IVAM Mid Week Coffee Break
Electrically Connecting Inkjet-Printed Silver Structures

Kerstin Gläser, Jonas Jäger, Sascha Buschkamp, Kai Werum

18.05.2022

Hahn-Schickard
Stuttgart, Germany

Hahn-Schickard

Applied research, development and foundry services for industry

DIN EN ISO 9001:2015

- Budget 2020: 37,7 Mio. € (9,4 Mio. € industry)
- Employees 2020: 257 FTE (300 persons)
- Part of the Innovation Alliance Baden-Württemberg (innBW)

Hahn-Schickard Stuttgart

Hahn-Schickard Villingen-Schwenningen

Hahn-Schickard Freiburg

Hahn-Schickard Stuttgart and IFM

Hahn-Schickard Stuttgart

www.hahn-schickard.de

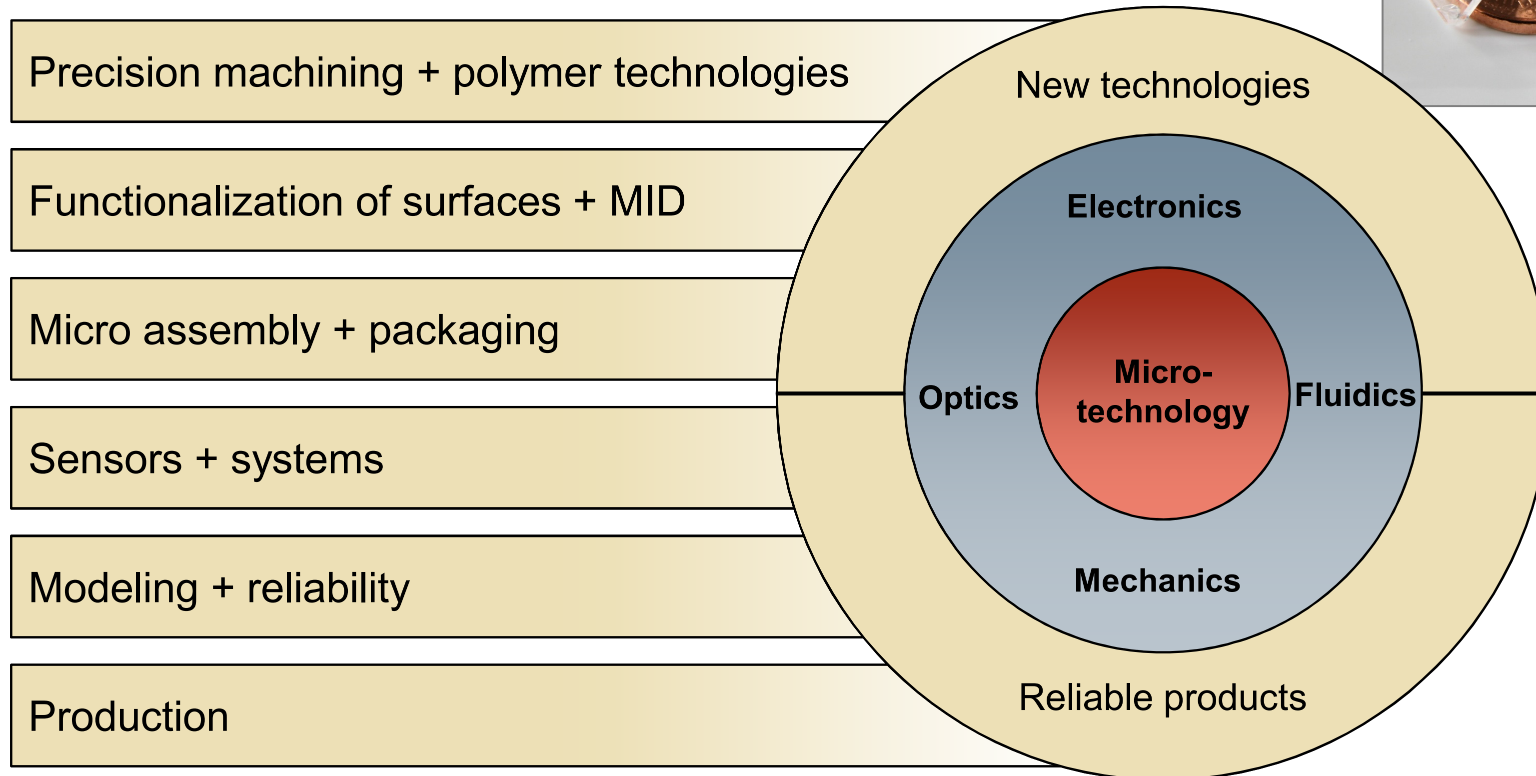
Institute for Micro Integration
University of Stuttgart

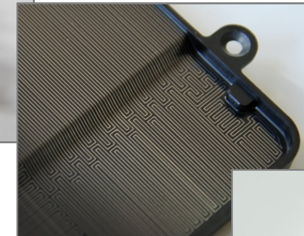
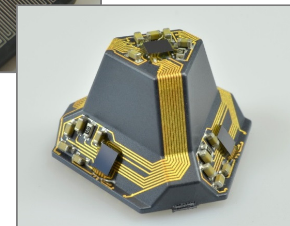
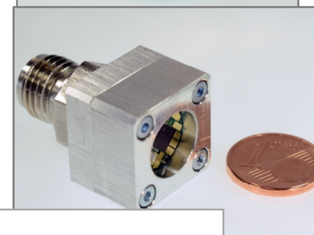
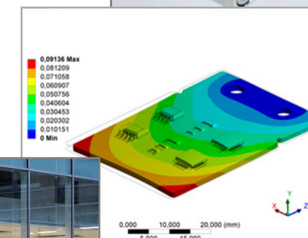
www.ifm.uni-stuttgart.de

We create innovations from research to transfer into industrial applications

AiF Mitglied innBW INNOVATIONSALLIANZ BADEN-WÜRTTEMBERG

Hahn-Schickard Stuttgart



Printing technologies

Hahn Schickard

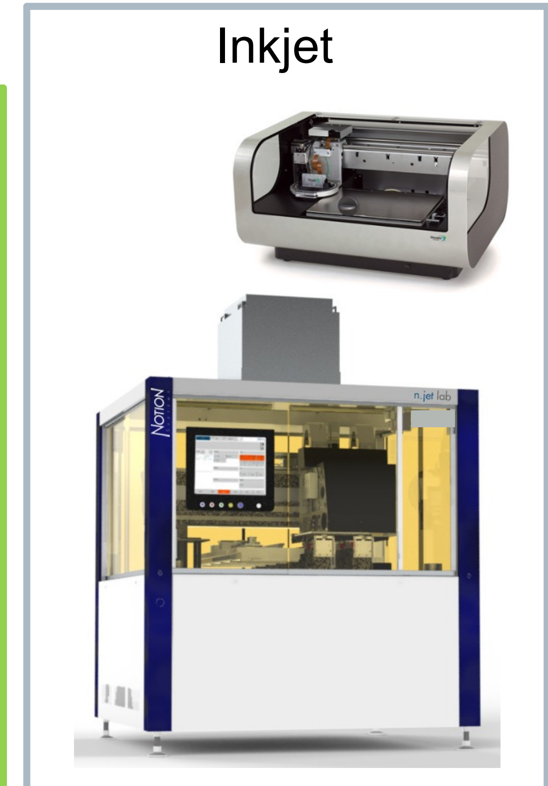
- Aerosol Jet®
- Nano Jet 3D, Piezo Jet 3D (ordered)
- Inkjet (Laboratory unit, industrial unit (ordered))

Advantages

- Fully additive processes with short process chains
- Contactless processes (Inkjet, Aerosol Jet®)
- Simple redesign of layout
- Resource and environmental friendly processes
- Many printable materials available
- Many substrate materials applicable

Aerosol Jet®

Inkjet



Pretreatment and Sintering Equipment

Hahn Schickard

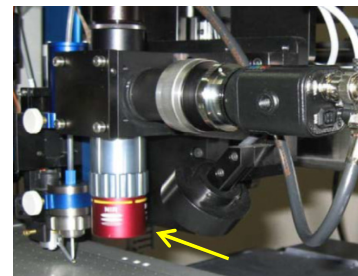
Substrate Pretreatment:

- Dry ice (CO_2) blasting
- Oxygen plasma
- Atmospheric-pressure plasma

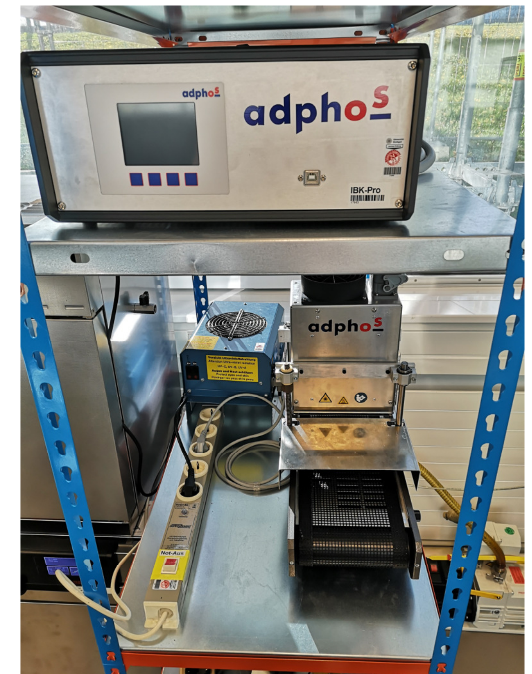
Sintering Process:

- Thermal sintering
- Laser sintering
- NIR sintering
- Photonic sintering (UV-Vis flash light)
  - Cu-inks, susceptible to oxidation
  - Nanoparticular metall inks on temperature sensitive substrates

Novacentrix Pulse Forge 1200
(Source: Novacentrix)



Laser Module (λ=808 nm) in Aerosol Jet System
(Source: Optomec)



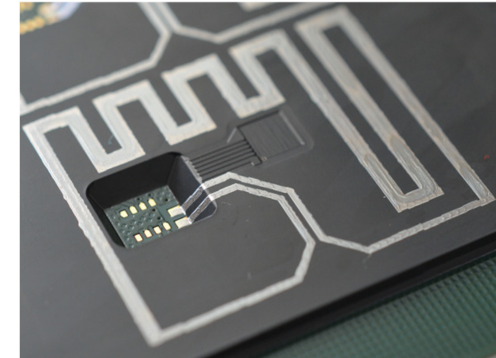
Heating module NIR 96 - 125 - E
(Source: adphos)

Printable Materials and Applications

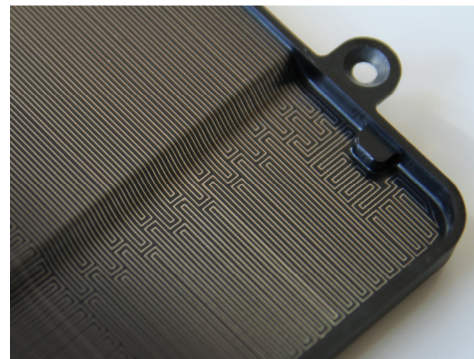
Hahn Schickard

- **Materials**
  - Conductive lines:
    - Metalls: Ag, Cu, Au, …
    - Polymers: PEDOT:PSS
  - Insulators
    - Materials: polyimide, epoxy, acrylate
    - Curing: thermal or UV
- **Applications**
  - Temperature sensors
  - Strain sensors
  - Intrusion sensors
  - Magnetic field sensors
  - Gas sensors
  - Touch sensors

Inkjet printed Au electrodes on COC
Source: ZIM CleBaWa



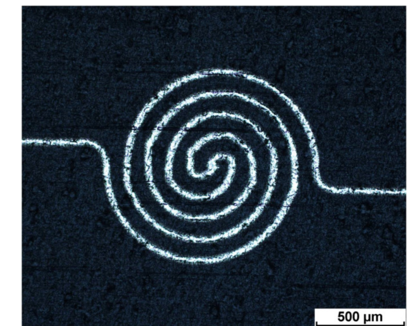
Inkjet printed antenna on transfer molded package
Source: BMBF project ITAS



Inkjet printed intrusion sensor (pitch 300 µm)

Source: BMBF project SADINA

Aerosol Jet printed strain sensor on ceramic

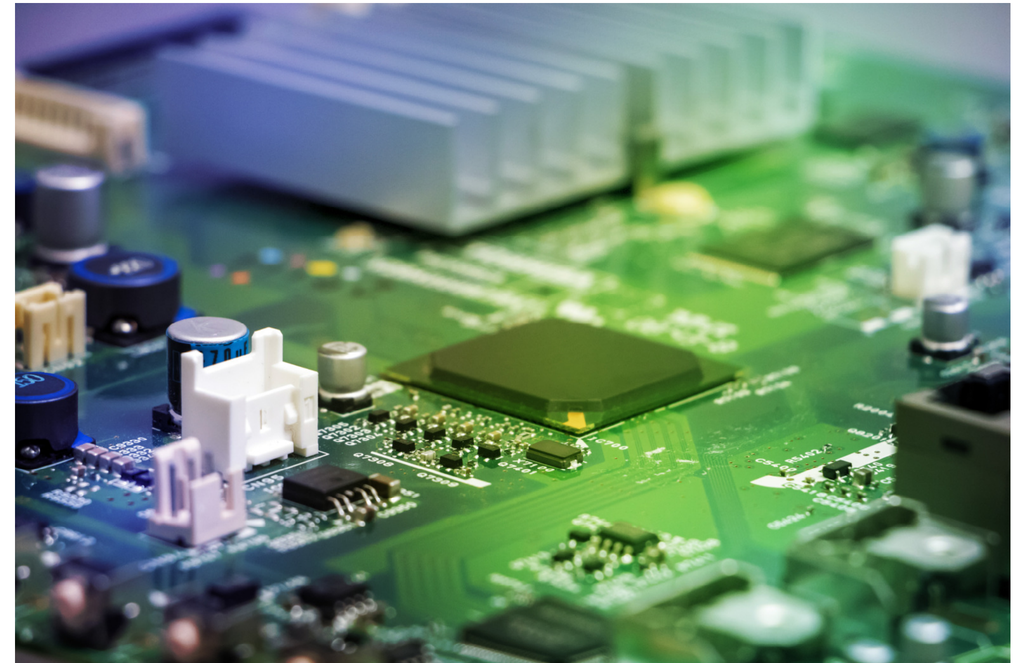


Aerosol Jet printed temperature sensor

AiF Mitglied innBW INNOVATIONSALLIANZ BADEN-WÜRTTEMBERG

Motivation: Why do we need electrical connections on printed electronics?

Hahn Schickard



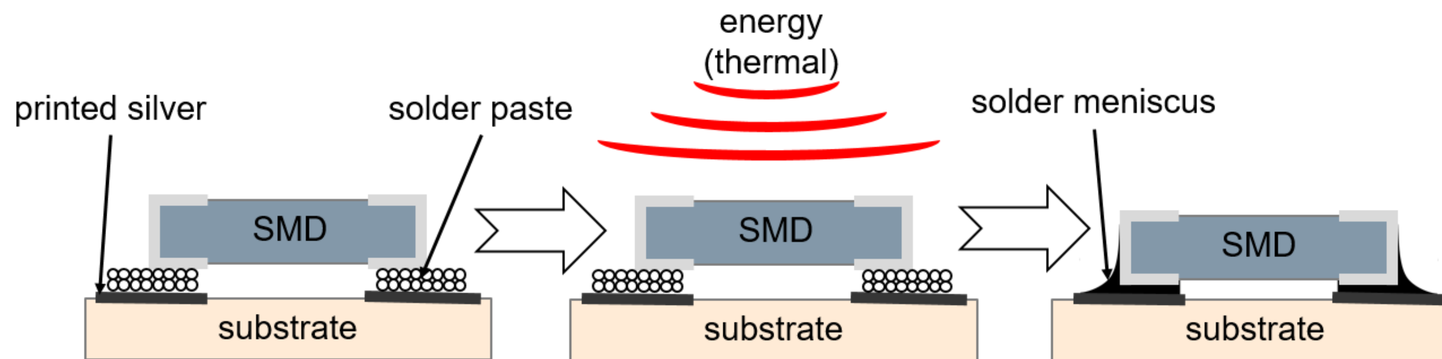
Digital printing technologies: Great value (3D, huge variety of substrates, resource-friendly), …

… but often not useful without connection to MCU, battery, sensors or other electronic components

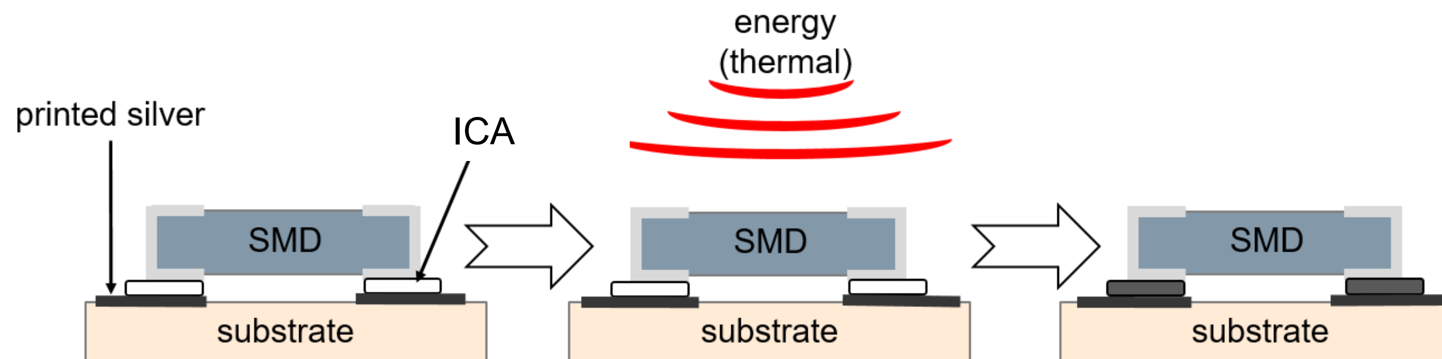
Surface Mount Technologies

Hahn Schickard

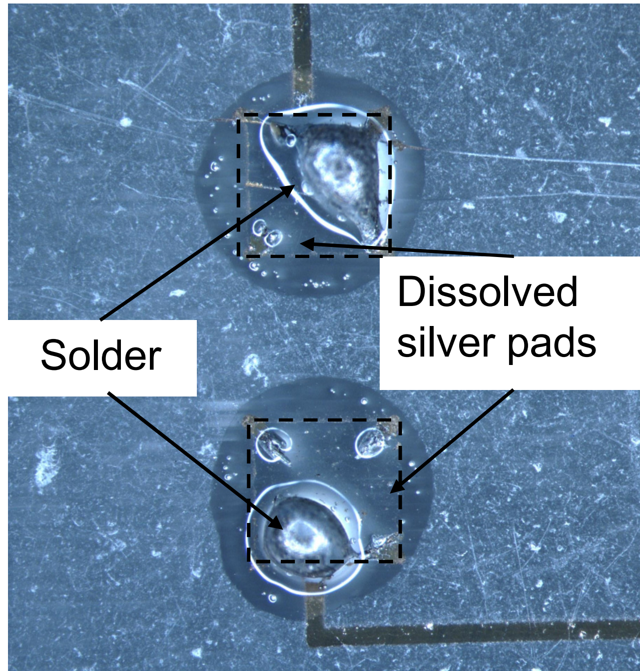
- **Soldering**



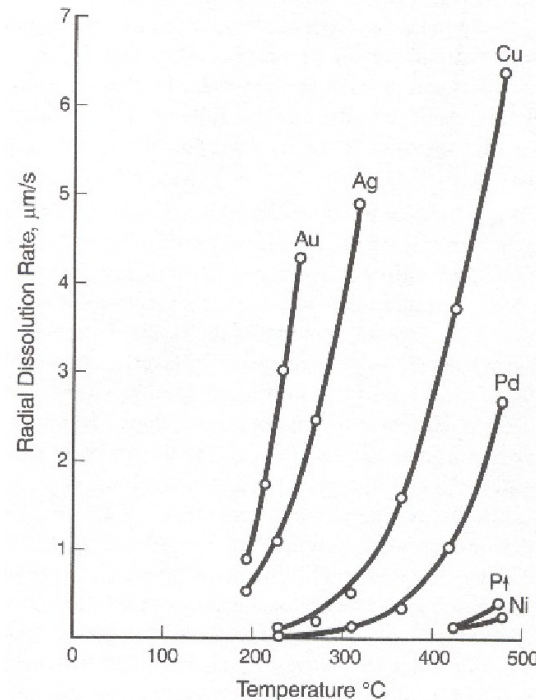
- **Adhesive bonding (Isotropic Conductive Adhesive), Semi-Sintering**



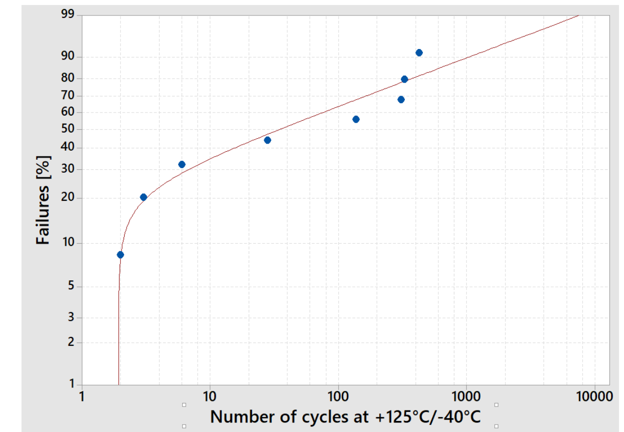
Why is contacting of digitally printed electronics difficult?

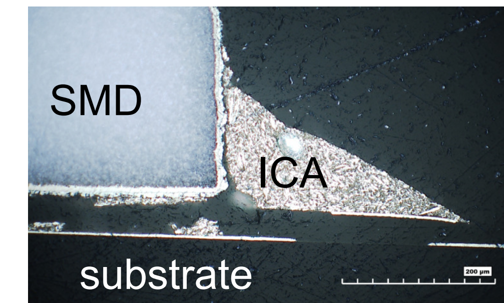


Dissolution of thin printed silver structures in SnAgCu solder



Dissolution rate of metals in SnPb solder [W.G. Bader „Dissolution of Au, Ag, Pd, Pt, Cu and Ni in a molten tin-lead solder“]



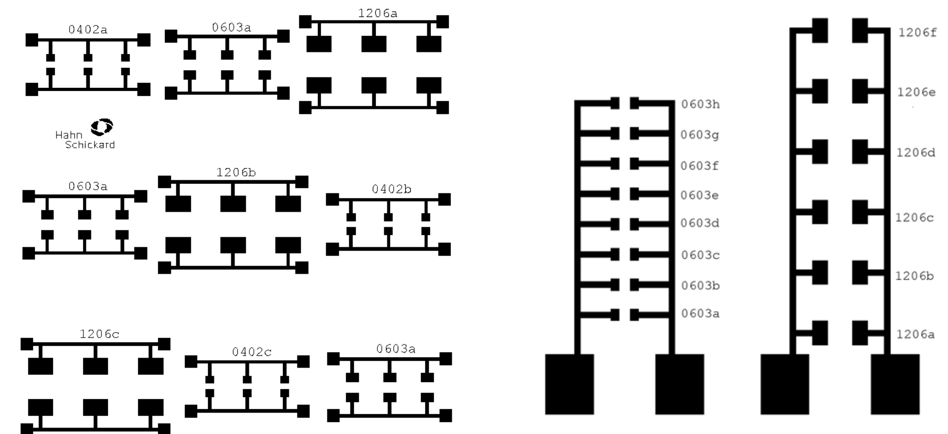


Low reliability of ICA connections between SMD and printed structures

AiF KonsDruckt - Inkjet-printing and SMD assembly

Hahn Schickard

- **Inkjet-printer: Dimatix Materials Printer 2850**
- **Pre-treatment of substrate: atmospheric plasma (depending on substrate)**
- **Silver nanoparticle ink (30% metal)**
- **Thermal curing: 120 °C – 200 °C**
- **SMD sizes:**
  - 0402 (1 mm x 0.5 mm)
  - 0603 (1.6 mm x 0.8 mm)
  - 1206 (2 mm x 1.25 mm)



Layouts for printing parallel connections: standard layout (left), layout for 4-wire-measurement (right).

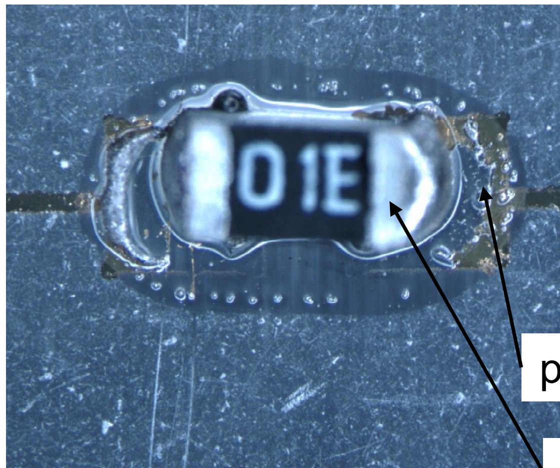
Soldering

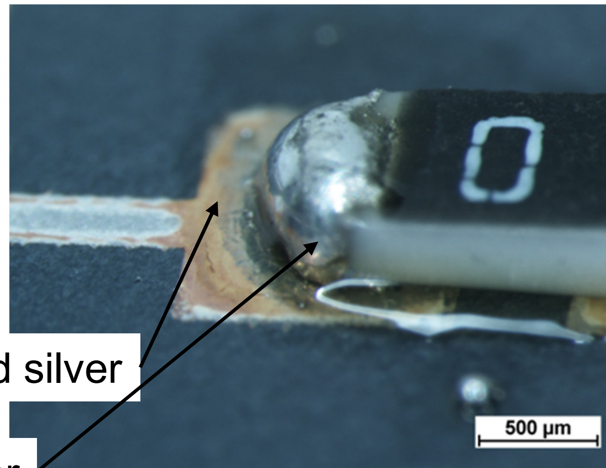
Hahn Schickard

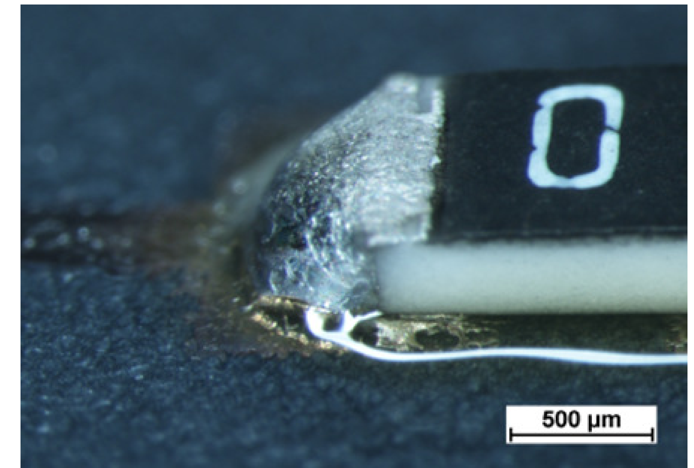
SnAgCu, high temperature

SnBi, low temperature, low layer thickness

SnBi, homogeneously printed structures > 5 µm







printed silver

solder

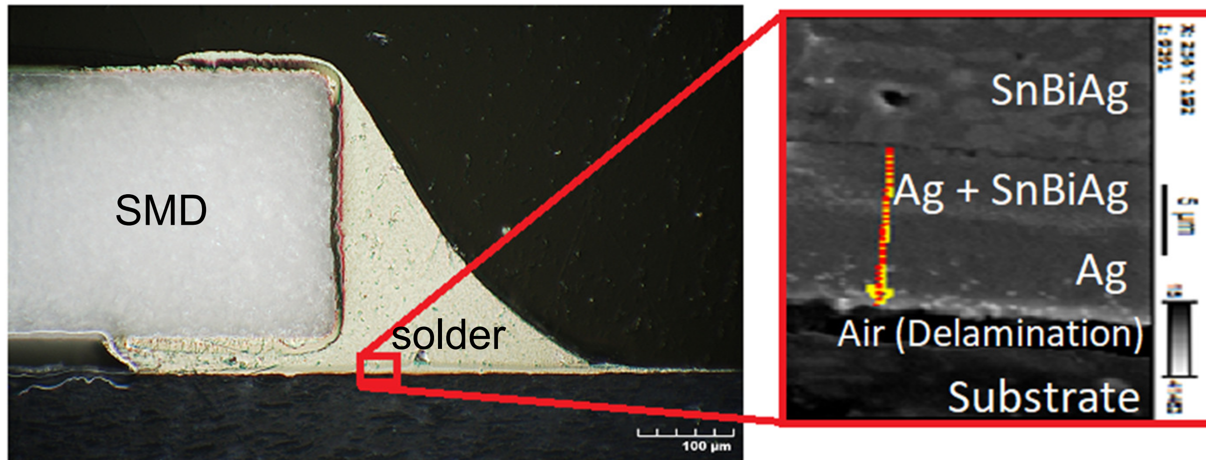
Complete dissolution of printed silver structures in SAC solder. High temperature, high dissolution.

Lower melting SnBi solder. Partly dissolution of printed silver structures at 155 °C for 5 min. Poor wetting of SnBi solder.

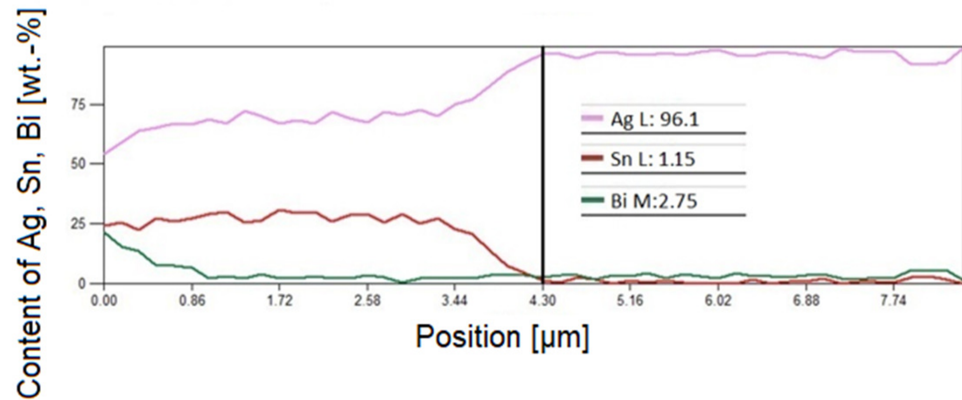
Homogeneously printed silver structures, thickness > 5 µm. No dissolution and good wetting of SnBi solder.

Soldering

Hahn Schickard



- **Thickness of intermetallic phase: 5 µm**
- **Soldering peak temperature: 155°C**
- **Substrate: LCP**



Soldering on 10 µm thick inkjet-printed silver structures. SEM and EDX analysis

Soldering: Reliability

Hahn Schickard

- 1206 SMD, SnBiAg solder, thermal shock (+ 125 °C, - 40 °C)
  - LCP perpendicular to flow direction (CTE 24-35 ppm/K): Low lifetime (441 cycles)
  - LCP parallel to flow direction CTE (9-17 ppm/K): High lifetime (> 2000 cycles)

  Good results! ☺

→ **Low coefficient of thermal expansion (CTE) of substrate benefits reliability**

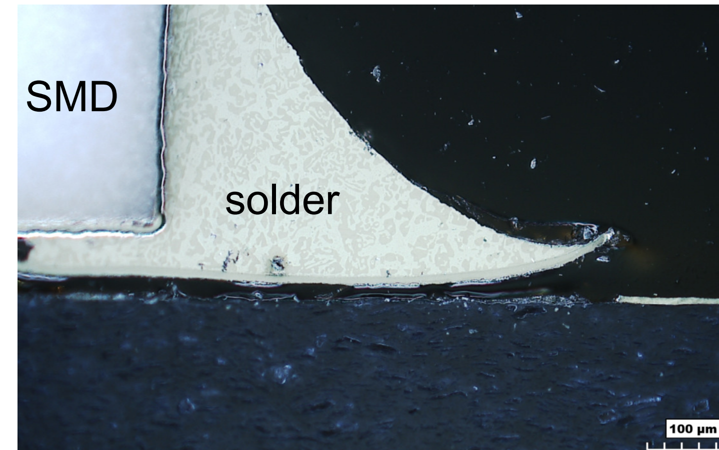
- 0603 SMD, SnBiAg solder, thermal shock
  - LCP perpendicular to flow direction (CTE 24-35 ppm/K): High lifetime (> 3500 cycles)

  Good results! ☺

→ **Small SMD size benefits reliability**

Soldering: Reliability

- Failure mechanisms after thermal shock
  - Delamination between printed structure and substrate



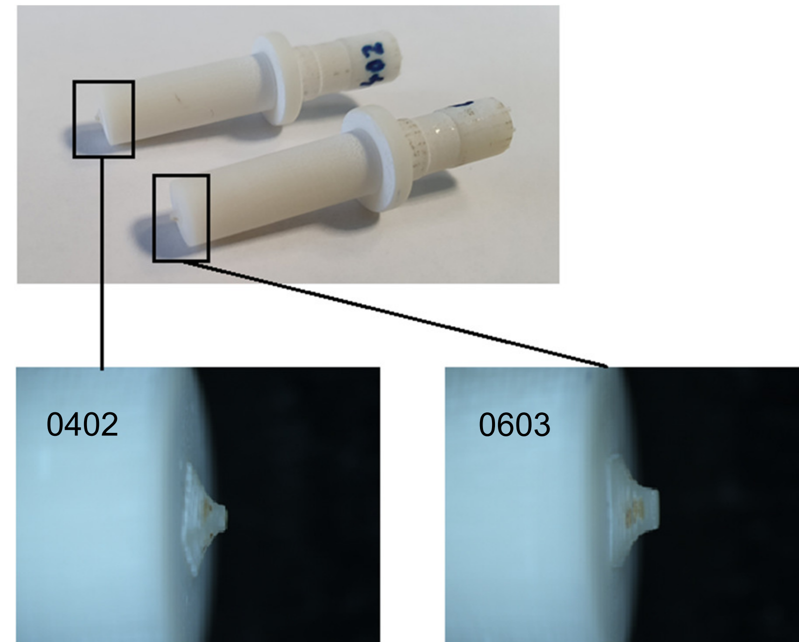
Delamination of solder joint of 1206 SMD after thermal shock [IGF report 20337N]

- Damp heat test SnBiAg, 0402, 0603, 1206:
  - 0 % failures after 1000 h at 85 °C, 85 % r.h.
  - **Good results!** ☺

Isotropic Conductive Adhesive

Hahn Schickard

- Two different silver-based epoxy ICA
- Dispensing or stamping
- Curing at 80 °C to 150 °C for 5 min to 120 min
- Substrate: LCP
- Printed structures: No special properties needed (thickness, homogeneity)



Additively manufactured stamps

Isotropic Conductive Adhesive: Reliability

Hahn Schickard

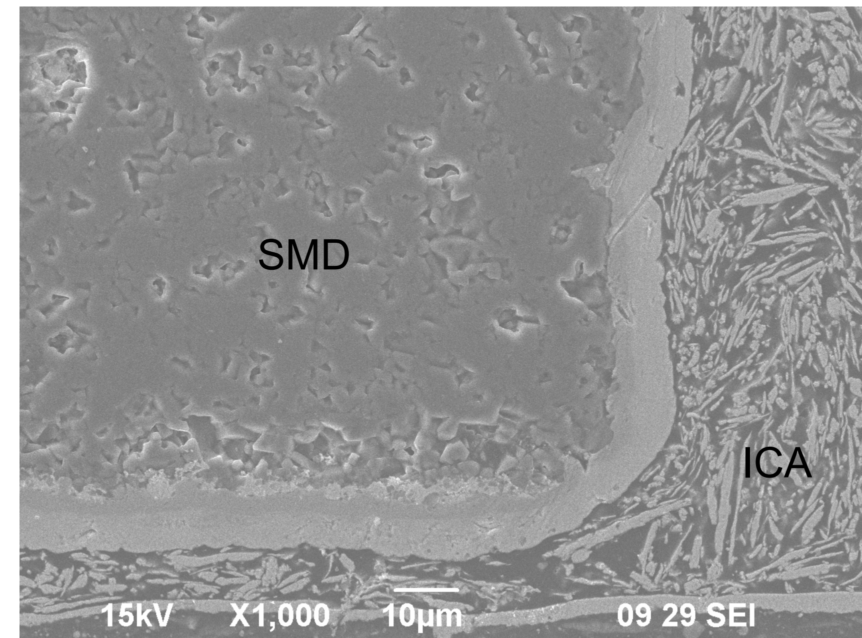
- Thermal shock 0603 and 1206 SMD on LCP (24-35 ppm/K) at + 125 °C / - 40 °C: lifetime > 3500 cycles

  Good results! ☺

- Delamination starts between SMD and ICA

- Only 1.1 % SMD (0402, 0603, 1206) on LCP failed after

  1000 h at 85 °C, 85 % r.h. **Good results!** ☺



SMD mounted with ICA on LCP after 3500 cycles thermal shock.

Conclusion

Hahn Schickard

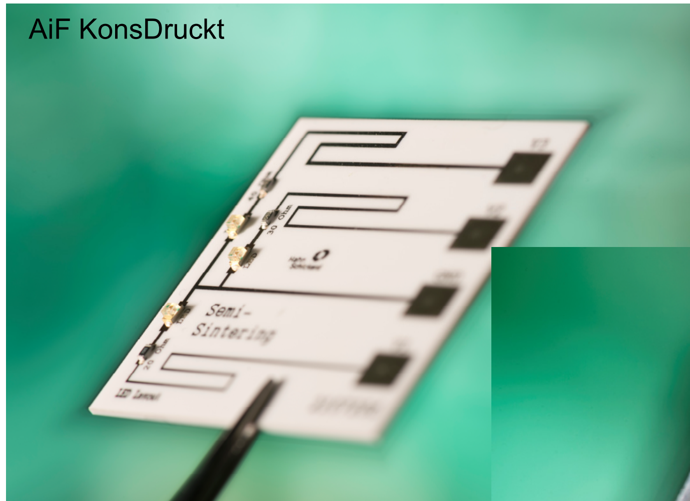
- **SMD assembly by soldering and ICA bonding successfully demonstrated on inkjet-printed silver structures**

- **Electrical connections between inkjet-printed silver structures and 0603 SMD on LCP substrates can withstand**
  - 3500 cycles at + 125 °C / - 40 °C
  - 1000 h at 85 °C / 85 % r.h.

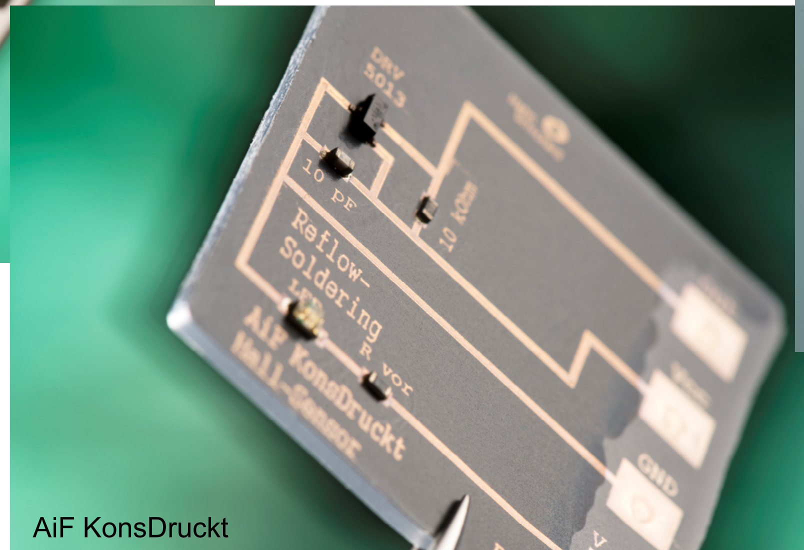
- **Selection of materials is crucial**

Conclusion / Outlook

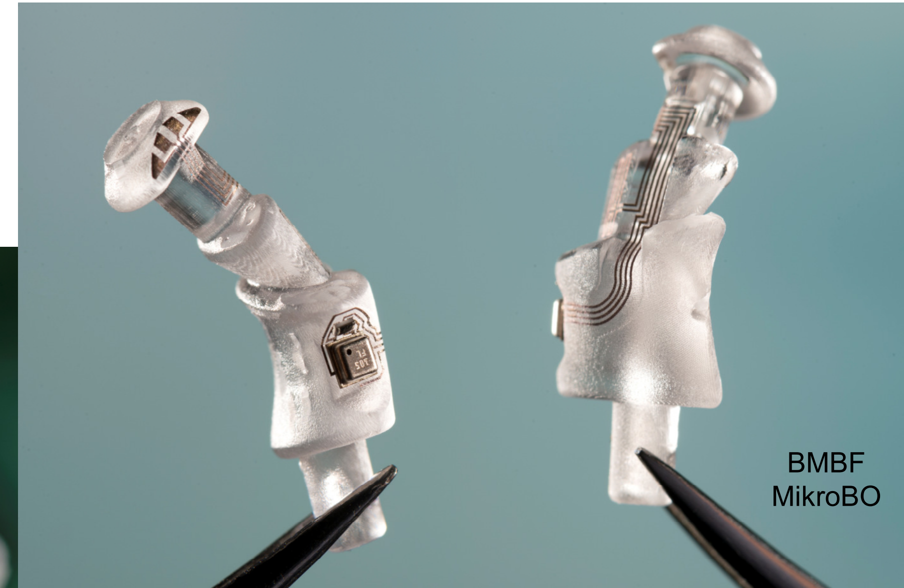
Hahn Schickard



AiF KonsDruckt



AiF KonsDruckt


BMBF
MikroBO

New products with digitally printed electronics can be designed and manufactured

Reliable connections between SMD and digitally printed conductive structures are feasible

Hahn Schickard

Dr. Kerstin Gläser

✉ Kerstin.Glaeser@Hahn-Schickard.de

☎ +49 711 685 84785

Thank you for your attention