Printing of Electrical Functional structures using additive technologies

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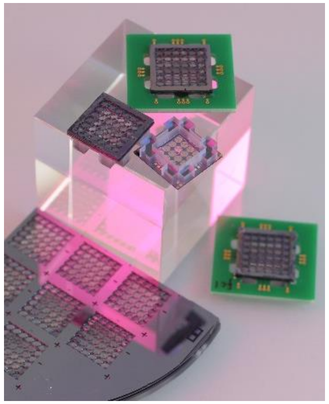

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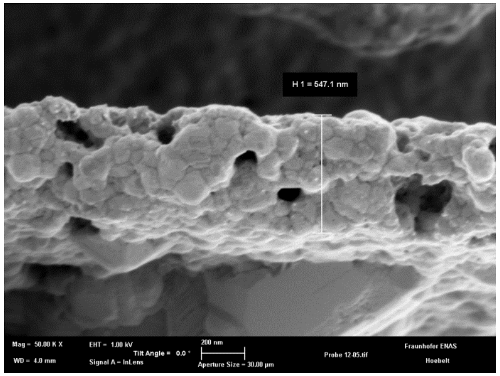

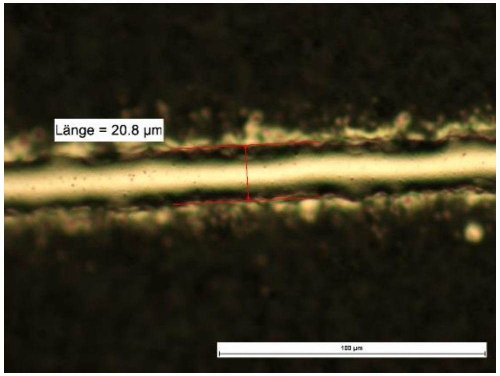

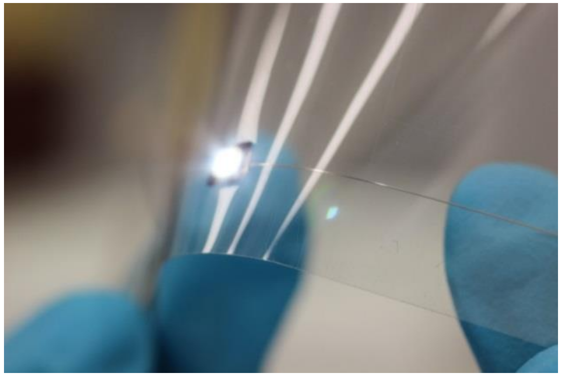

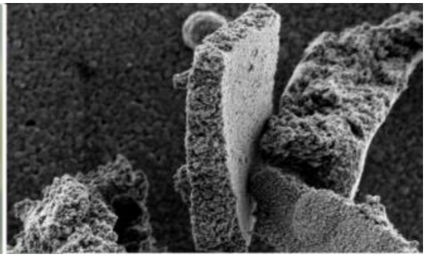

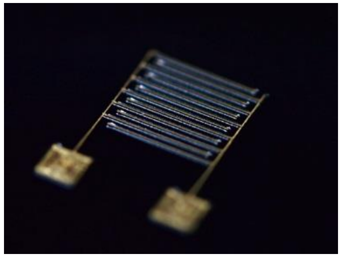

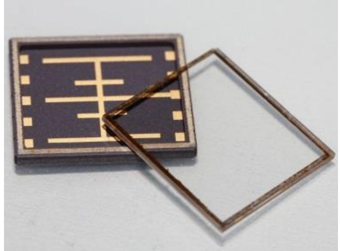

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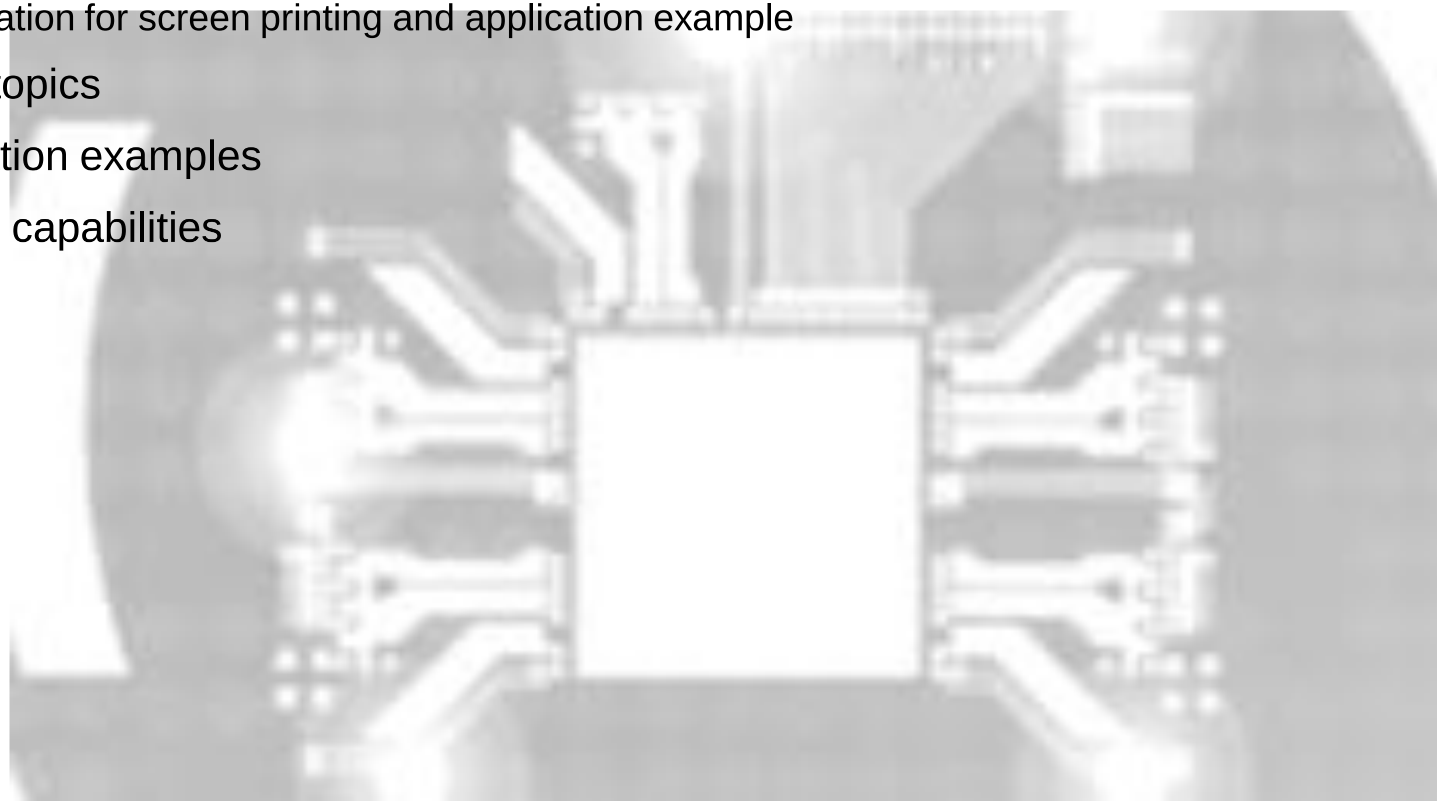
Outline

1. Technologies / Materials / Process Flow
   1. Aerosol-Jet-Deposition & Screen Printing
   2. Paste formulation for screen printing and application example
2. Selected R&D topics
3. Further Application examples
4. Further printing capabilities



1. Technologies / Materials / Process Flow

Aerosol-Jet-Printing Deposition Technology for Nanoparticle inks

Equipment @ ENAS

- Customized Optomec AJ300 System
- 300 x 300 mm x-y-Vacuum stage
- Print Speed: max. 200 mm/s

- 2 Atomizer systems:
  - 2 x Pneumatic Atomizer incl. Mixing option
    - [1cP – 1000cP]
  - Ultrasonic Atomizer
    - [1cP – 5cP, from 1ml Fluid]

- 200°C Substrate heater
- Min. line width 10 µm to 20 µm
- Laser-Curing-System included [IR Laser, 700mW, 830nm] and material mixing option

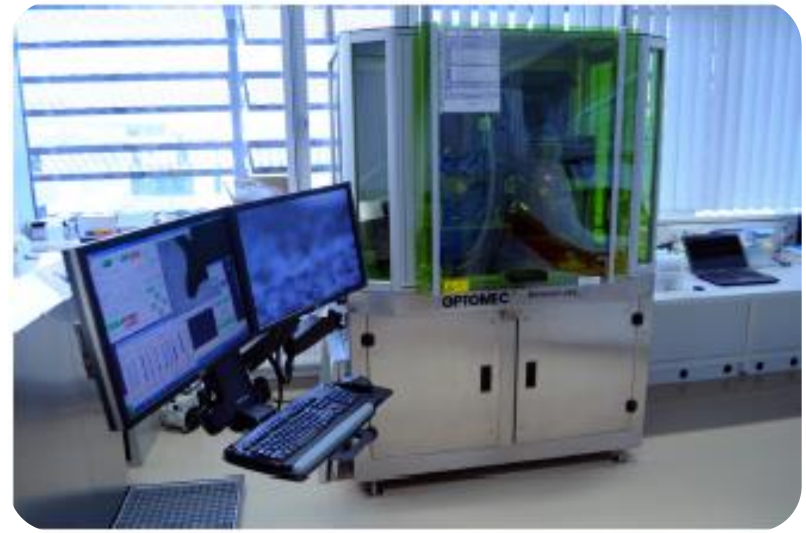


Fig 1: ***Aerosol-Jet 300 System @ Fraunhofer ENAS***

1. Technologies / Materials / Process Flow

Aerosol-Jet-Printing General Work Flow

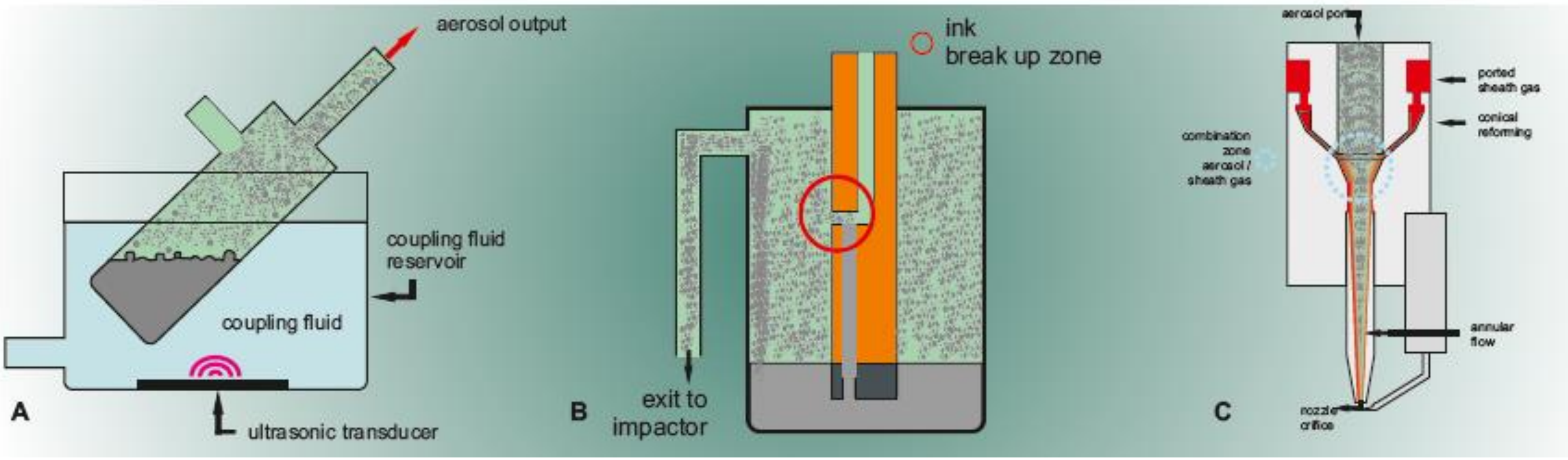


Fig 2: General Workflow overview

A & B: Producing Aerosol by A: Ultrasonic or B: Pneumatic Atomizer Systeme

C: Focusing Material Beam in printhead and direct maskless deposition on substrate

1. Technologies / Materials / Process Flow

Aerosol-Jet-Printing General Work Flow

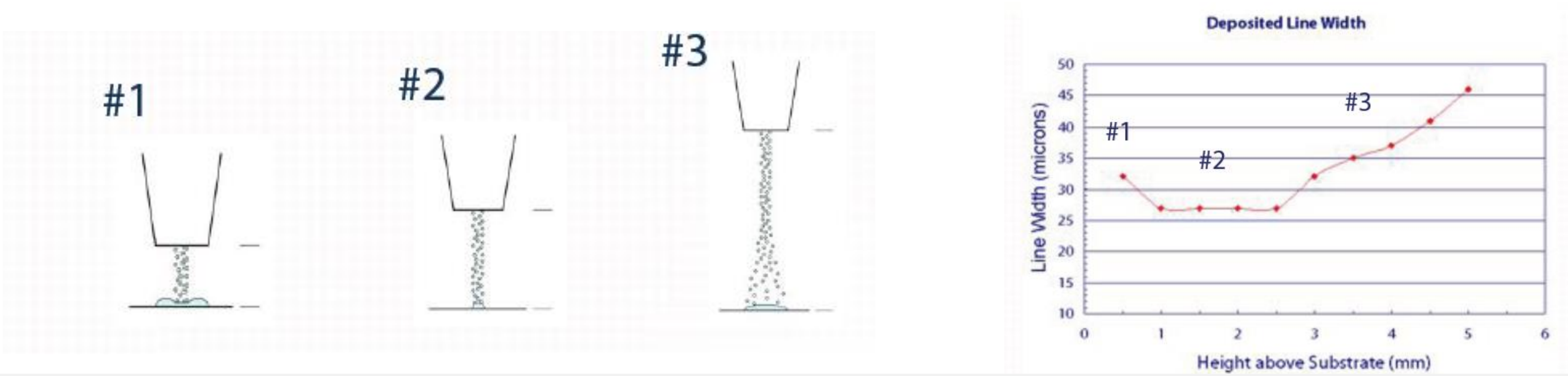


Fig 3: Focused material beam over several millimeters enables deposition on 3D substrates without moving z-axes, diagram shows constant line width between 1mm to 3mm distance between printhead and substrate [Source: Optomec]

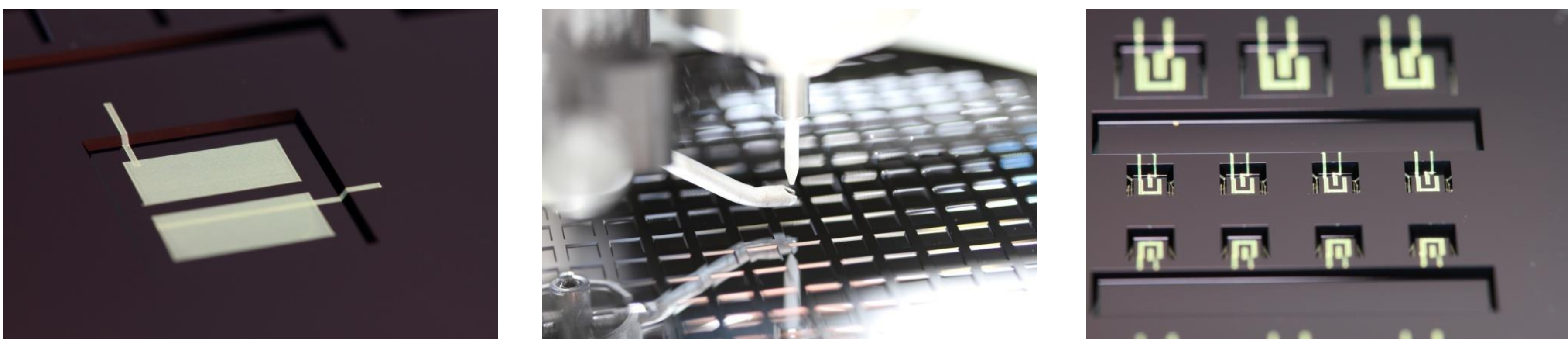
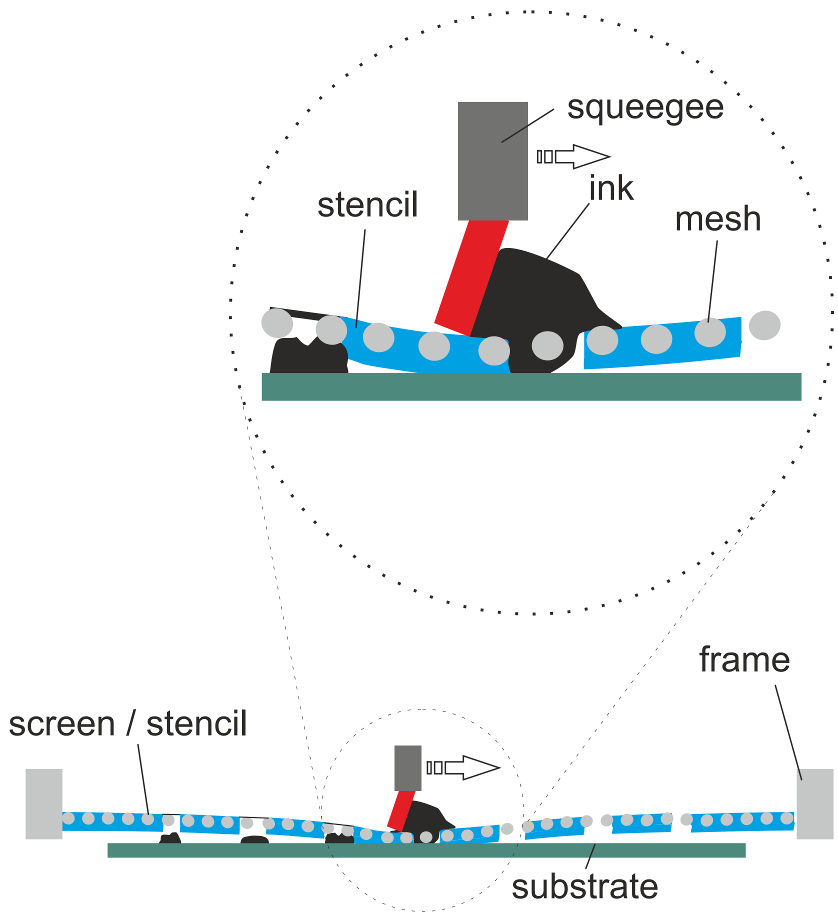


Fig 4: Examples for Ag deposition on 3D surfaces [deep etched cavities in Si Wafers]

1. Technologies / Materials / Process Flow

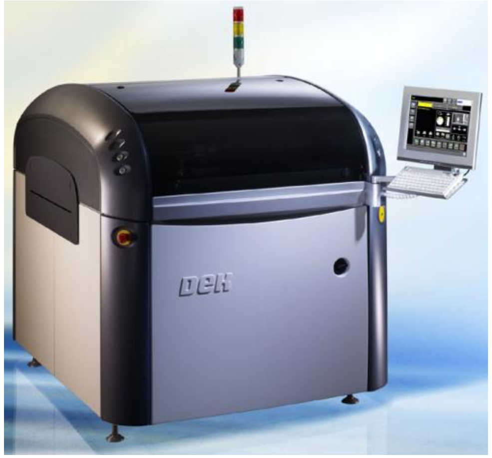
Screen Printing General Work Flow



- Screen mask works as stencil
- Mesh made from polymers or metalls
- Screen openings represent printable pattern
- Squeege transfers paste through screen openings onto substrate

1. Technologies / Materials / Process Flow

Screen Printing Equipment



Reprint
R29 Spectrum

- Screen frame: 736 x 736 mm (29”x 29") to 736 x 812 mm (29” x 32”)
- Camera alignment
- Fully automated vision system
- Registration +/- 10 µm

DEK Horizon 03iX

- Screen frame: 736 x 736mm (29" x 29") standard
- Printable Area (510mm x 508.5mm)
- ***Modul for Via Filling***
- ***Modul for Dispensing***
- Vector Guard stencil printing
- Machine Alignment >2 Cpk @ +/- 12.5µm, 6 Sigma
- Process Alignment >2 Cpk @ +/- 25µm, 6 Sigma #

Morphology: Lateral 50 µm - 150 mm; Vertical **10 µm - 1 mm**

1. Technologies / Materials / Process Flow

Metal Nanoparticle Inks Overview Sintering Process

Nanoparticle Inks – Post-treatment and sintering

- Suspensions of metal particles in solvents
- Pretreatment for dense layer and electrical conductivity:
  - Drying out solvents, burning out organic shells, sintering

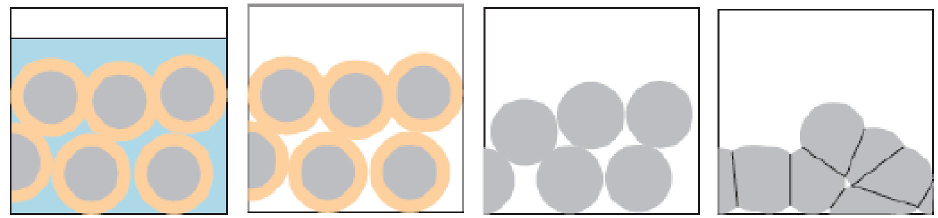


Fig 3: ***Nanoparticle filled Ink, Drying out solvents, burning out organic shells, sintering***

Sintering without pressure

- Particle necking due to diffusion effects

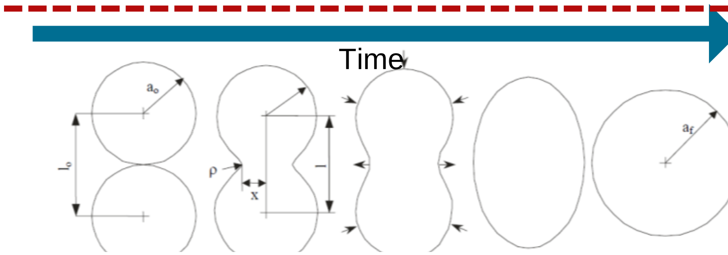


Fig 4: ***2 Particle Model [J. I. Frenkel (1945)]***

Experimental Setup

- Sintering of Ag Nanoparticles and SEM investigation at different temperature steps

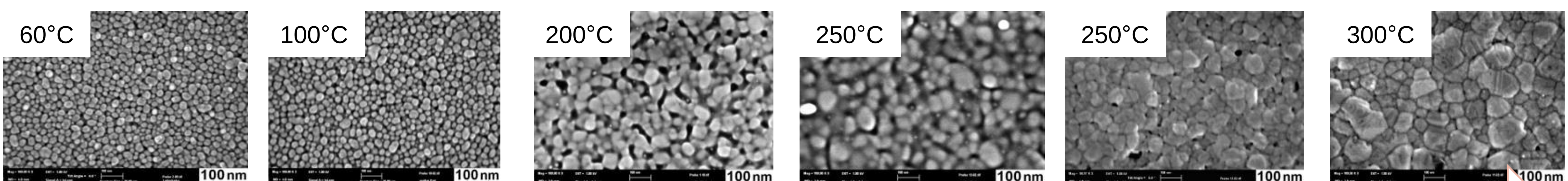
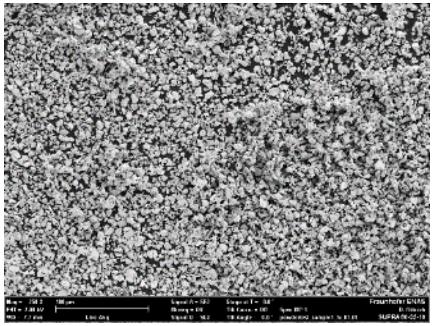
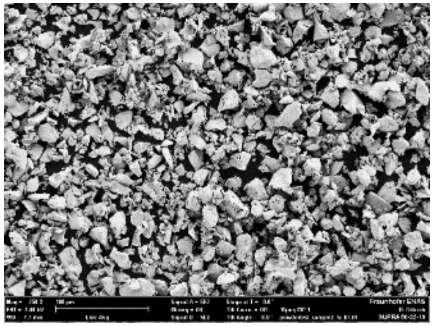
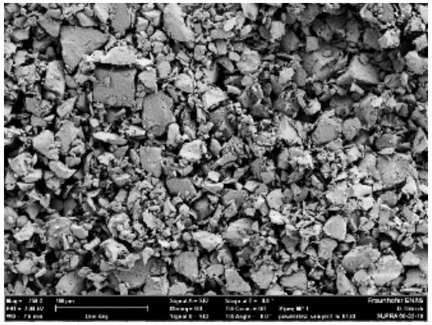
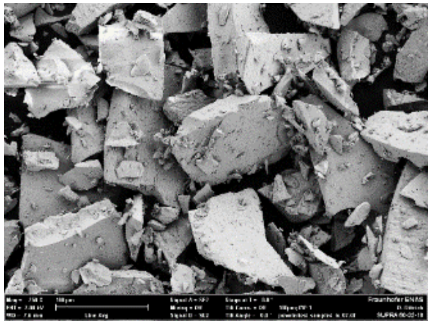


Fig 5: SEM Investigation - Sintering of Ag Nanoparticles and grain size at 60°C, 100°C, 200°C, 250°C, 300°C

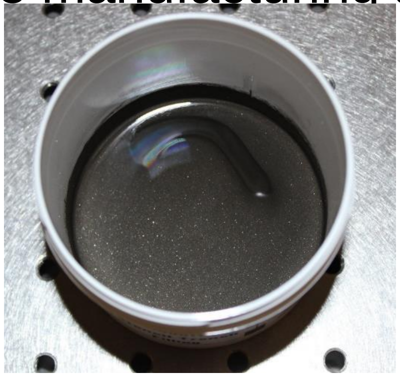
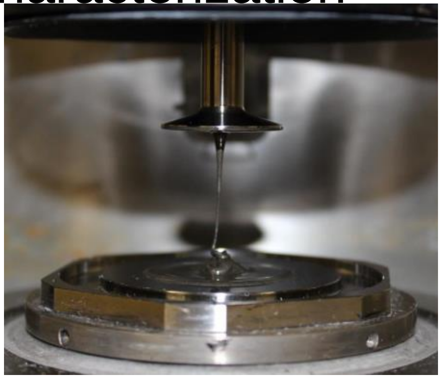
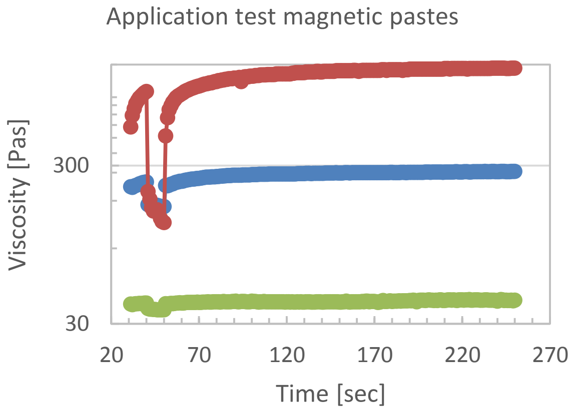
1. Technologies / Materials / Process Flow

Paste formulation for Screenprinting

Paste Particle characterization

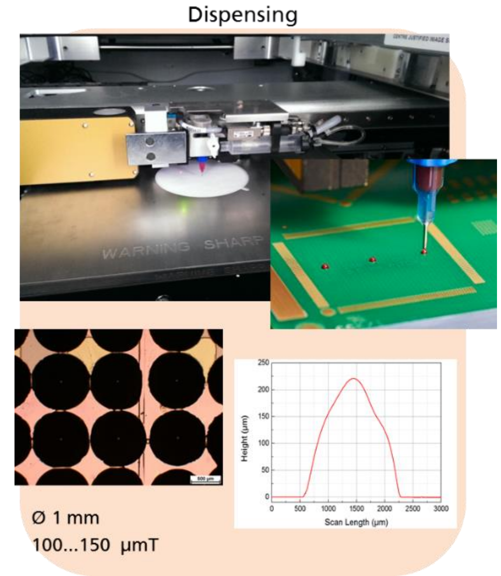
Paste manufacturing and characterization

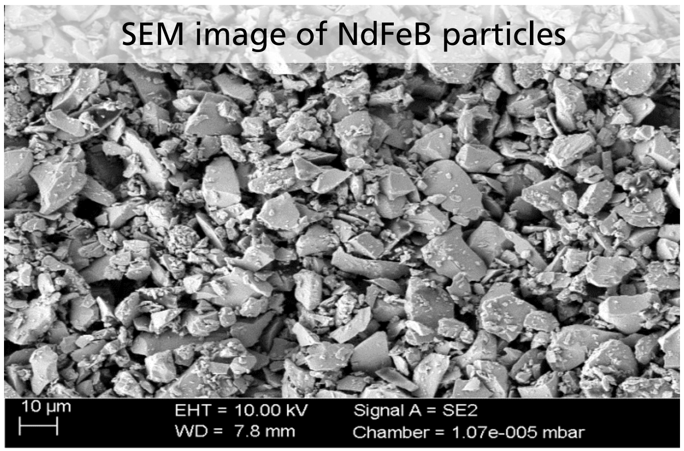




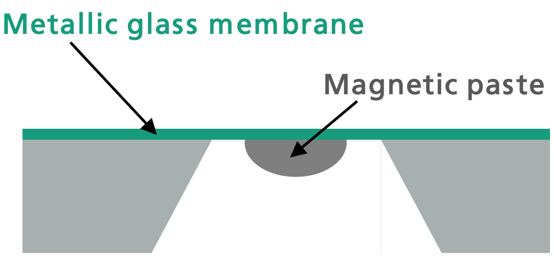
1. Technologies / Materials / Process Flow

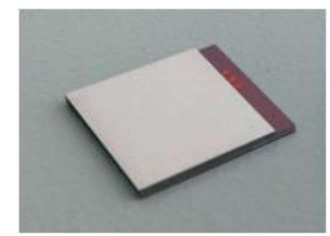
Paste formulation for Screen printing

Using magnetic paste for screen printing a MEMS speaker (electromagnetic actuation) was demonstrated









MEMS Speaker

Deposition → Curing 120 °C, 30 min → Magnetization → Integrated permanent magnet

3. R&D Focus

1. Printed RDLs for polymer substrates

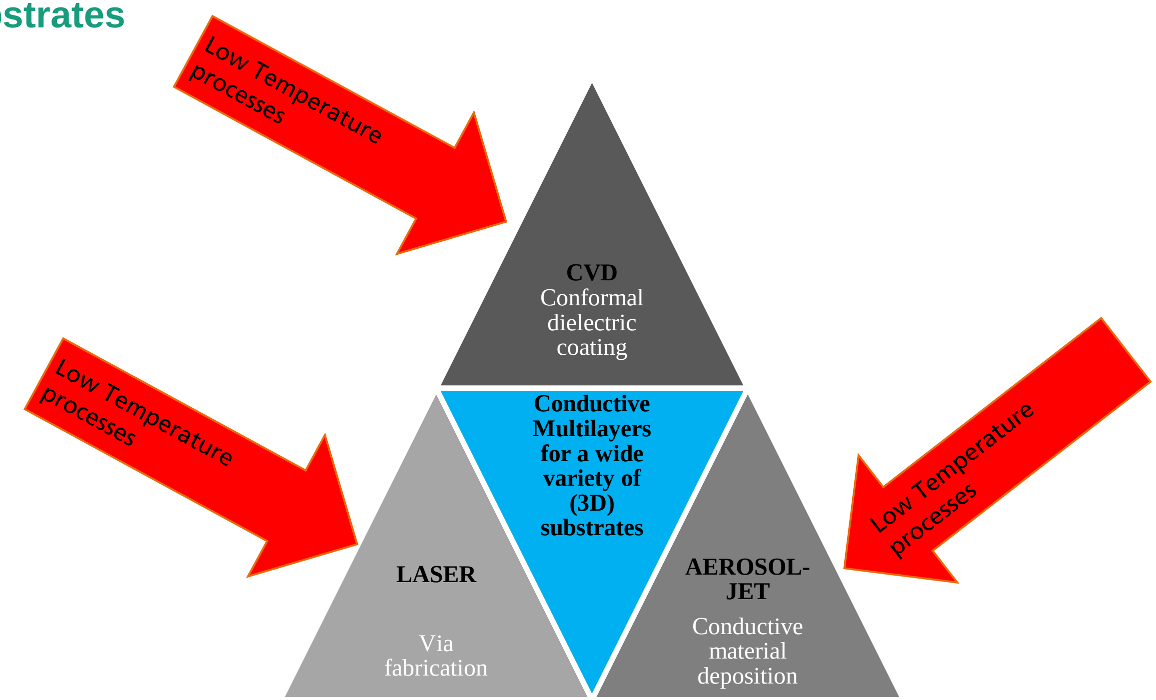
Concept

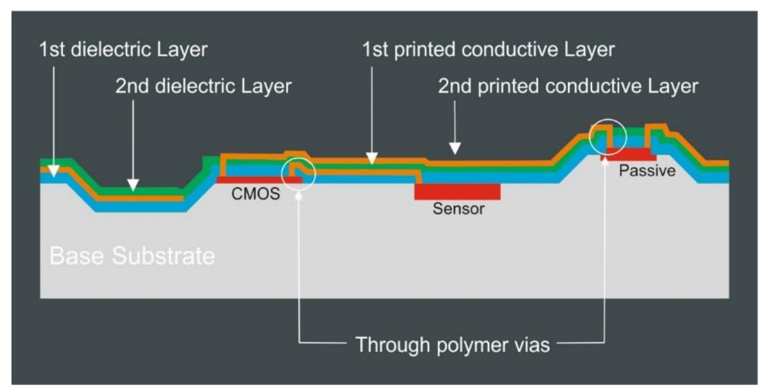
Printing conductive fine pitch multilayers for a variety of substrates materials enable smart systems

Needed:

- Fine pitch, 3D ready deposition process for conductive materials
- Conformal dielectric coating technology for 3D substrates
- Process for via fabrication to enable multilayers

Low temperature processes < 150°C to enable the usage of sensitive / polymer / low cost substrates





3. R&D Focus

1. Printed RDLs for polymer substrates

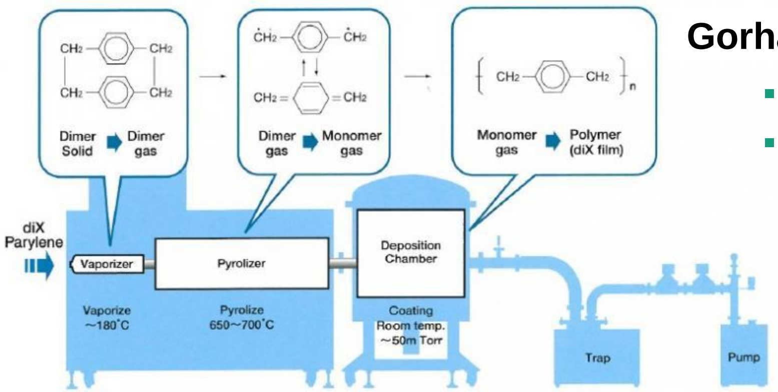
Plasma Parylene LC 300 RW
(Plasma Parylene Systems – PPS)

Motivation for Parylene:

- Deposition at ambient temperatures (no thermal stresses)
- Pinhole-free at d > 0,2µm
- Uniform layer thickness, in particular at edges, excellent gap penetration

- No solvent or catalyst required
- Yield of 100% monomer above 550°C in vacuum (using [2,2]p-cyclophane)
- No by-products
- Batch process for high throughput
- Bio compatible - medicine products

Parylene = Poly(p-xylylene)



Gorham Process

- 3 step deposition
- Polymerization @ Roomtemperature (condensation)

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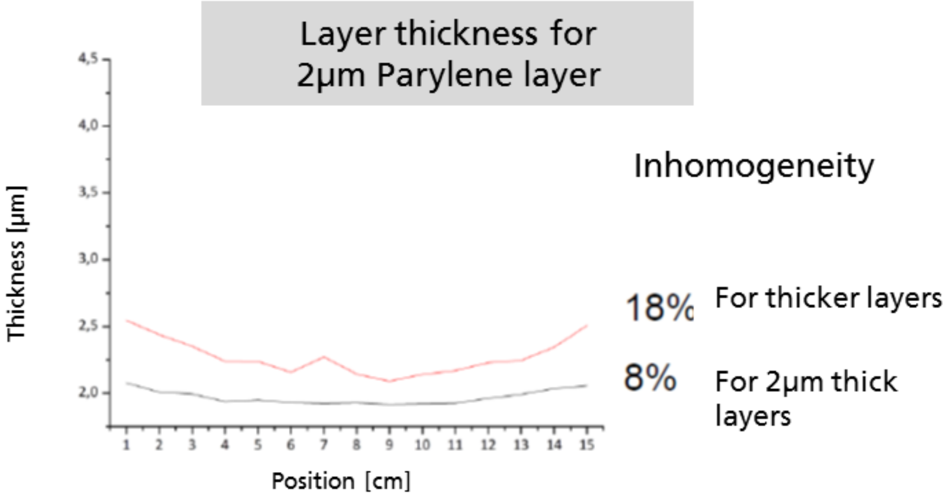
3. R&D Focus

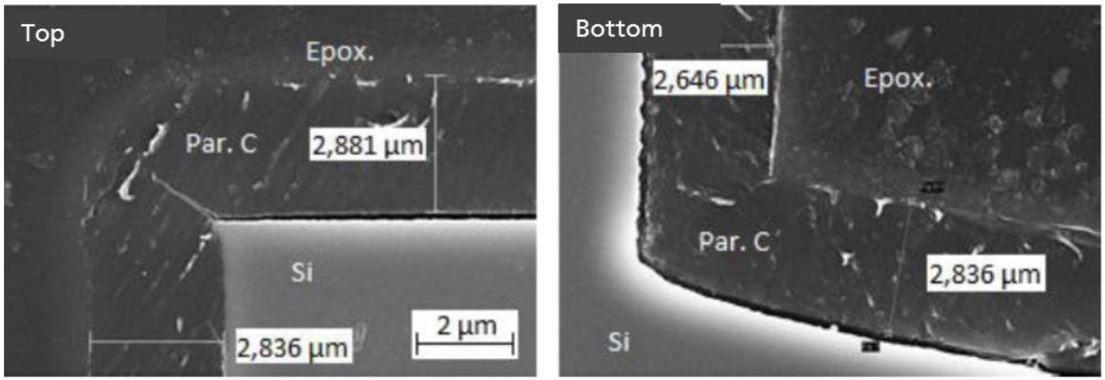
1. Printed RDLs for polymer substrates

Parylene Properties

- Conformal coating on Waferlevel < 10% thickness variation developed
- Conformal coating for high aspect ratio patterns
- Highly transparent
- Ar plasma pretreatment enables printing process
- Good moisture barrier



Properties of Parylene C	
Melting point	290°C
Temperature stability	125°C
Peak Temperature	200°C
Water absorption in 24h	0,06%



3. R&D Focus

1. Printed RDLs for polymer substrates

Laser-Workstation with two laser sources

Picosecond Laser with four wavelengths
→ for micro-structuring

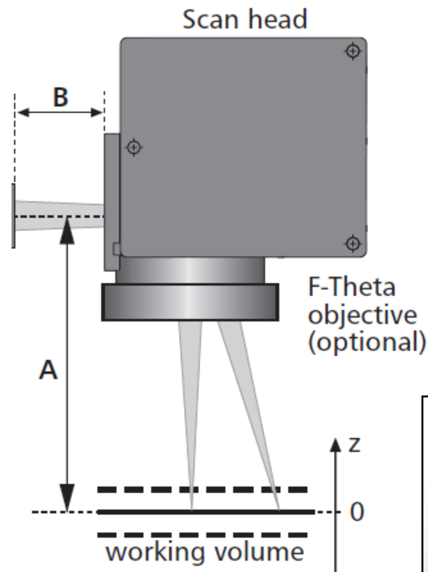
266nm	355nm	532 nm	1064 nm

Power: 10W

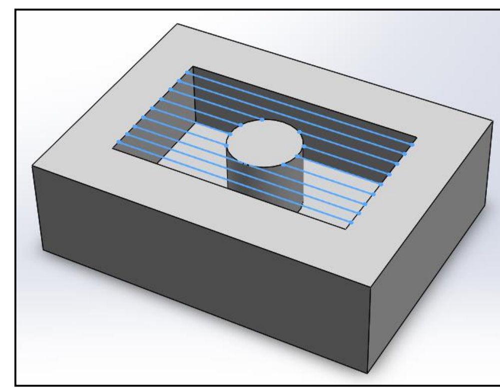
Thulium-Fiber-Laser (CW)
→ for welding

1908 nm

Power: 20W



Beam movement

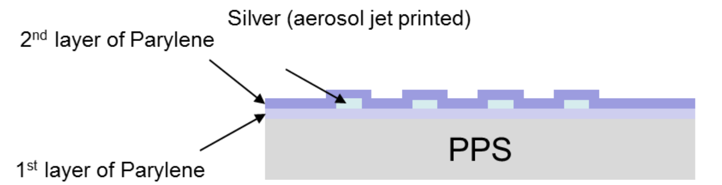


→ Structuring of almost any material for various applications

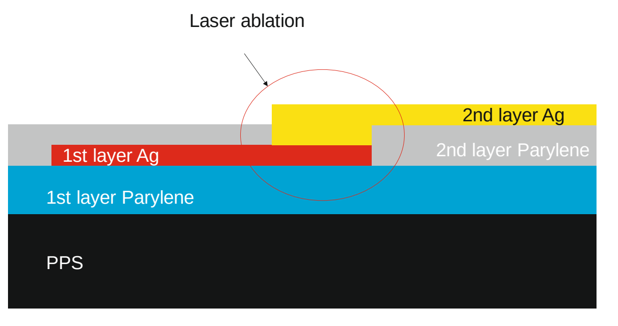
3. R&D Focus

1. Printed RDLs for polymer substrates

1. • Substrate cleaning
2. • 1^{st} layer Parylene deposition (optional)
3. • pretreatment to enable printability on Parylene + 1^{st} layer Ag deposition and sintering
4. • 2^{nd} layer Parylene deposition
5. • Laser ablation / via drilling for interconnects
6. • pretreatment to enable printability on Parylene + 2^{nd} layer Ag deposition



Schematic cross section



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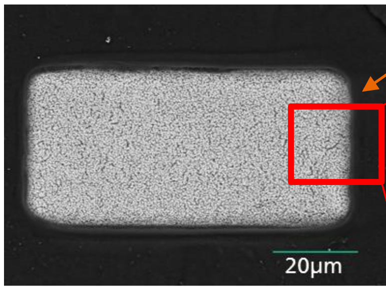
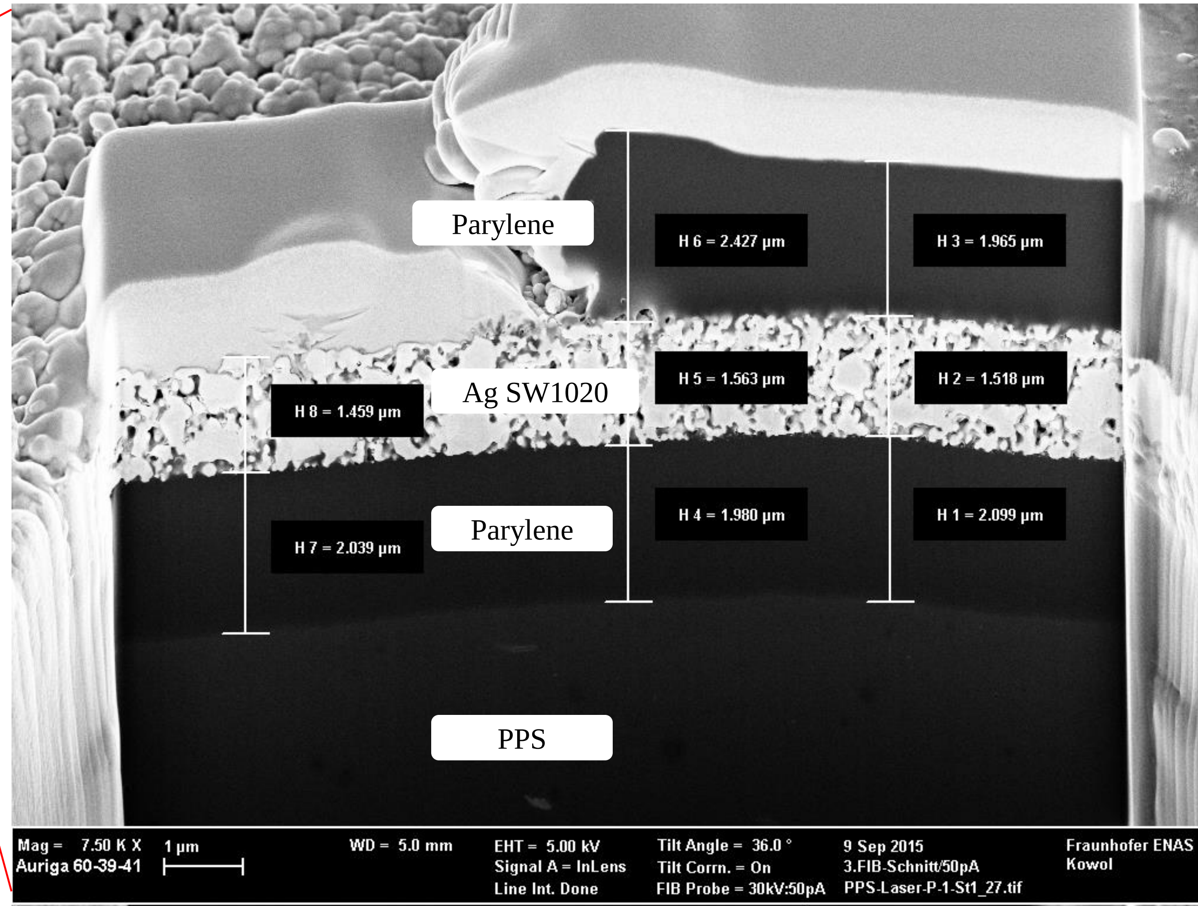
3. R&D Focus

1. Printed RDLs for polymer substrates

Laser Ablation of Parylene on top of printed Ag

FIB Cross Section





FIB Cross Section Investigation

- Conformal Parylene Coating
- No Ag ablation visible
- Sidewall effects of laser ablation visible

→ **Parylene thickness increasing**

→ **Some defects near Parylene sidewall visible**

3. R&D Focus

1. Printed RDLs for polymer substrates

Via Results

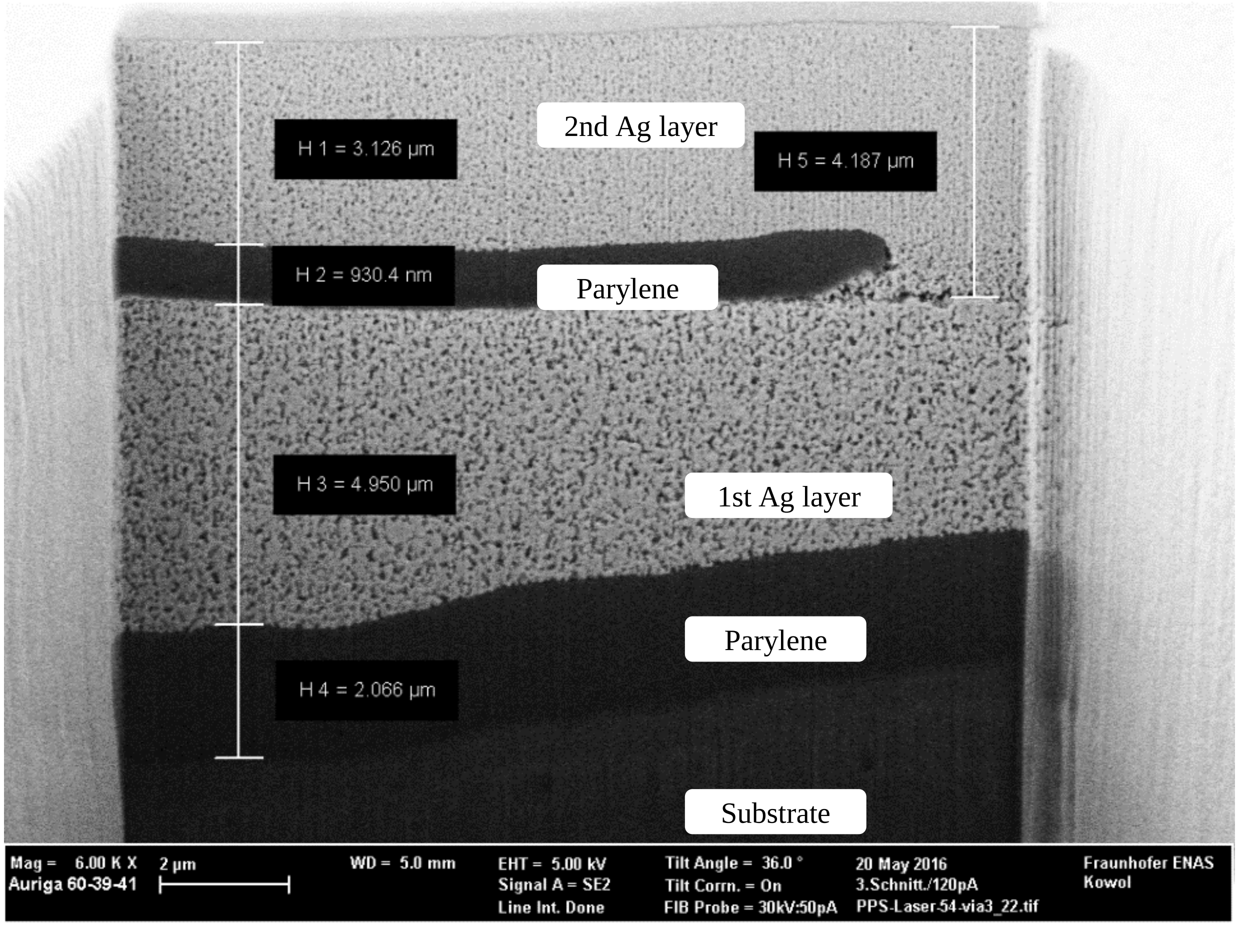
2nd layer Ag printing to fill vias, sintering

+

Electrical Testing

- Via resistance [50µmx200µm] < **10** Ω after fabrication
- Thermal cycling (-55/125°C,30min) performed

→ After **>300cycles** resistance is stable with around **5 Ω** / Interconnect due to additional sintering

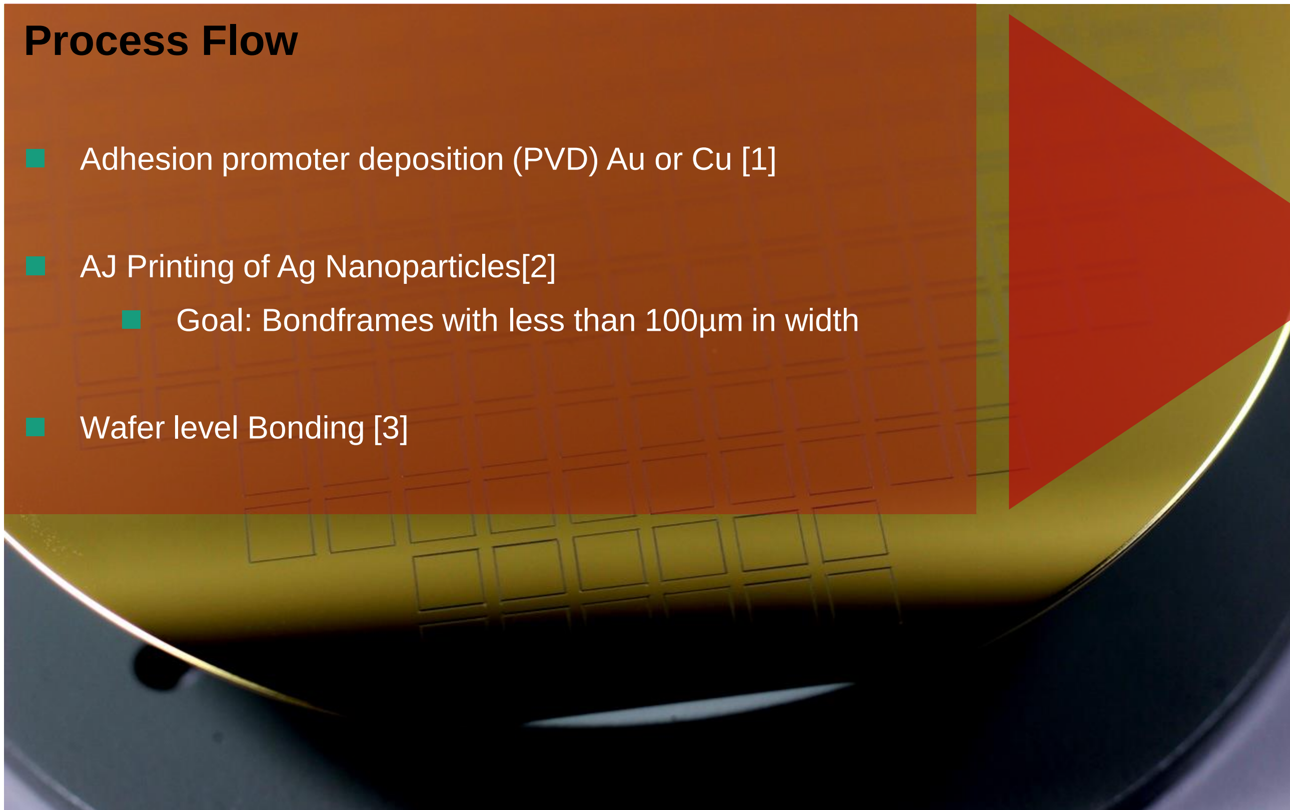


3. R&D Focus

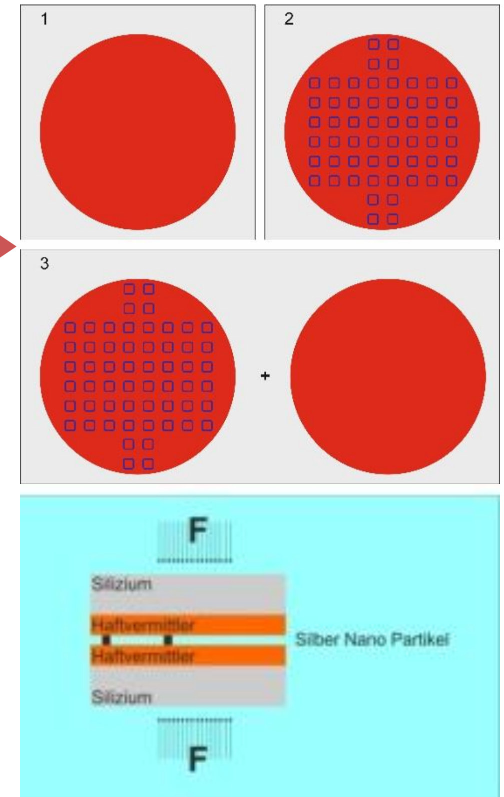
1. Low temperature Wafer level Bonding using metal nanoparticles

Process Flow

- Adhesion promoter deposition (PVD) Au or Cu [1]
- AJ Printing of Ag Nanoparticles[2]
  - Goal: Bondframes with less than 100µm in width
- Wafer level Bonding [3]



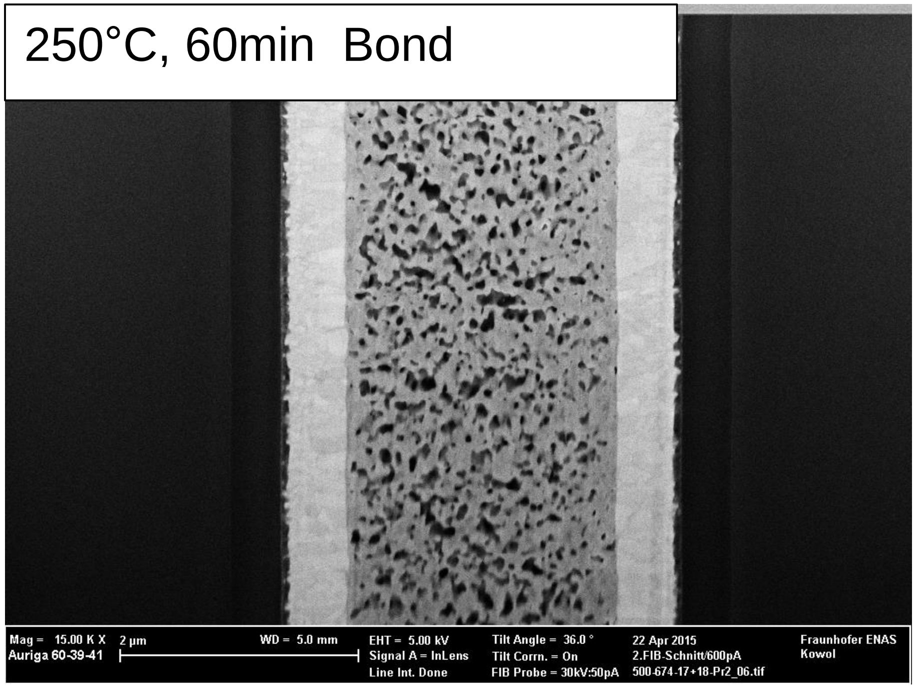
Si Wafer with Au adhesion promoter and printed Ag Bondframes



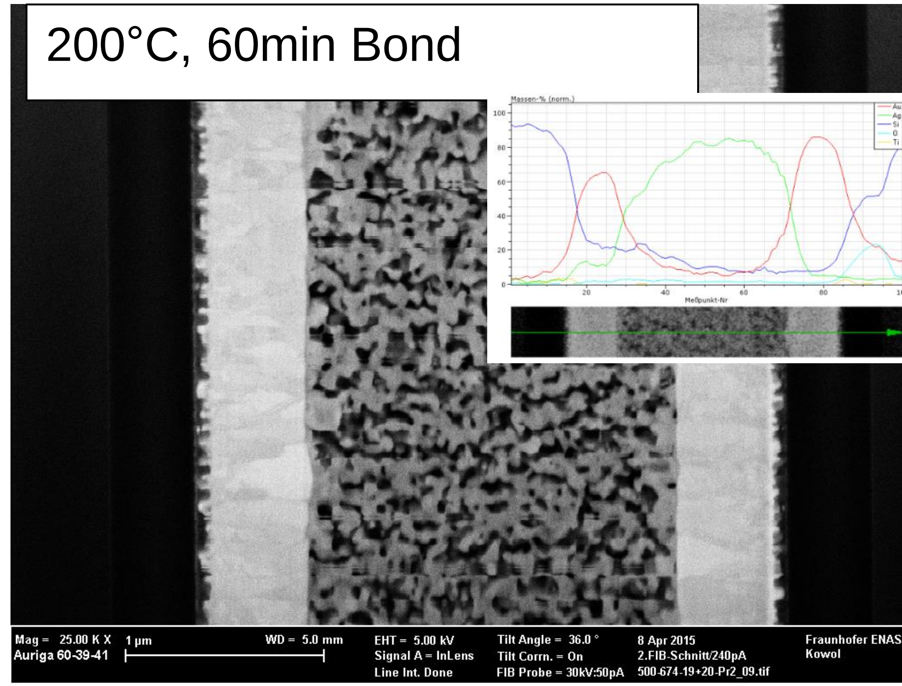
schematic process flow

3. R&D Focus

1. Low temperature Wafer level Bonding using metal nanoparticles



FIB&SEM investigations at the Interface Au-Ag-Au, 250°C: *Ag layer is fully wetting the Au adhesion promoter, porous interface*



FIB&SEM investigations at the Interface Au-Ag-Au, 250°C: *Ag layer is fully wetting the Au adhesion promoter, pore size increasing, diffusion Au – Ag visible using EDX*

Conclusion for all bonds (for all temperatures 350°C to 200°C and Au / Cu adhesion layer) today→ hermetic sealing using Ag Nanoparticle intermediate layer not possible but mechanical bond is succesful

Reasons: porous interface and inhomogeneous thickness of Bondframe due to printing process at start and endpoint of printed microstructures

3. R&D Focus

1. Low temperature Wafer level Bonding using metal nanoparticles

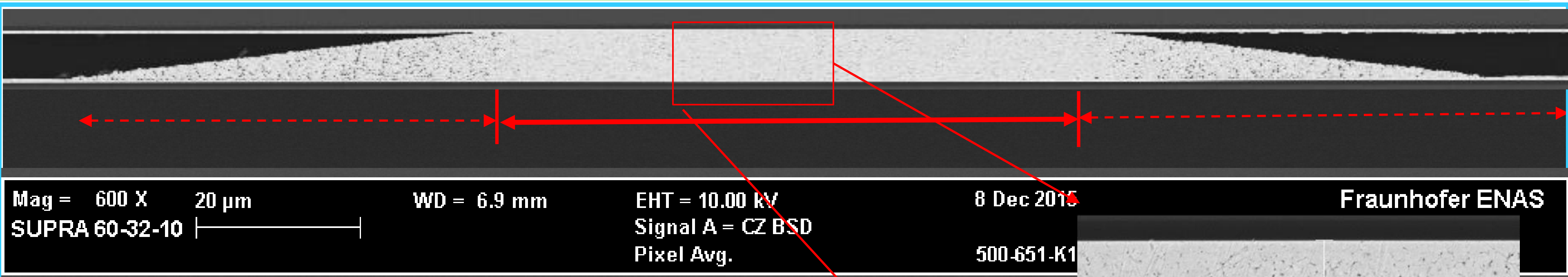
Analogue process was developed for screen printing technology using Au Nanoparticles:

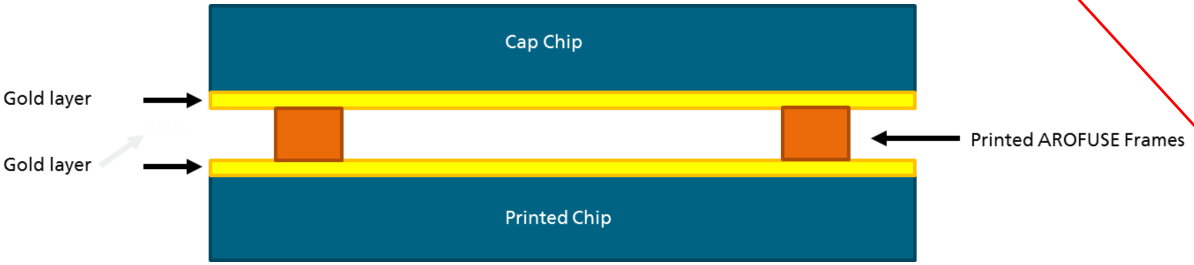
- Applied bond pressure 6.5kN
- Bonding Temperature 200°C

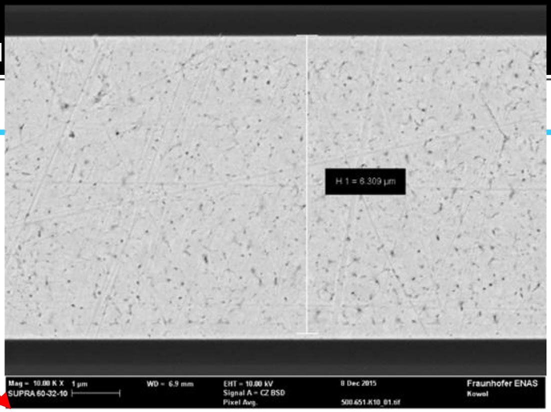
→ ***High densification within the Bondframe***

→ ***100% yield after dicing***

→ ***Hermeticity evaluations ongoing***

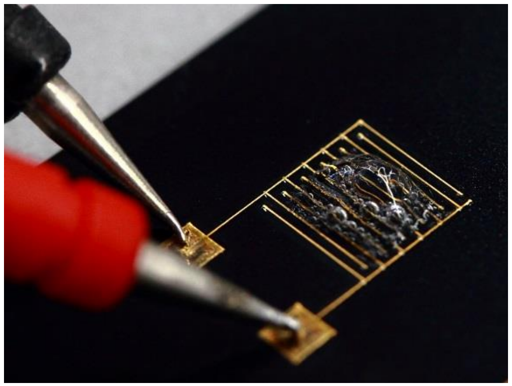




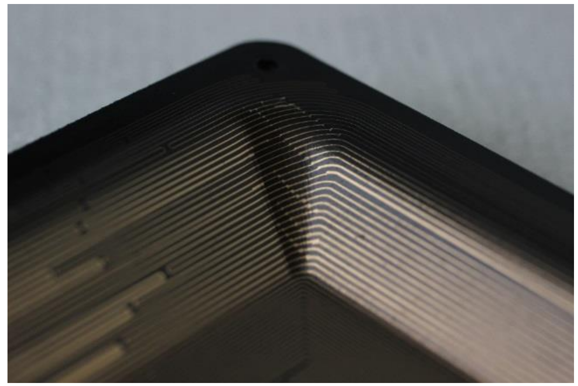


4. Further Application Scenarios

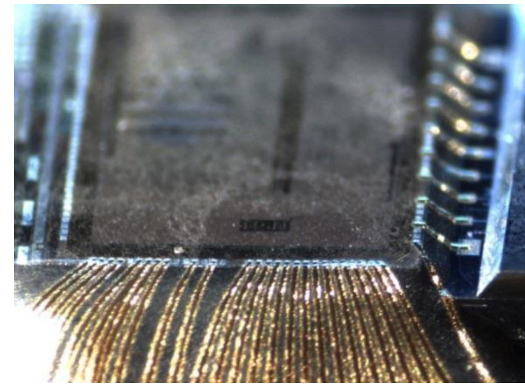
using 3D suitable deposition technology for Nanoparticle Inks



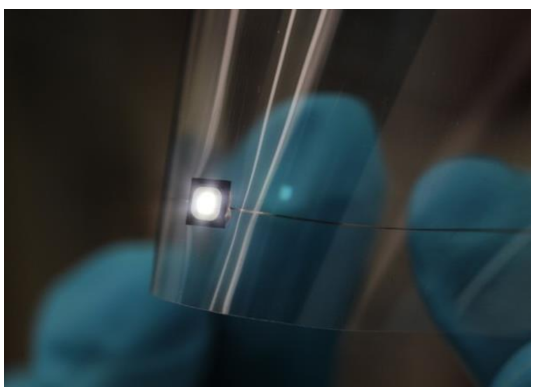
Printed Sensors (Au Nanoparticles) on low cost substrates



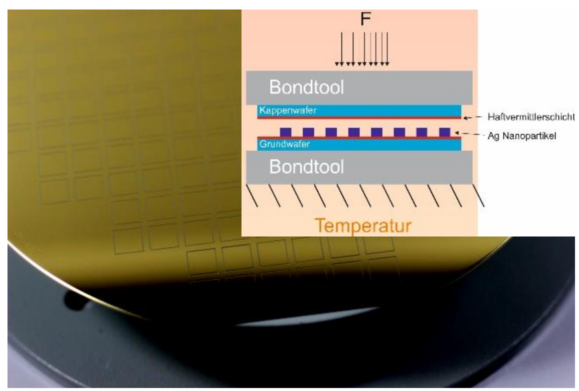
High density 3D MID Substrates by additive manufacturing

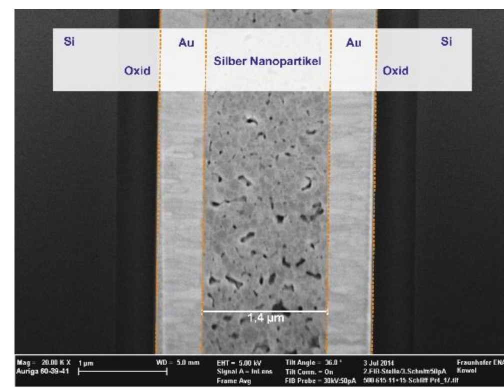


Printed Interconnects for stacked components



Flexible Electronics

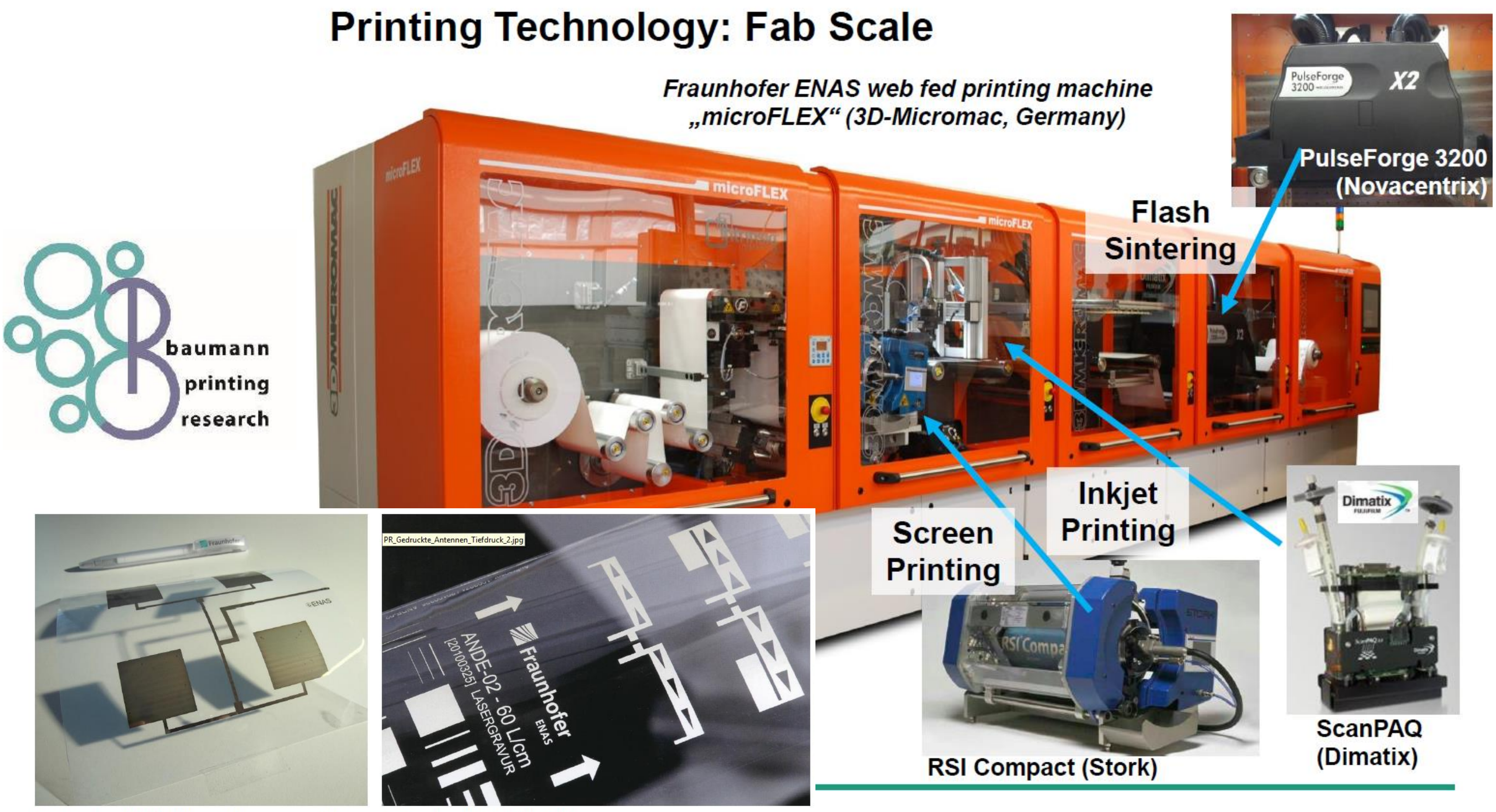




Joining (WLB and CLP) using Nanoparticle intermediate layers – low sintering temperature enables Bonding < 250°C

4. Further printing capabilities

upscaling and R2R manufacturing (i.e. printed RFID Antennas)

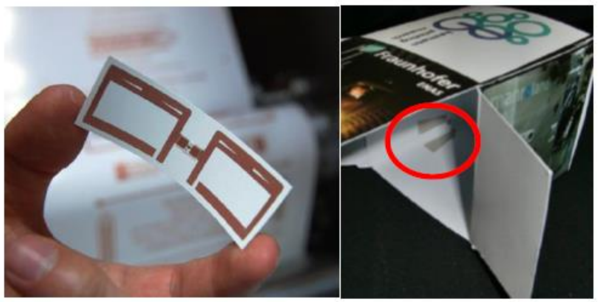


4. Further printing capabilities

institute for print and media technologies TUC

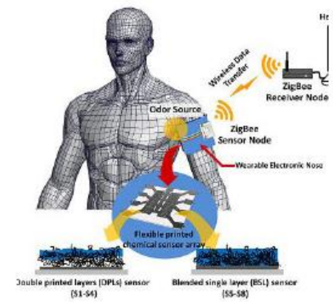
…this is what we do: Printing beyond color – printed functionalities

baumann printing research

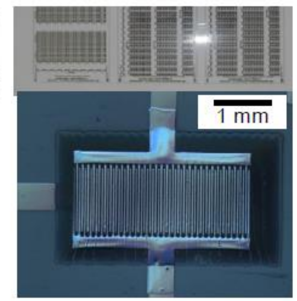


Printed antennas – planar and 3D

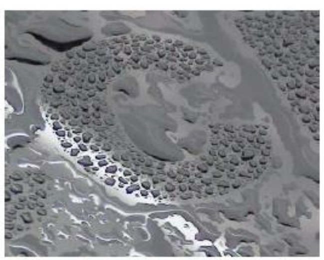
Printed batteries



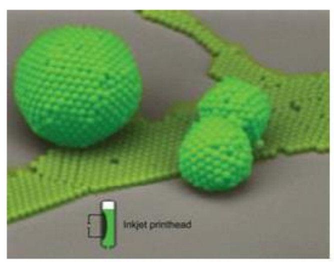
Printed sensors



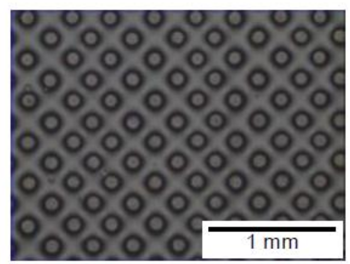
Printed transistors



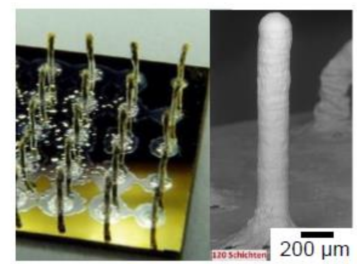
Printed SAMs



Printed photonics



Printed microsieves



Printed pillars

[a) Hammerschmidt et al., Langmuir 28, 2012; b) Belgardt et al., Phys. Chem. Chem. Phys. 15, 2013; c) Sowade et al., Adv. Eng. Mat. 14, 2012; Sowade et al., Cryst. Growth Des. 16, 2016; d) Zichner et al., Jpn. J. Appl. Phys. 53, 2014; Kang et al., Appl. Mater. Interfaces 6, 2014; Sowade et al., J. Mater. Chem. C. 3, 2015; d) Marjanovic et al., J. Mater. Chem. 21, 2011; e) Lorwongtragool et al., Sensors 14, 2014; Dinh et al., Carbon 96, 2016; f) Castro et al., Journal of Electronic Materials 7, 2014; g) Sowade et al., Organic Electronics 30, 2016]

Thank you for the kind attention

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