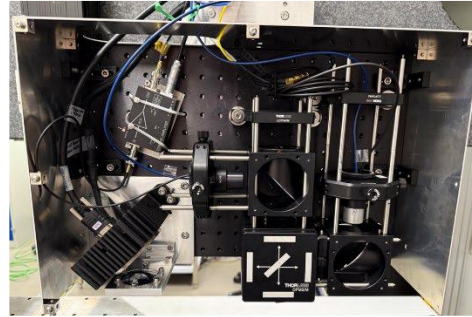
Far field THz

- Using a scanner-based system to map an area
- Area rate: 0,33 cm²/s

Processing chain:



- Selective laser sintering can be applied to locally adjust the conductivity



Near field THz

- Laser crystallization of amorphous silicon wafer → adjustment of sheet resistance
- Near field THz measurement by PROTEMIX

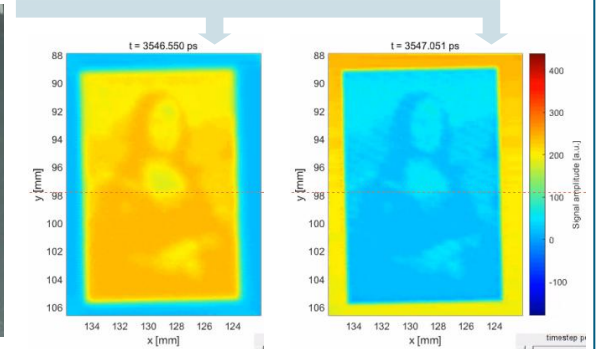
Laser Process Energy Map



Wafer after crystallization



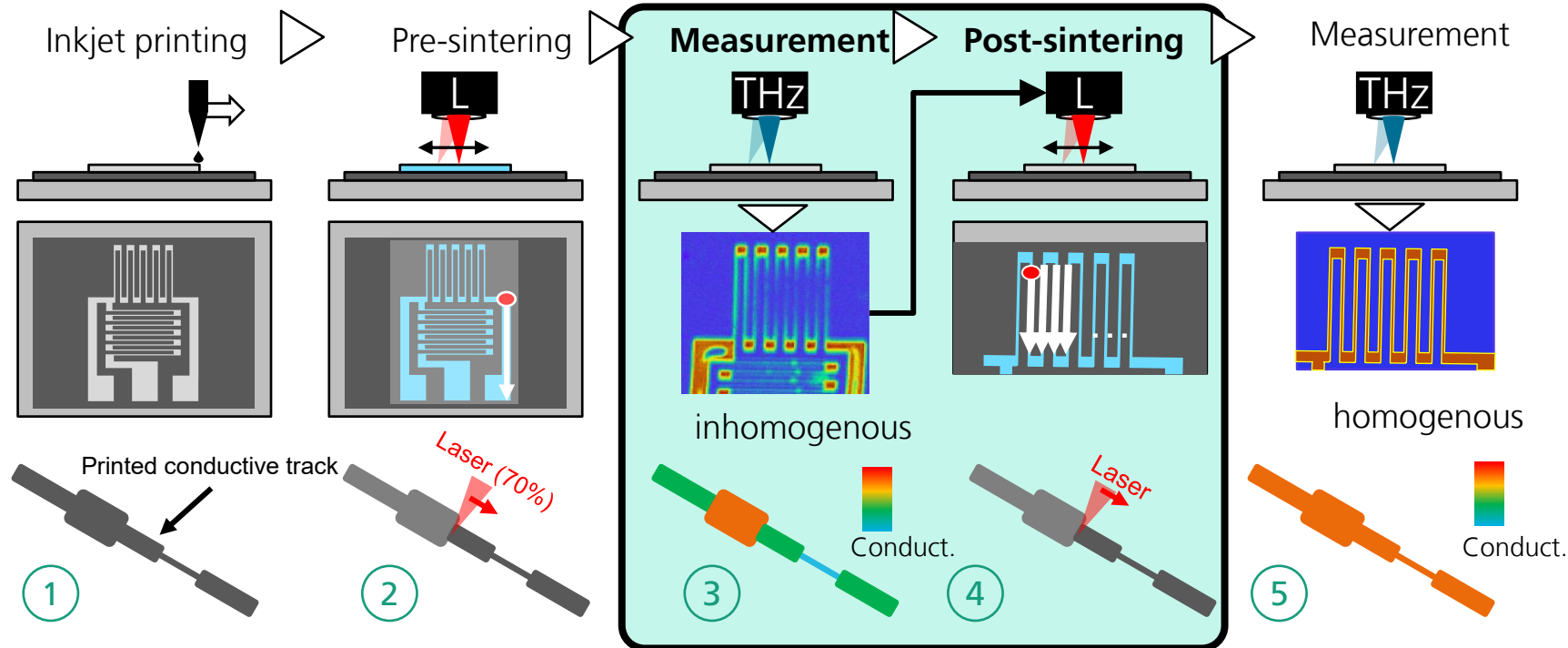
THz measurement (at different time offsets between reference-pulse and signal pulse)



- Near Field THz lateral resolution up to 80 $\mu\text{m}/\text{px}$ > spot size
- Measuring time: 250 ms/px

THz-based Quality Control and Laser-based Error Correction

BMFTR VIP+ Call for Validation



Looking for:

- Industry input for applications
- Associated partners
- Letters of Intent (LOI)

Project Goals Outline:

- Demonstrating laser processing for selective re-sintering
- Pre- and post-Sintering informed by accurate THz-Measurement of local resistivity
- Inline capable measuring speeds and resolutions → ready for industry