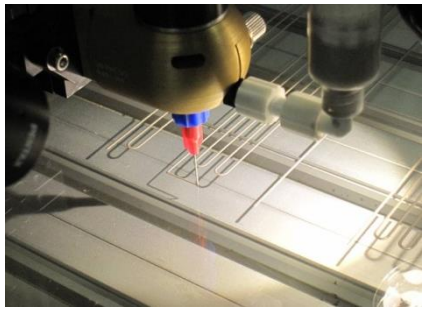
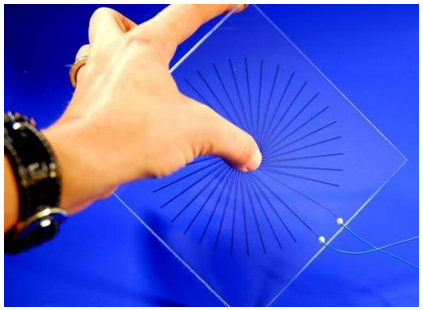
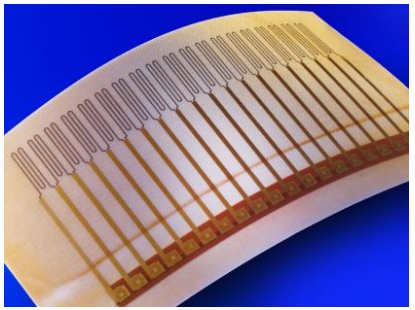
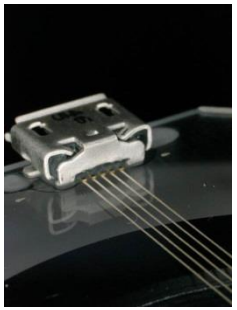
Additive manufacturing as a flexible tool for electrical engineering

Electrical Engineering, Valencia, November 3rd 2015

Dr. Volker Zöllmer

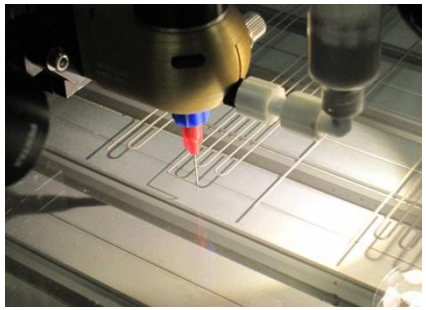
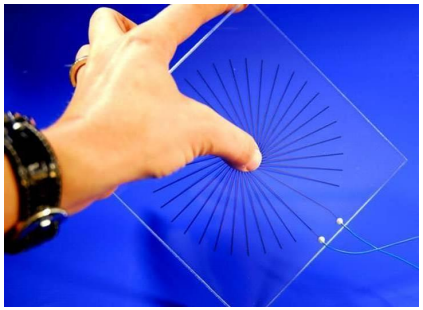



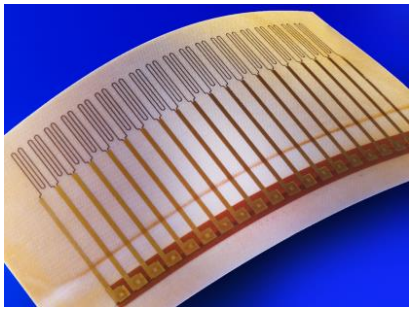
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Fraunhofer IFAM

Additive manufacturing as a flexible tool for electrical engineering

1. Introduction Fraunhofer IFAM
2. Functional Printing - Electrical engineering by use of printing technologies
3. Sensor Integration
4. Energy Harvesting
5. Electronics on 3d-surfaces – „3d-Electronics“
6. Summary




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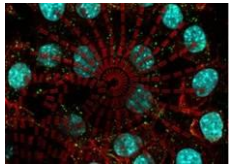
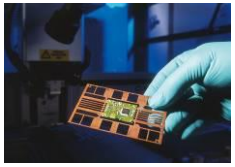
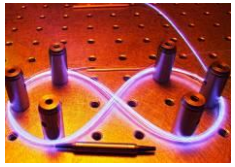
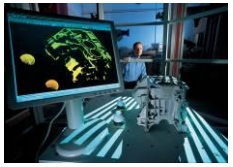
1. Introduction
Fraunhofer-Society

- Fraunhofer is the largest organization for applied research in Europe
- More than 80 research institutions, including 66 Fraunhofer institutes 22000 employees
- Research volume: 2 billion €

- Information and Communication Technology
- Life Sciences
- Materials and Components
- Microelectronics
- Production
- Surface Technology and Photonics
- Defense and Security







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Fraunhofer IFAM

1. Introduction
Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM

- Departments
  - Shaping and Functional Materials
  - Adhesive Bonding Technology and Surfaces
- Locations in Bremen and Dresden
- Project groups in Oldenburg, Stade and Wolfsburg
- 589 Employees
- Overall budget in 2014: 47 Mio. €



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Fraunhofer IFAM

2. Functional Printing
Motivation – Printed Electronics



- Lighting (LED & OLED)
- (Organic) Photovoltaics
- Flexible Displays
- Electronics (RFIDs, Energy Storages, …
- Integrated Smart Systems (Sensors, Textilies,…)

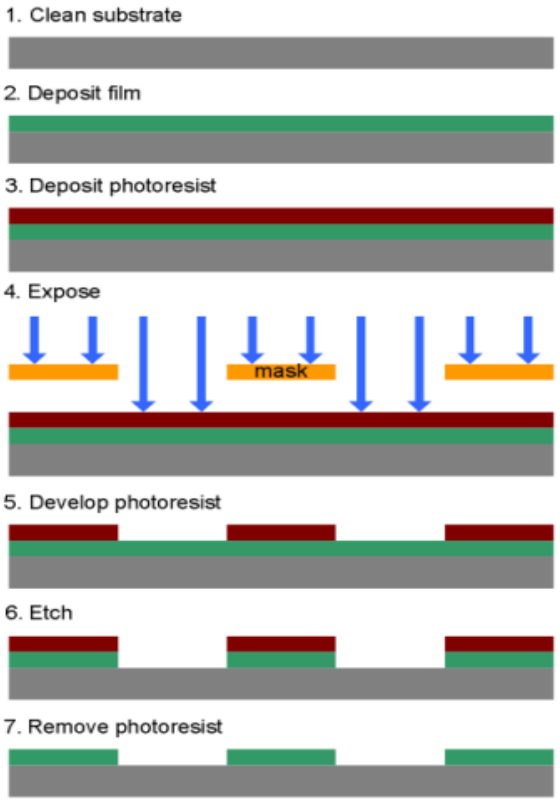
(© OE-A Roadmap for Organic and Printed Electonics, 6th Ed. 2015)

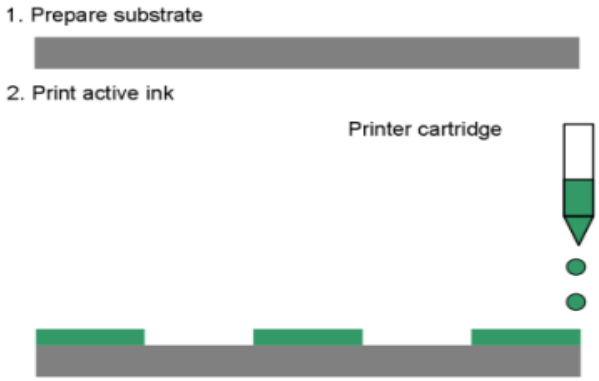
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2. Functional Printing
Motivation – Printed Electronics

Advantages of Functional Printing:





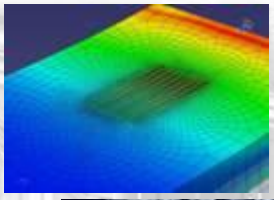
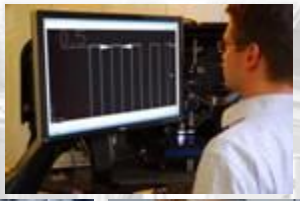
Additive Manufacturing:

- Less processing steps
- Few material
- High design freedom
- Fast product development
- (Digital design)

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2. Functional Printing
Additive Manufacturing of Smart Structures







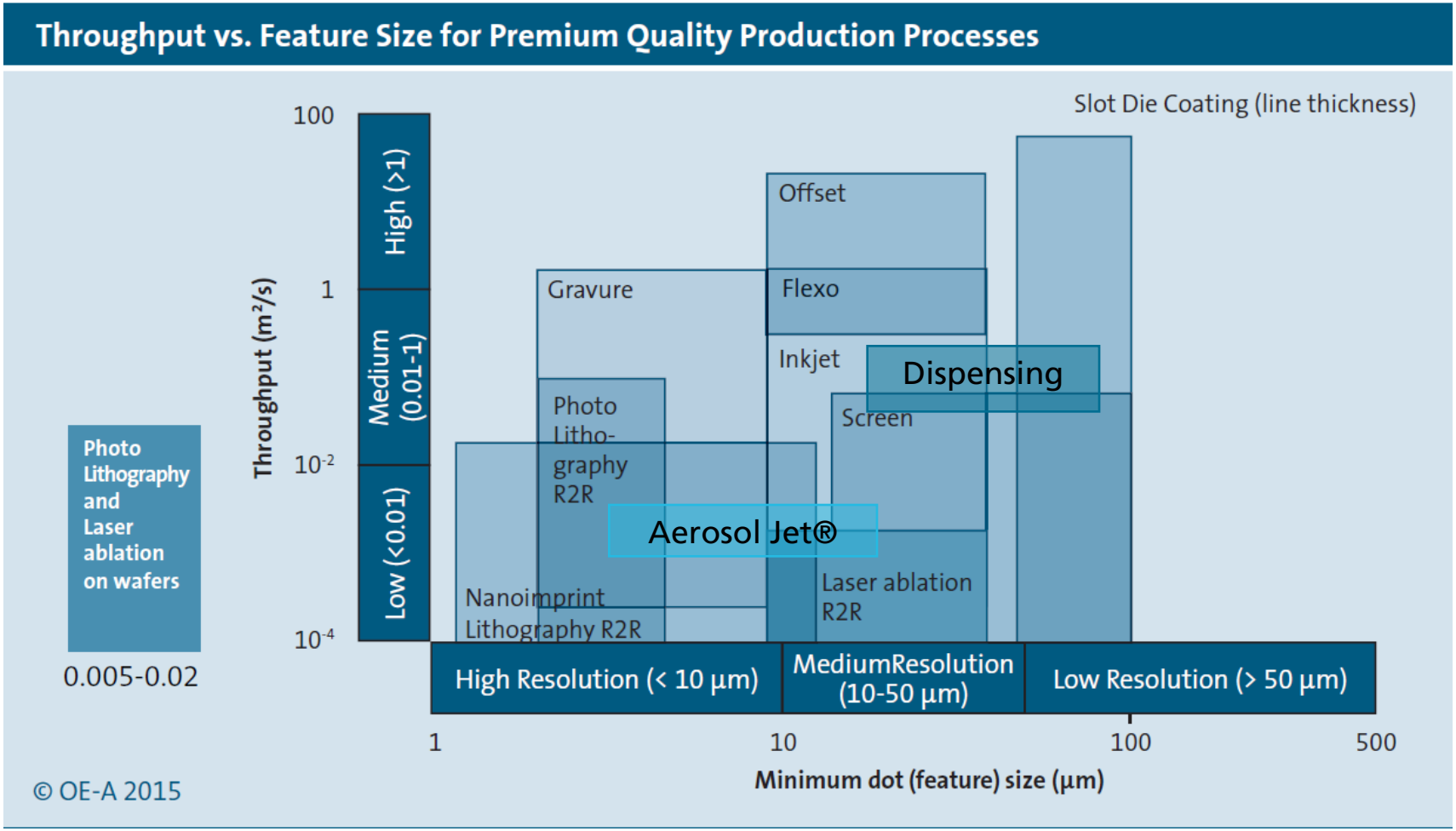


- Design & Layout
- Material screening: metals, alloys, polymers, ceramics, bio-materials, …
- Ink / paste formulation
- Printing processes: InkJet, Aerosol Jet, Screen printing, dispensing …
- Thermal activation: UV, Laser, Oven, …
- Characterization: Mechanical, optical, electrical, …

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2. Functional Printing
Features of different printing technologies

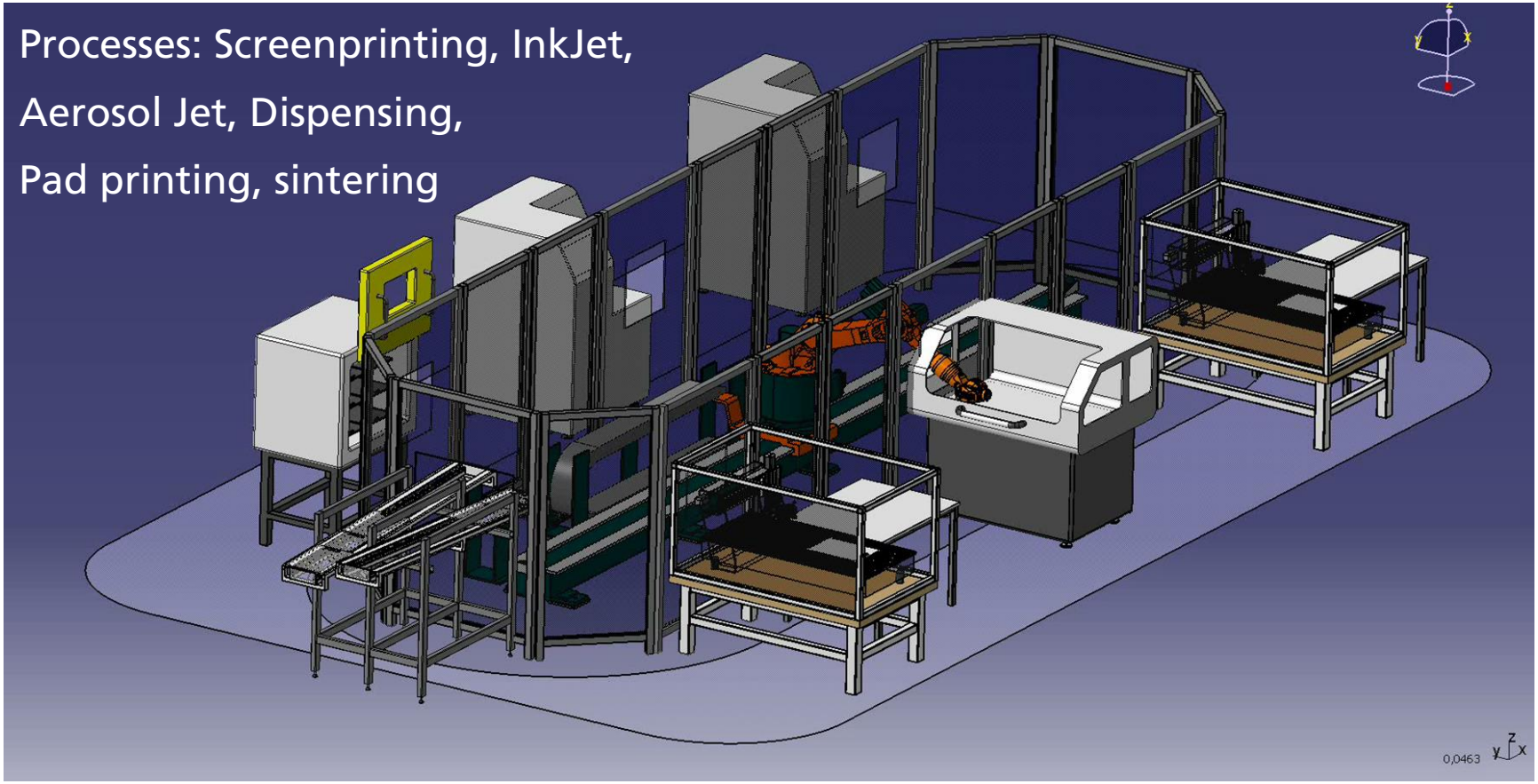


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2. Functional Printing
Modular Manufacturing Platform



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2. Functional Printing
Modular Manufacturing Platform



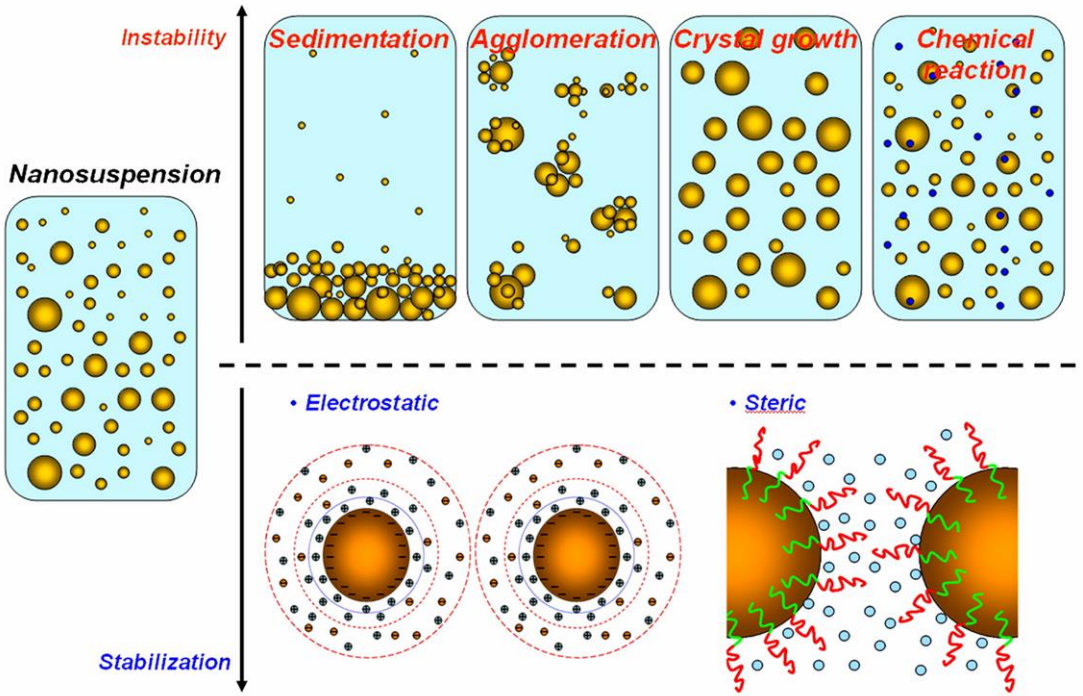




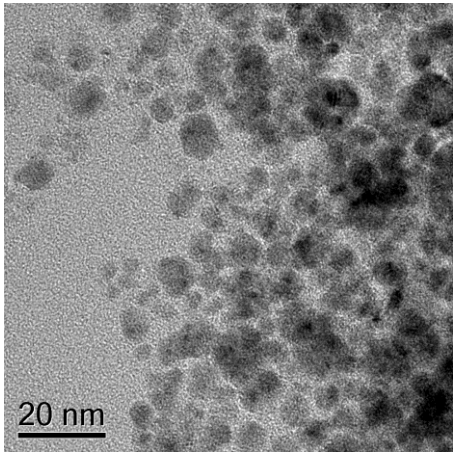
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2. Functional Printing
Material Development







Interactions between (nano-) particles and ink solvents

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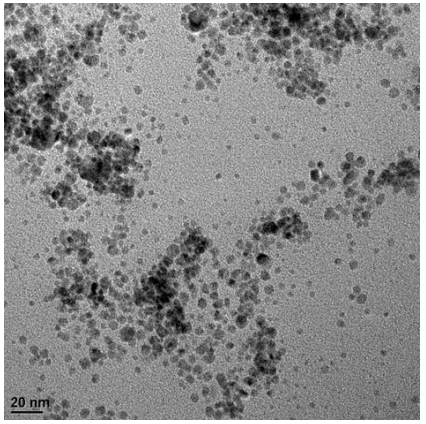
2. Functional Printing
Material Development

Ink / paste development:

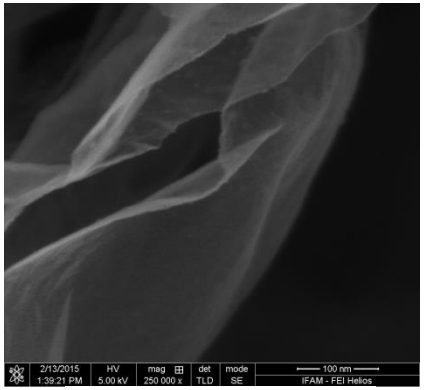
- Ag, Cu, alloys (e.g. CuNi)
- Isolators: Ceramics (TiO_2, SiO_2, …), Polymers
- Dielectric Materials
- Biological materials: Enzymes, Proteins, DNA, Bio-ceramics…
- Graphen and Graphen-Composites

Ink / paste optimization in view of:

- Sedimentation stabilities
- Surface tensions / contact angle
- Viscosity / Particle size distributions
- particle morphology (SEM,TEM,...)
- Material/phase analysis (EDX, XRD, ...)
- Surface characterization (BET, XPS, ...)



TEM: CuNiMn-Ink



SEM: Graphen-Ink

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2. Functional Printing
Material Development

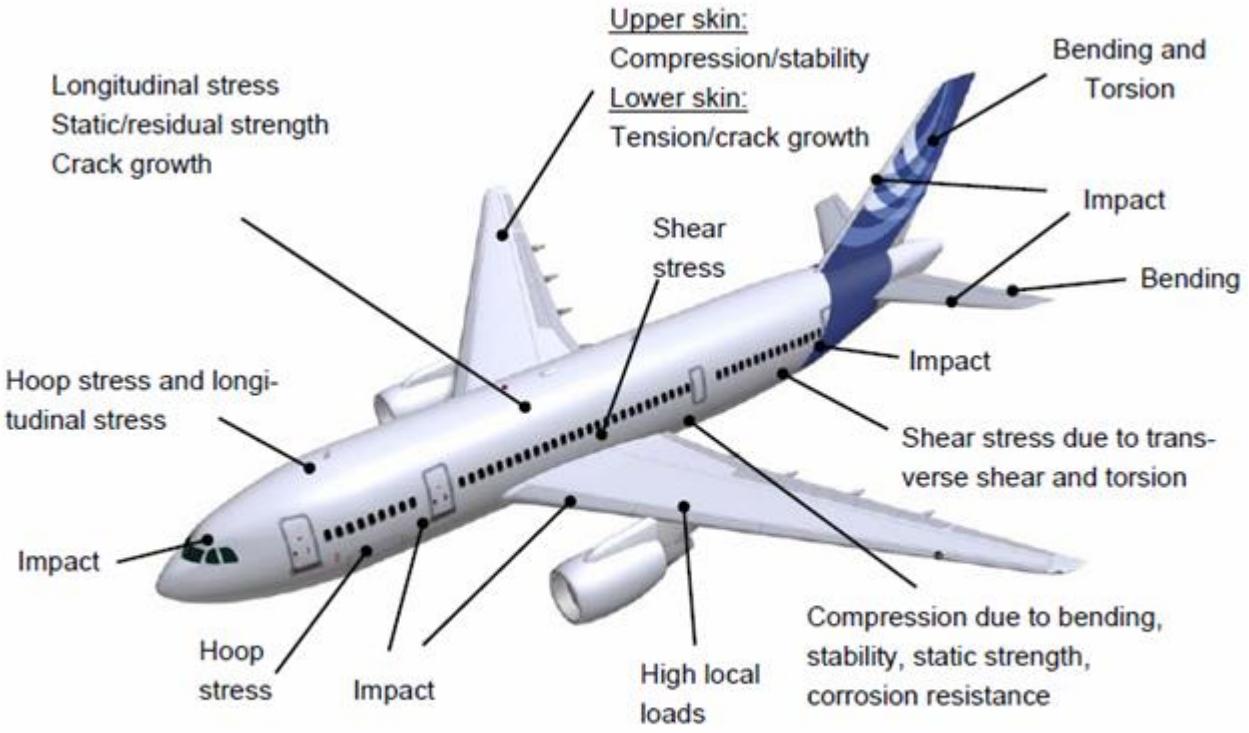
- CuNiMn is an appropriate material for printed strain gauges
  - $Cu_{0.55}Ni_{0.44}Mn_{0.01}$ (constantan)
  - low temperature coefficienct of resistance (TCR)
  - mechanical properties

Ag	CuNiMn
TCR: 3.8 x 10^{-3} K^{-1}	TCR: 0.01 x 10^{-3} K^{-1}
Commercially available from different suppliers	not commercially available

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3. Sensor Integration
Printed strain gauges for SHM - applications



Non-destructive testing (NDT) is needed in order to ensure the integrity of the airframe.

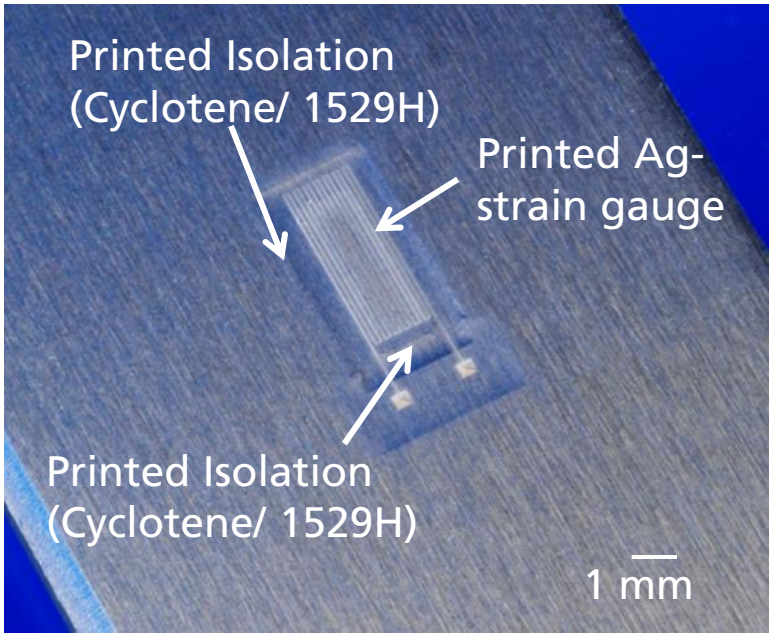
© C. Bockenheimer, Airbus Deutschland GmbH: SMIST – Structural Monitoring with Advanced Integrated Sensor Technologies – Aeronautic Days, Vienna, 19.-21.06.2006

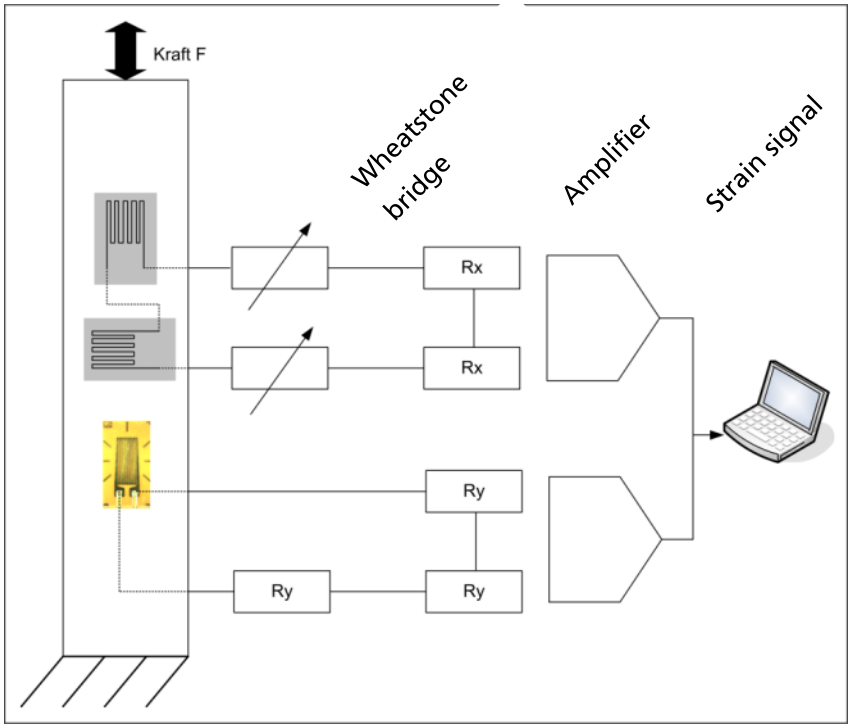
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3. Sensor Integration
Printed strain gauges for SHM - applications

- Characterization setup





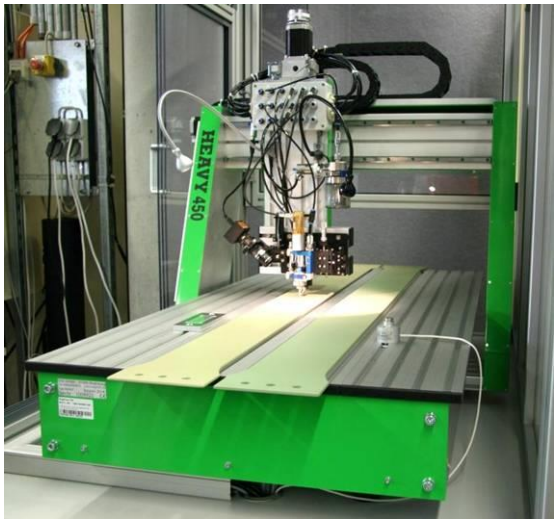
$$R = \frac{\rho \cdot l}{A} \qquad \frac{\Delta R}{R} = k \cdot \frac{\Delta l}{l}$$

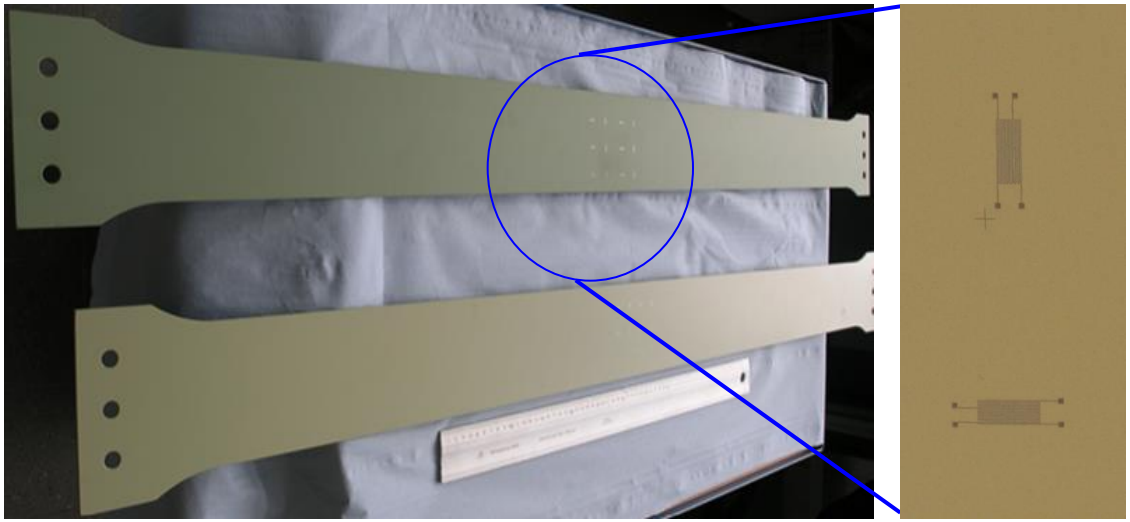
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3. Sensor Integration
Printed strain gauges for SHM - applications

- Printing on 3-d-components for e.g. Structural Health Monitoring (SHM) applications with Aerosol Jet®



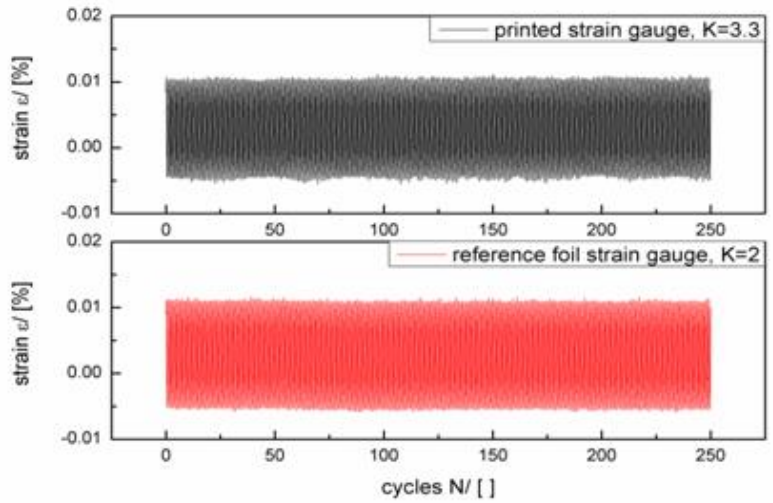


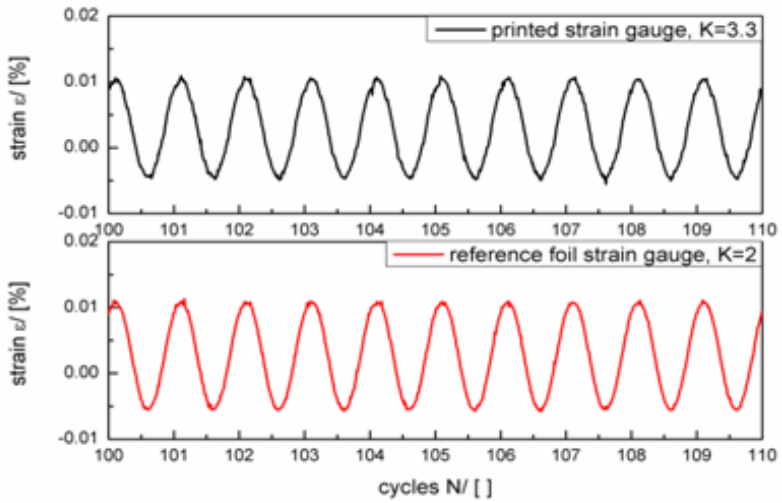
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3. Sensor Integration
Printed strain gauges for SHM - applications

- Dynamic test (tensile stress: 1000 N, compressive stress: 500 N, 25 Hz, 7675 cycles)
- Reproducible signals of Ag-strain gauges
- No significant influence of typical printed micro structure





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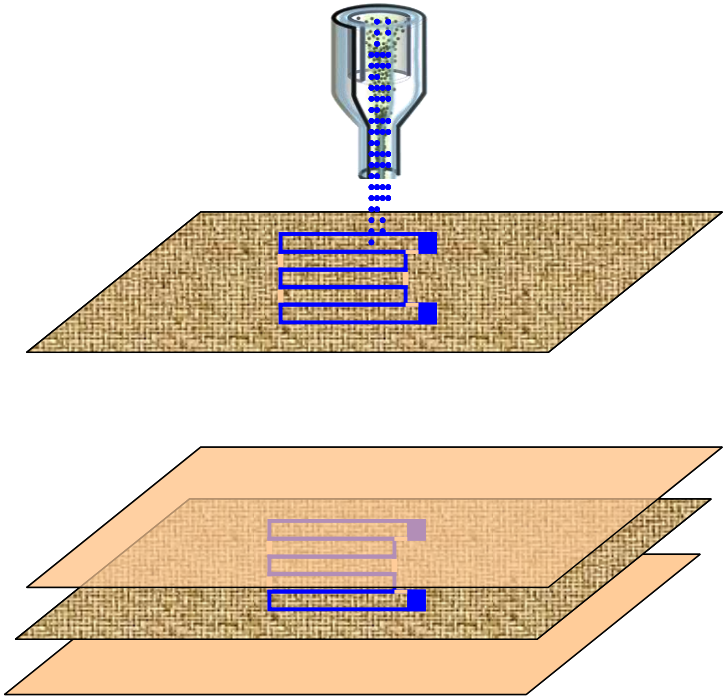
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3. Sensor Integration
Integration of sensor structures into fiber composites

- BMBF-Project „DEFIS“: Sensorintegration



Natural fibre composite rotorblade
(© Invent GmbH)



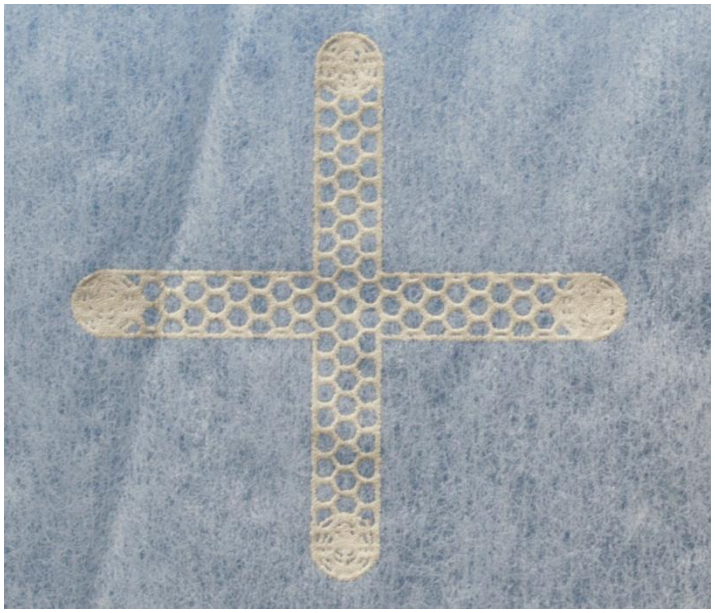
Integration in composites by printing on fleece substrate

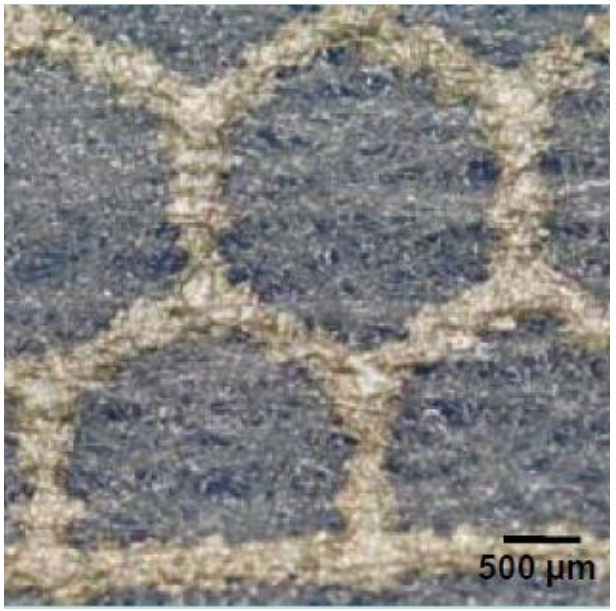
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3. Sensor Integration
Integration of sensor structures into fiber composites

- BMBF-Project „DEFIS“: Sensorintegration





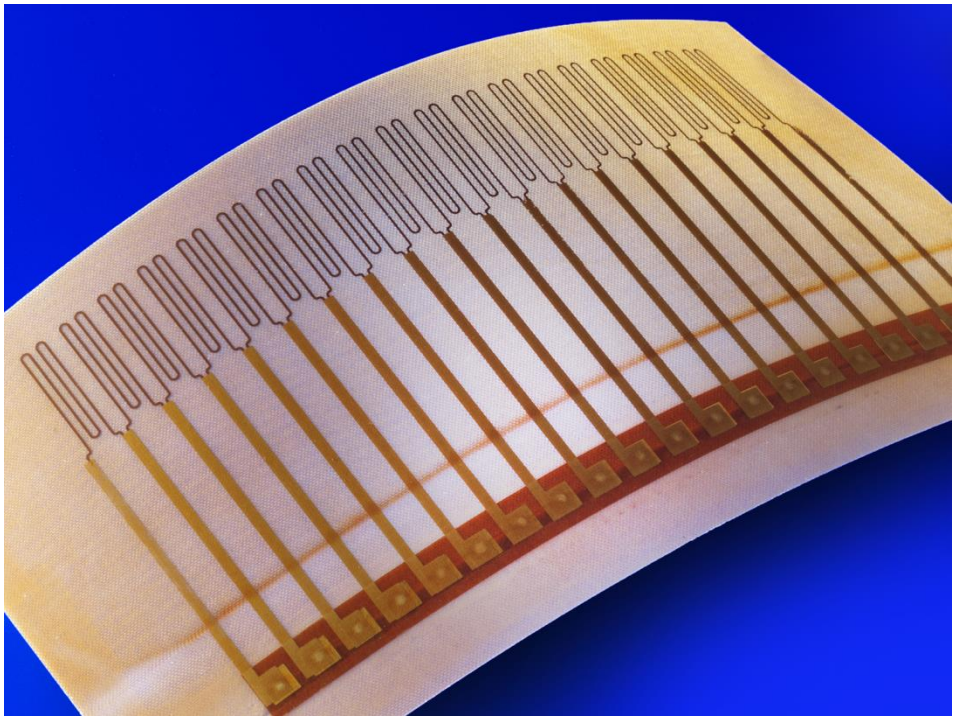
Printed Ag- structure on fleece substrates

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3. Sensor Integration
Integration of sensor structures into fiber composites

- BMBF-Project „DEFIS“: Sensorintegration



Integrated sensor structures into glas fibre composite

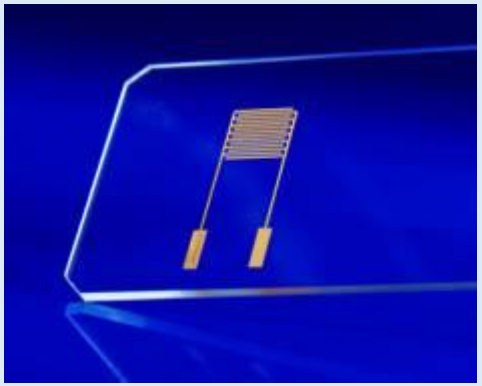
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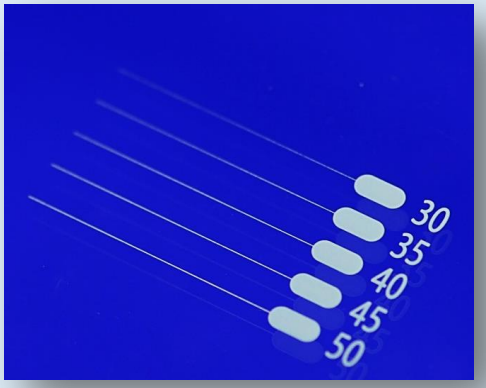
3. Sensor Integration
Printed electronics and printed sensor structures



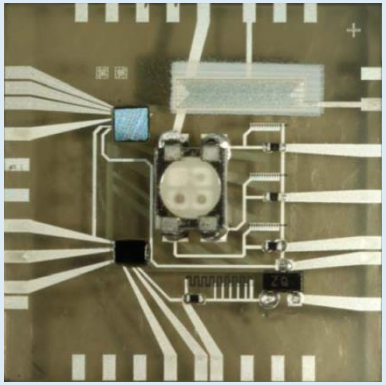
- Temperature sensor



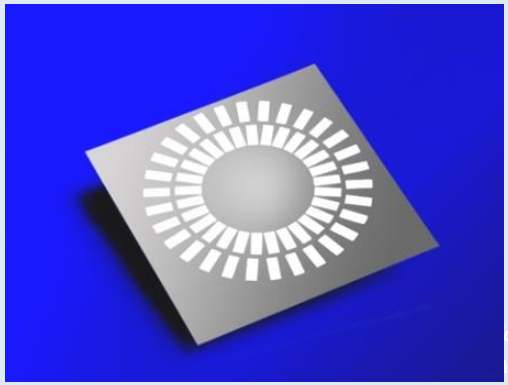
- Interdigital structures



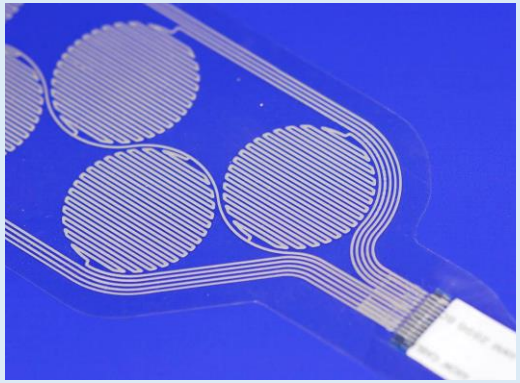
- Conductive traces on glass



- Resistors, capacitors, circuit boards, …



- Magnetic structures for position sensors



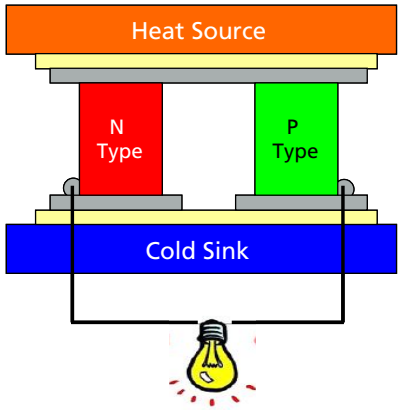
- Temperature sensor on flexible foils

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4. Energy Harvesting

Energy Harvesting with printed thermoelectric devices



"Figure of merit" - value:

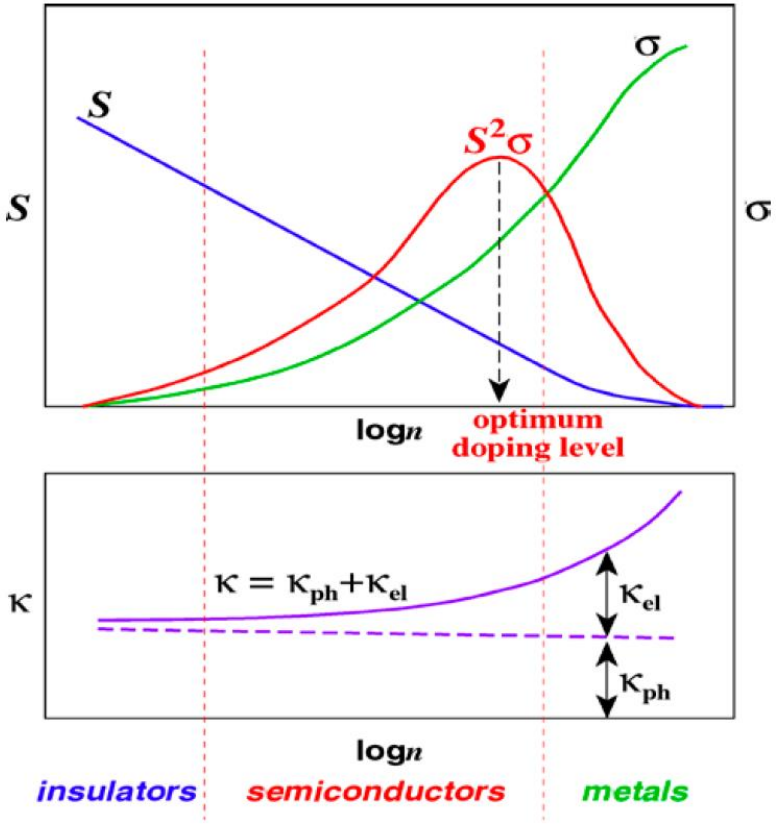
$ZT = S^2T\sigma/\kappa$

S = Seebeck coefficient

σ = electrical conductivity

κ = thermal conductivity

T = absolute temperature



(© Michitaka Ohtaki: „Oxide Thermoelectric Materials For Heat-to-Electricity Direct Energy Conversion")

Requirements on thermoelectric materials

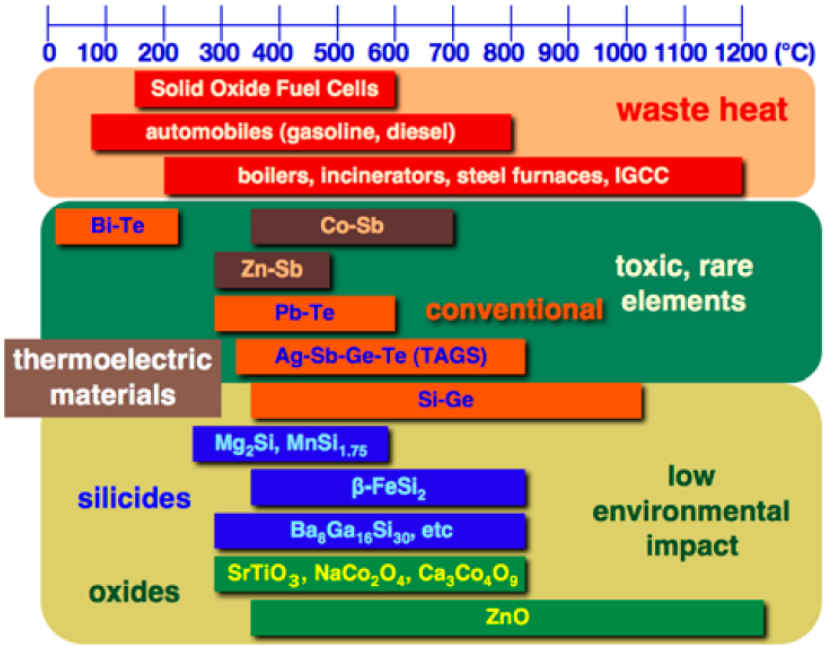
- High electrical conductivity
- Low thermal conductivity
- Semiconductors are of great interest
- ZT >1: high efficient material (~10% efficiency)

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4. Energy Harvesting
Energy Harvesting with printed thermoelectric devices

- Typical thermoelectric materials



Disadvantages:

- Special temperature regimes
- Toxicity
- Costs

R&D-topics:

- Oxides & nano-structured materials
- Electrical conductive polymers
- Polymer-composites

(© Michitaka Ohtaki: Oxide Thermoelectric Materials for Heat-to-Electricity Direct Energy Conversion)

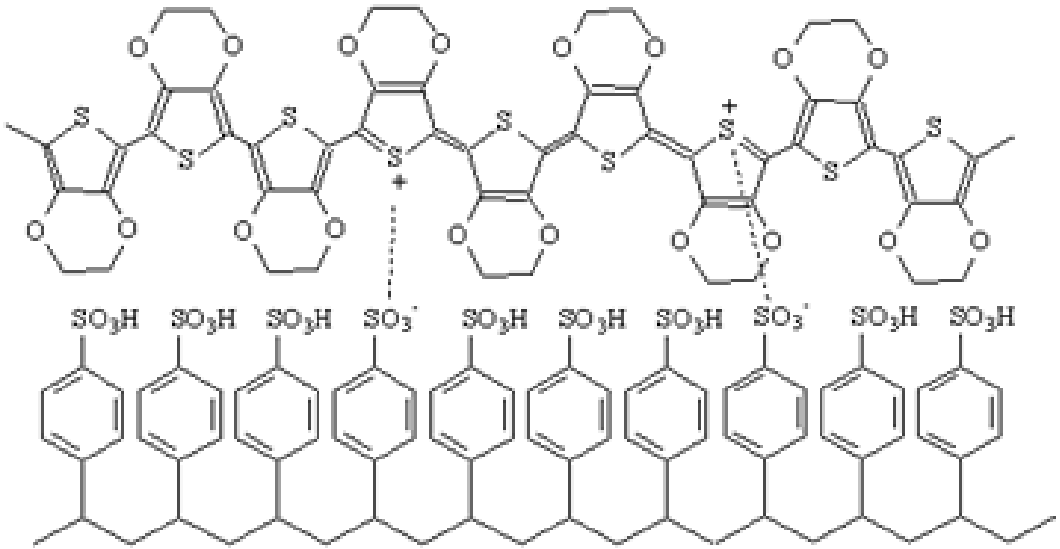
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4. Energy Harvesting
Energy Harvesting with printed thermoelectric devices

Possible thermoelectric material for printing:

- Electrical conductive polymers, e.g. PEDOT:PSS



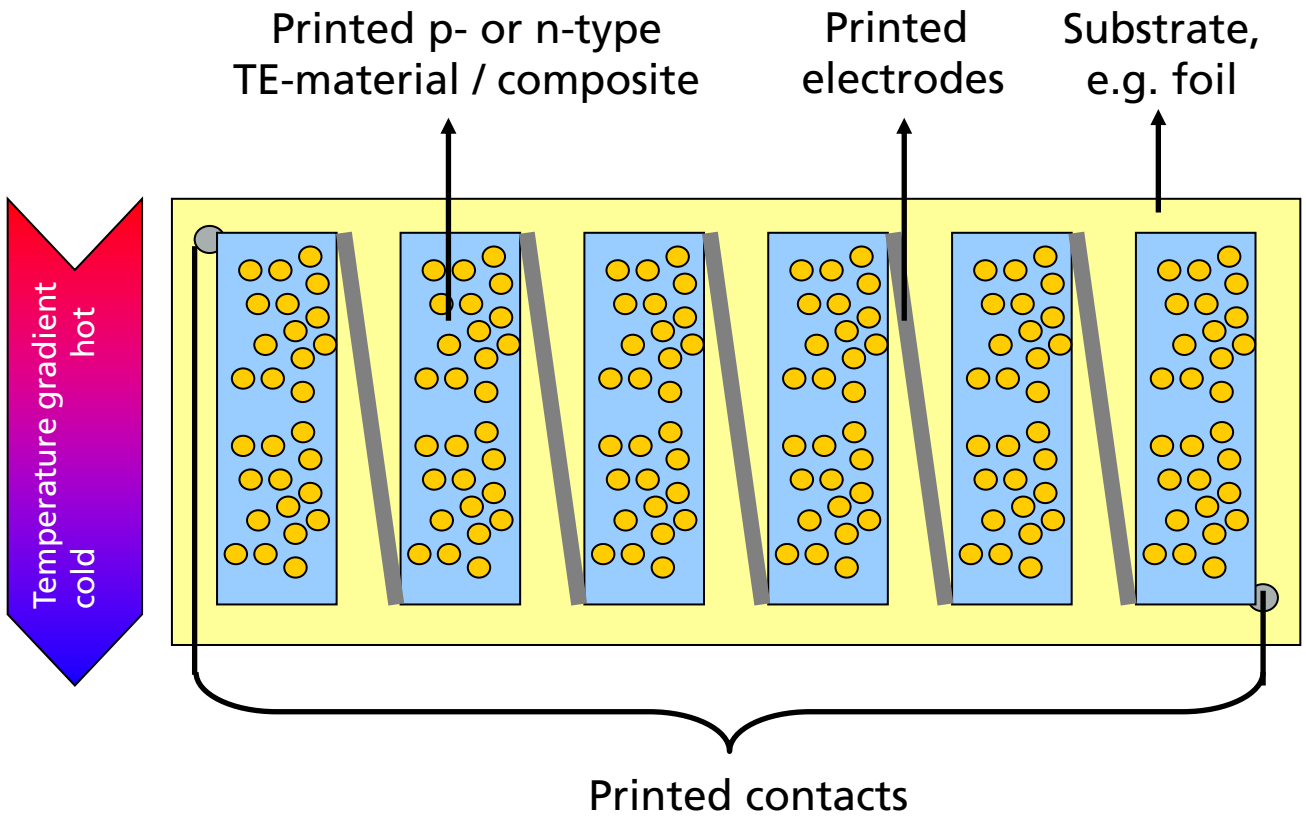
- PEDOT: Poly-3,4-ethylendioxythiophen
- PSS: Polystyrolsulfonat

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4. Energy Harvesting

Energy Harvesting with printed thermoelectric devices

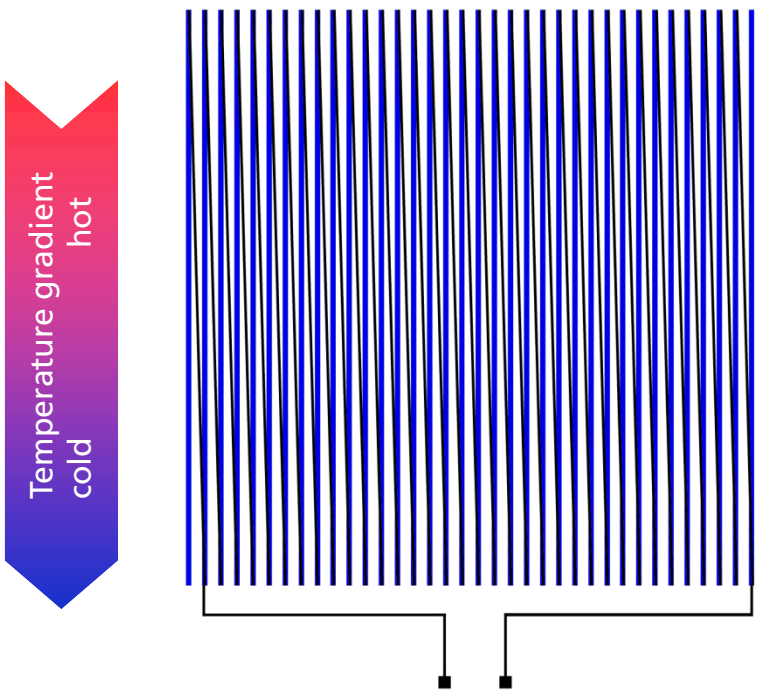


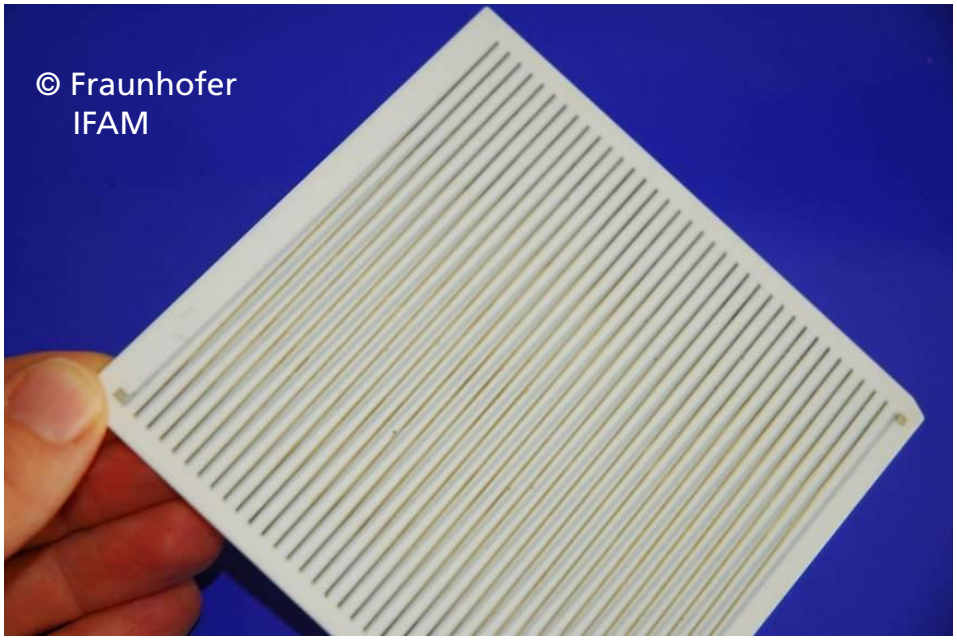
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4. Energy Harvesting

Energy Harvesting with printed thermoelectric devices





Layout and printed TEG-structure (thermal activation: T:150°C, t:30min)

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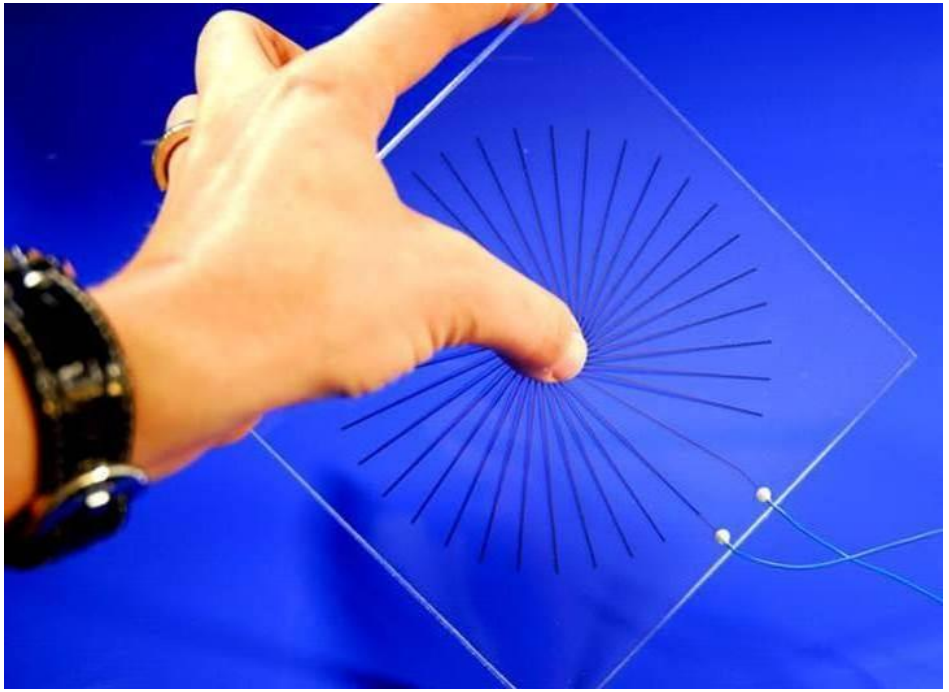
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4. Energy Harvesting

Energy Harvesting with printed thermoelectric devices

Characterization:

- Material A: Silver
- Material B: Alloys (e.g. $Cu_{55}Ni_{44}Mn_1$) or Polymers (e.g. PEDOT:PSS)
- ΔT of few K sufficient to harvest electrical energy
- Harvested energy depends on:
  - Heat flow
  - Number of contacts
  - ZT-value of materials
- Aim: Power in µW – range for Ultra-Low-Power (ULP) applications (e.g. sensor networks)

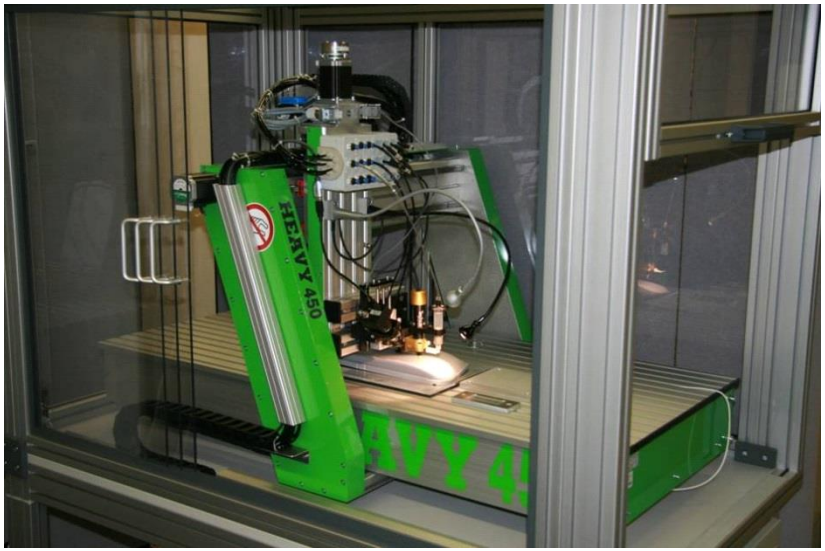


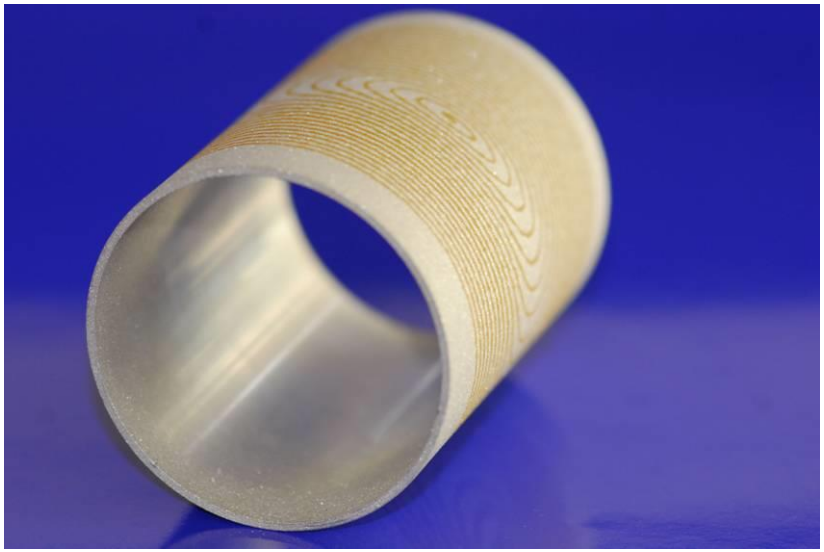
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5. Electronics on 3d-surfaces – „3d-Electronics“
Printing on 3d-Surfaces

Printing on 3-d-components





- Flexible module for customized functionalization of 3d-shaped parts

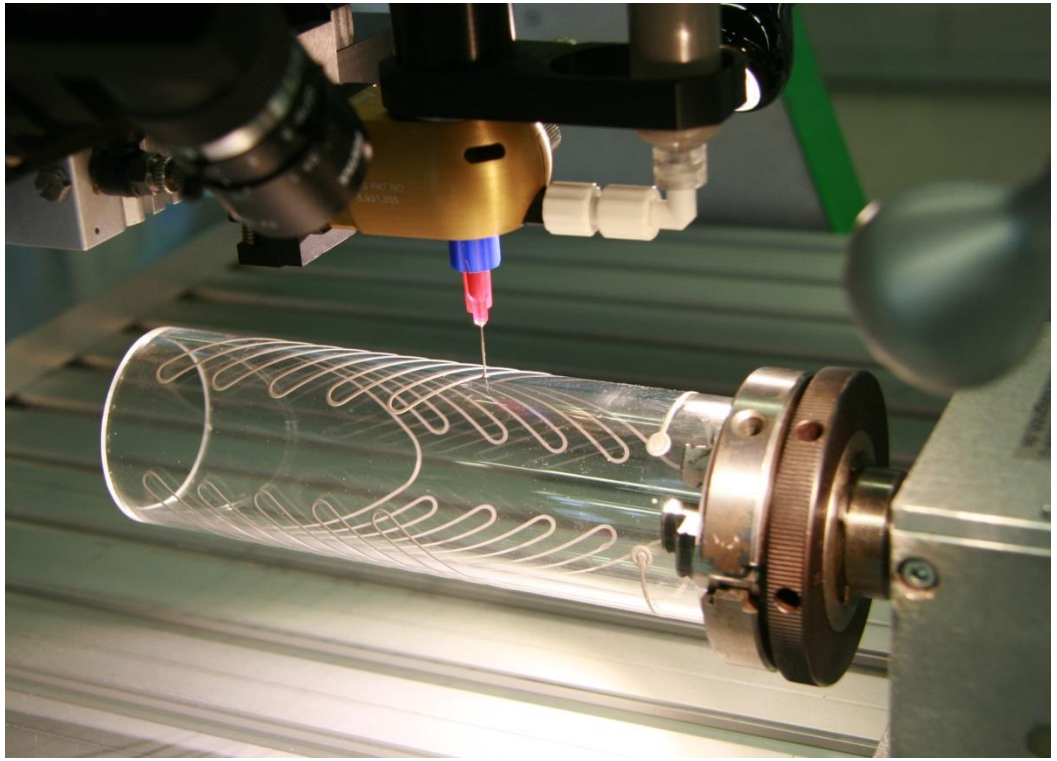
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5. Electronics on 3d-surfaces – „3d-Electronics“
Printing on 3d-Surfaces

Printing on 3d-parts:

- Printing sensors, actors, and heating sructures on complex shaped parts
- High flexibility of the process concerning geometry of the printed structures and the substrates
- New applications



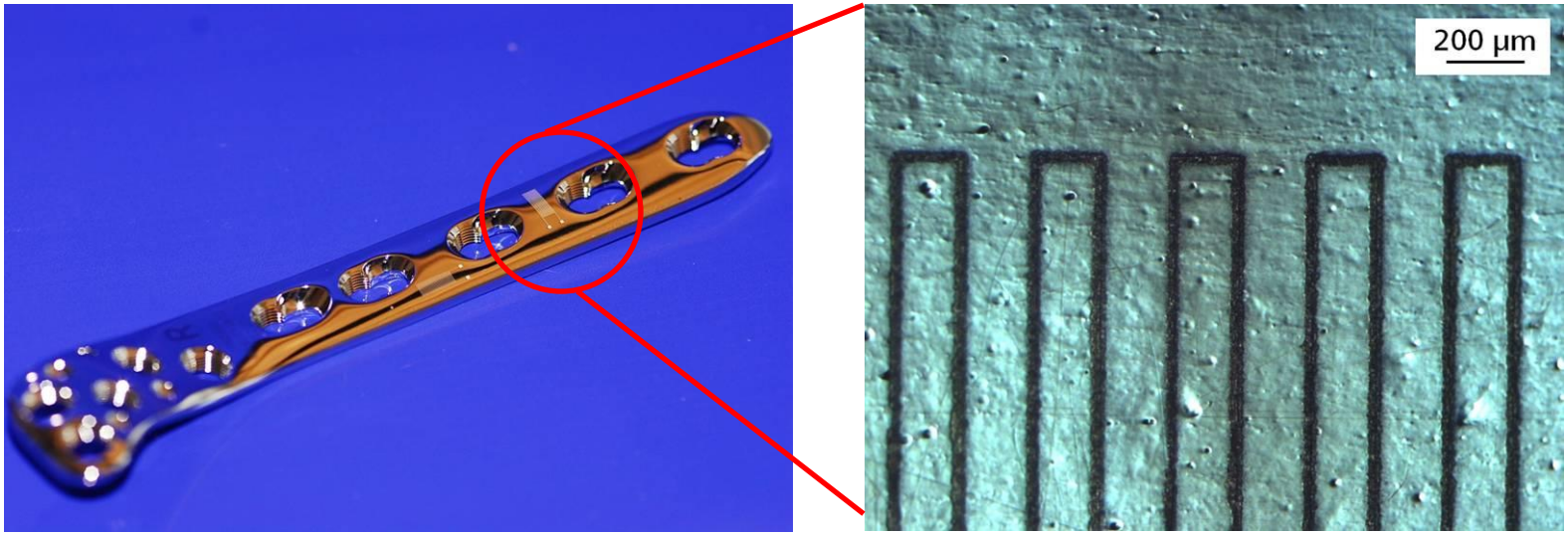
- Printed heating structure on glass cylinder

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5. Electronics on 3d-surfaces – „3d-Electronics“
Printing on 3d-Surfaces

- Printing on 3d-parts: Printed strain gauges on implant structures



Stainless steel LCP-PLT implant (Synthes Inc.), functionalized with aerosol printed strain gauges (left); microscopic view of printed strain gauge detail (right).

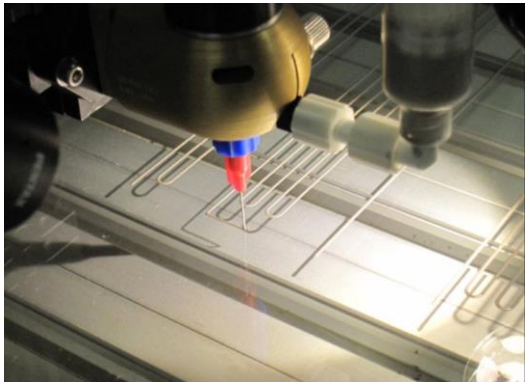
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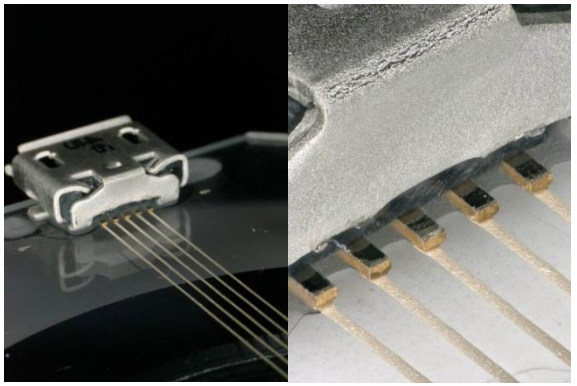
6. Additive manufacturing as a flexible tool for electrical engineering

Summary

- Additive Manufacturing / Functional Printing is a flexible technology platform for integration of sensors, actuators and electronics.
- Printing processes, functional inks and thermal post treatment have to be considered
- Considering 2d- and 3d-electronics will offer possibilities for new applications and new products







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6. Additive manufacturing as a flexible tool for electrical engineering

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Additive manufacturing as a flexible tool for electrical engineering

Electrical Engineering, Valencia, November 3rd 2015

Thank you for your attention!



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