Fraunhofer ENAS

3D PEIM 2023
Day 2 – S4 “Additive Manufacturing”

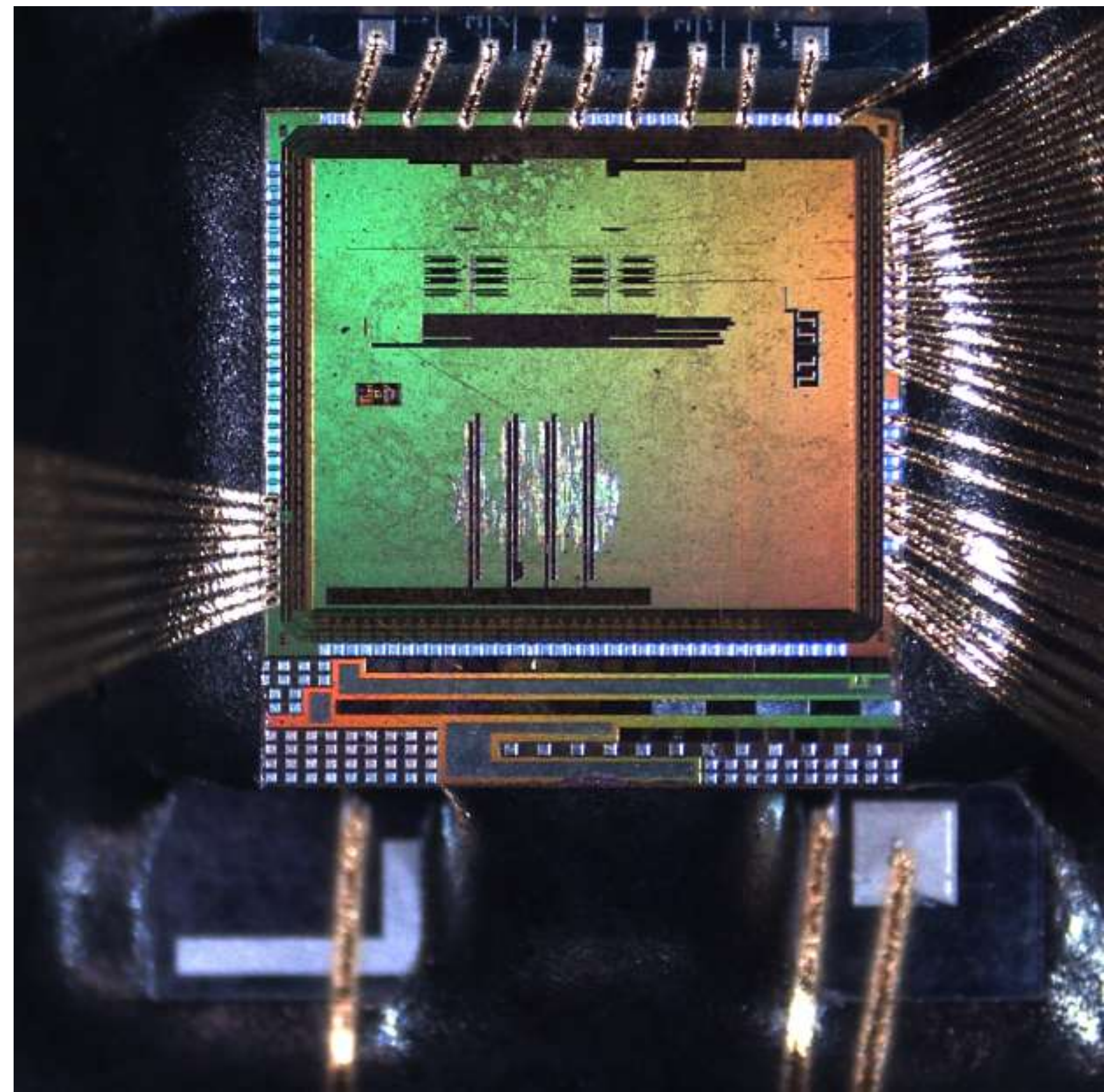
Frank Roscher,
Faunhofer ENAS

Titel:
“Additive deposition technologies: from 2D towards 3D electronic systems”

Outline

Additive deposition technologies: from 2D towards 3D electronic systems

- Fraunhofer ENAS, short overview
- Introduction: Additive Technologies in Semi/ MEMS fabrication chains
- Focus on Technologies vs Application examples
  - 2D Screen printing
  - 2,5D Aerosol-Jet
  - Moving from 2D towards 3D
- Conclusion



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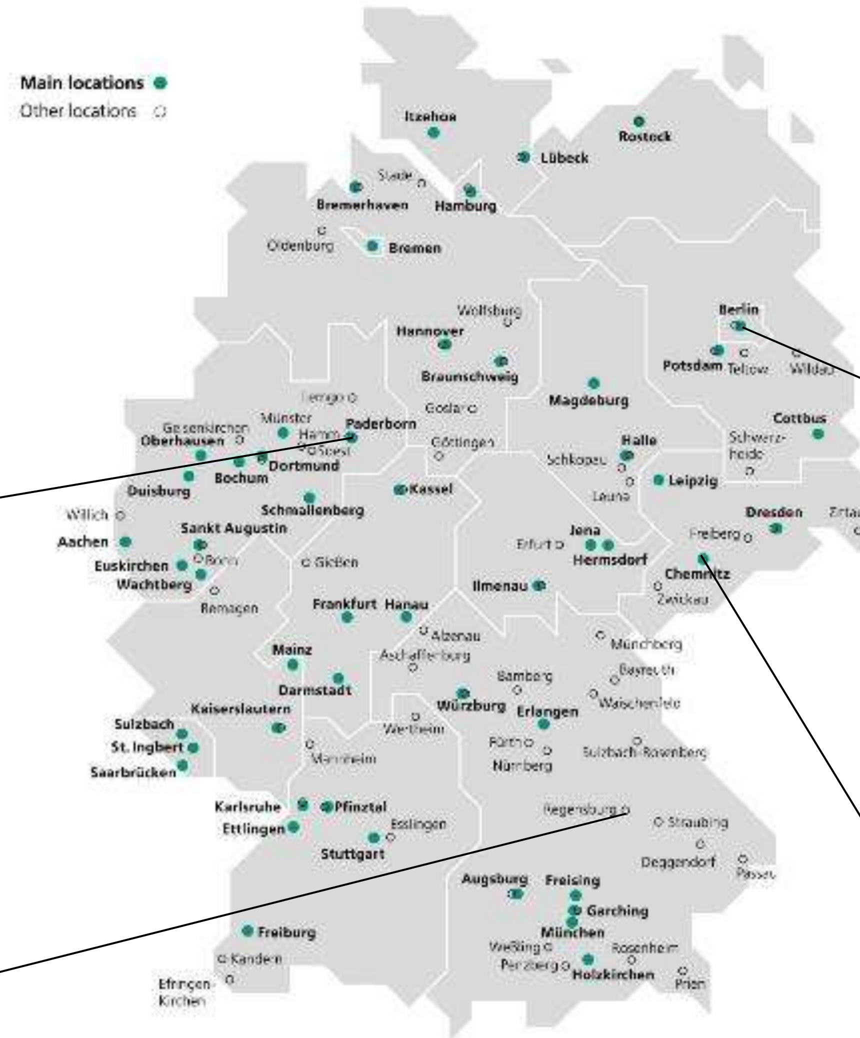
Short Introduction

Fraunhofer ENAS – an institute of Fraunhofer-Gesellschaft

Paderborn

Regensburg



Berlin

Chemnitz

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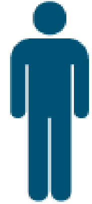
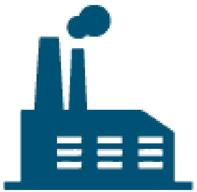
Chemnitz **European Capital of Culture in 2025**

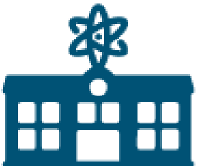


243.659 inhabitants
(06/2021)

Chemnitz University of Technology:
About 10.000 students

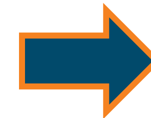


About 18.500 Industrial and handicraft enterprises
(06/2021)



Nonacademic RTOs: Fraunhofer IWU and Fraunhofer ENAS, Saxon Textile Research Institute e.V. (STFI)

Main industry: automotive industry and its components suppliers, mechanical and plant engineering



Leading R&D place for micro system technology, sensors and textile

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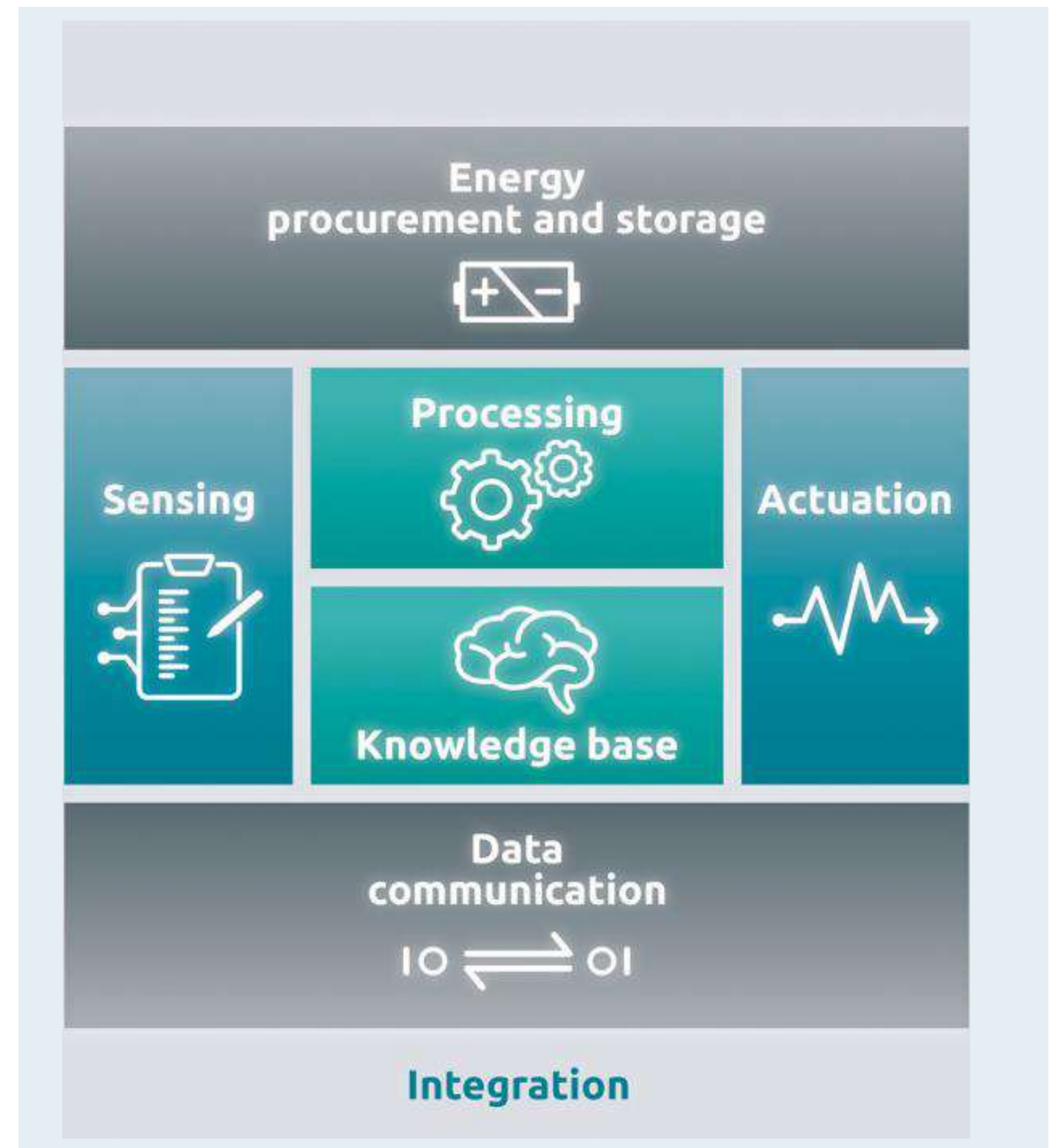
Main Working Field
– Smart Systems Integration

- Self-sufficient intelligent technical systems or subsystems with advanced functionality
- Combine sensing, actuation and data processing, informatics / communication
- Autonomous systems
- Highly reliable, often miniaturized, predictive, linked in networks
- Their operation being further enhanced by their ability to mutually address, identify and work in consortia

→ Basic components for the Internet of Things



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Fraunhofer ENAS and Center for Microtechnologies (ZfM) at TU Chemnitz

Cluster of clean rooms at ZfM: 1000 m^2, 300 m^2 of them are class ISO 4
Fraunhofer ENAS: 1400 m^2 of laboratories, 400 m^2 of them with improved cleanness

Fraunhofer
ENAS

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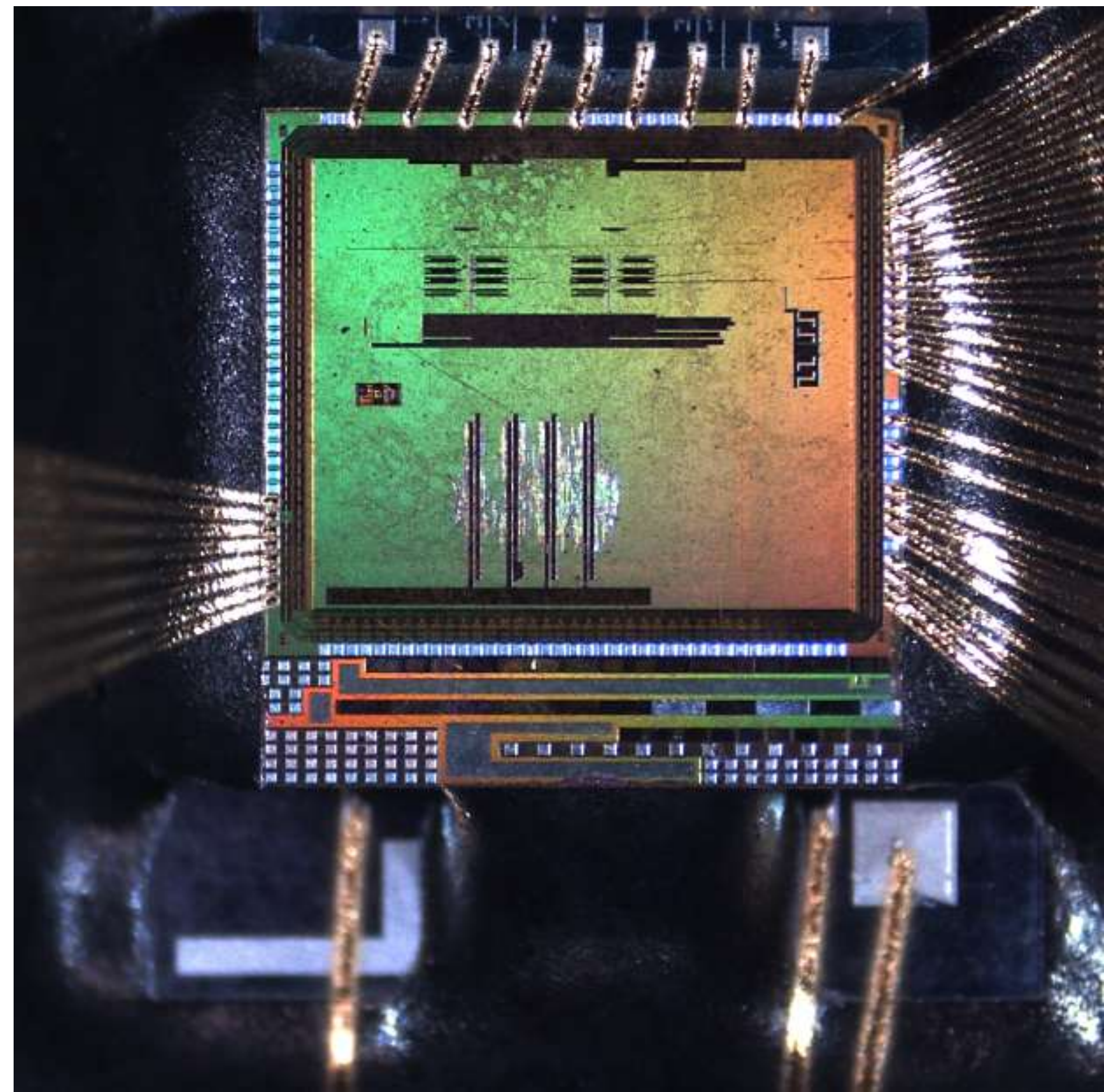

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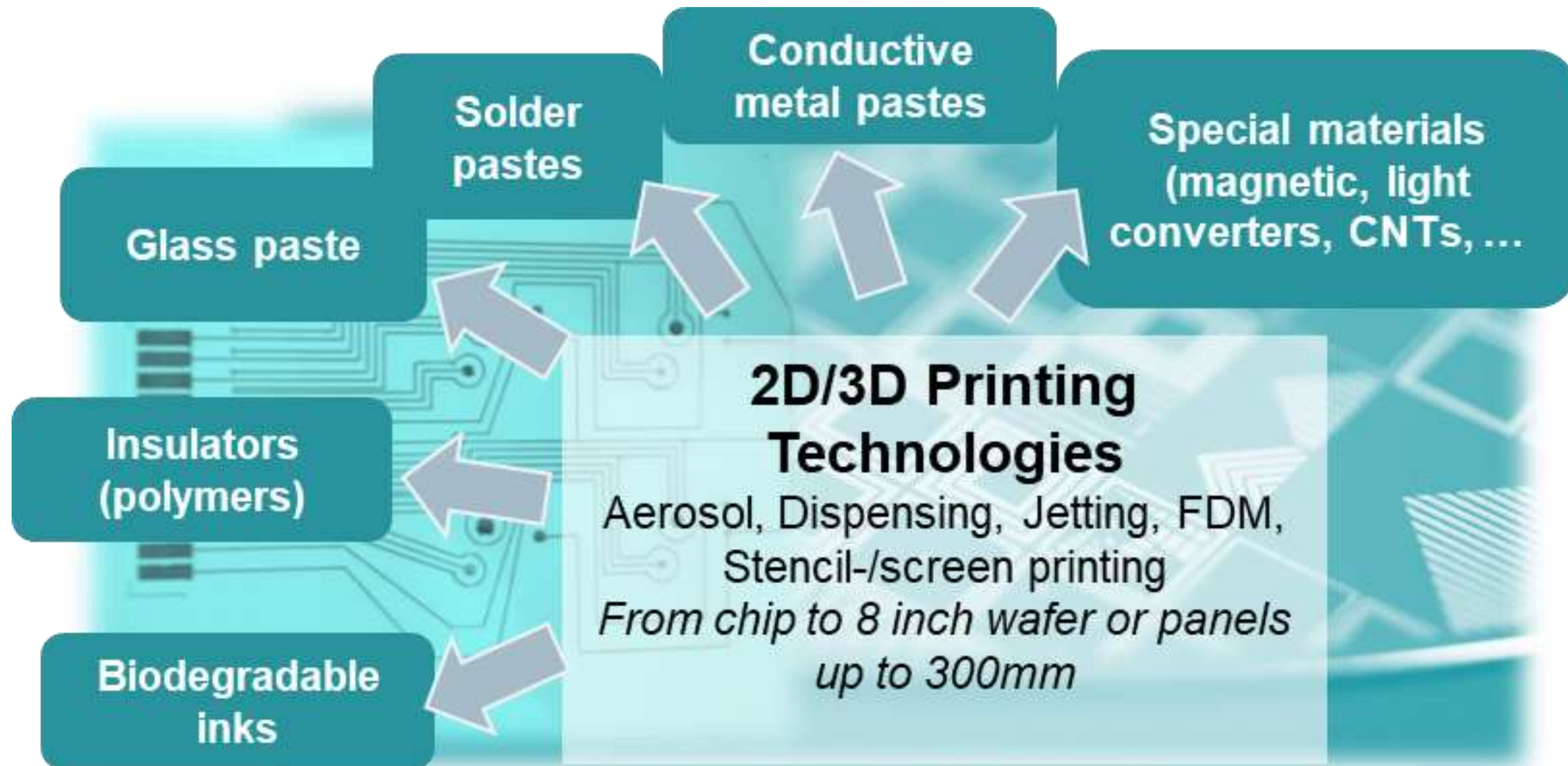
Introduction:
Additive Technologies in Semi/ MEMS fabrication chains



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Introduction:

Additive Technologies in Semi/ MEMS fabrication chains

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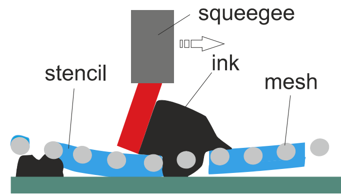
Additive Technologies in Semi/ MEMS fabrication chains

From 2D towards 3D

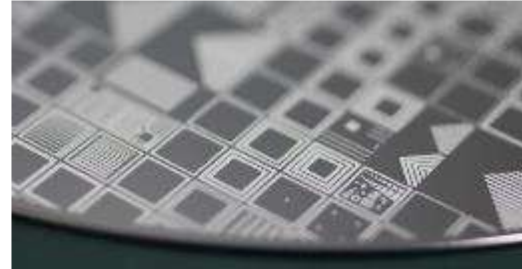
Screen/Stencil Printing



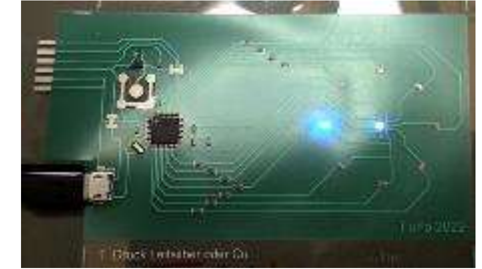
Precision screen-/stencil printing

MATERIAL EXAMPLES

- Glass frit for WL/CL Bonding
- Conductive / Insulating paste systems / printed electronics
- Solder pastes
- Application specific materials

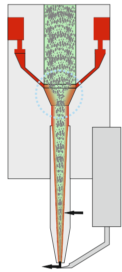


Printed glass frit on WL for Bonding from CL to 8" Wafer



Fully printed circuit on flex polymer substrate

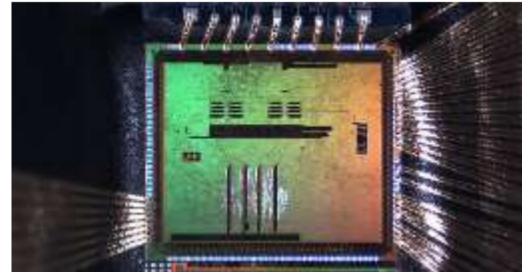
Aerosol Jet



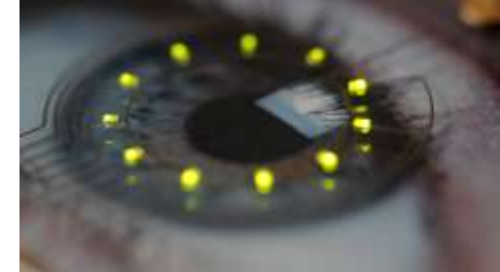
Precision Jetting down to 10µm

MATERIAL EXAMPLES

- Conductive or insulating inks
- Nanoparticle based Solder pastes
- Application specific nanoparticle inks (i.e. optics, resins, ..)

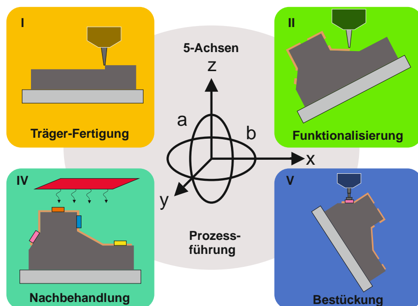


Aerosol-Jet printed interconnects using Ag nanoparticle inks



Aerosol-Jet printed interconnects and SMT on optics / co-polymer

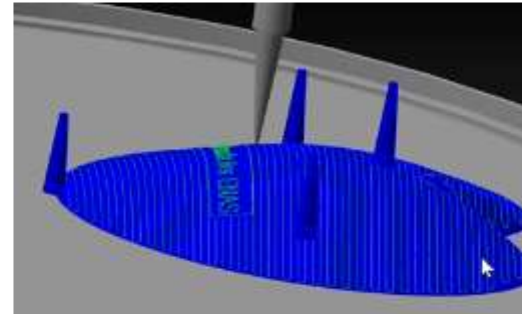
3D Cluster



Precision Jetting / Dispensing

MATERIAL EXAMPLES

- Ag paste
- Cu paste
- C-paste
- Ceramic pastes
- Insulators, glass paste, solder paste, adhesives, …



3D CAD CAM Strategy

Conformal dispensing n 3D substrates (i.e. out of injection moulding)

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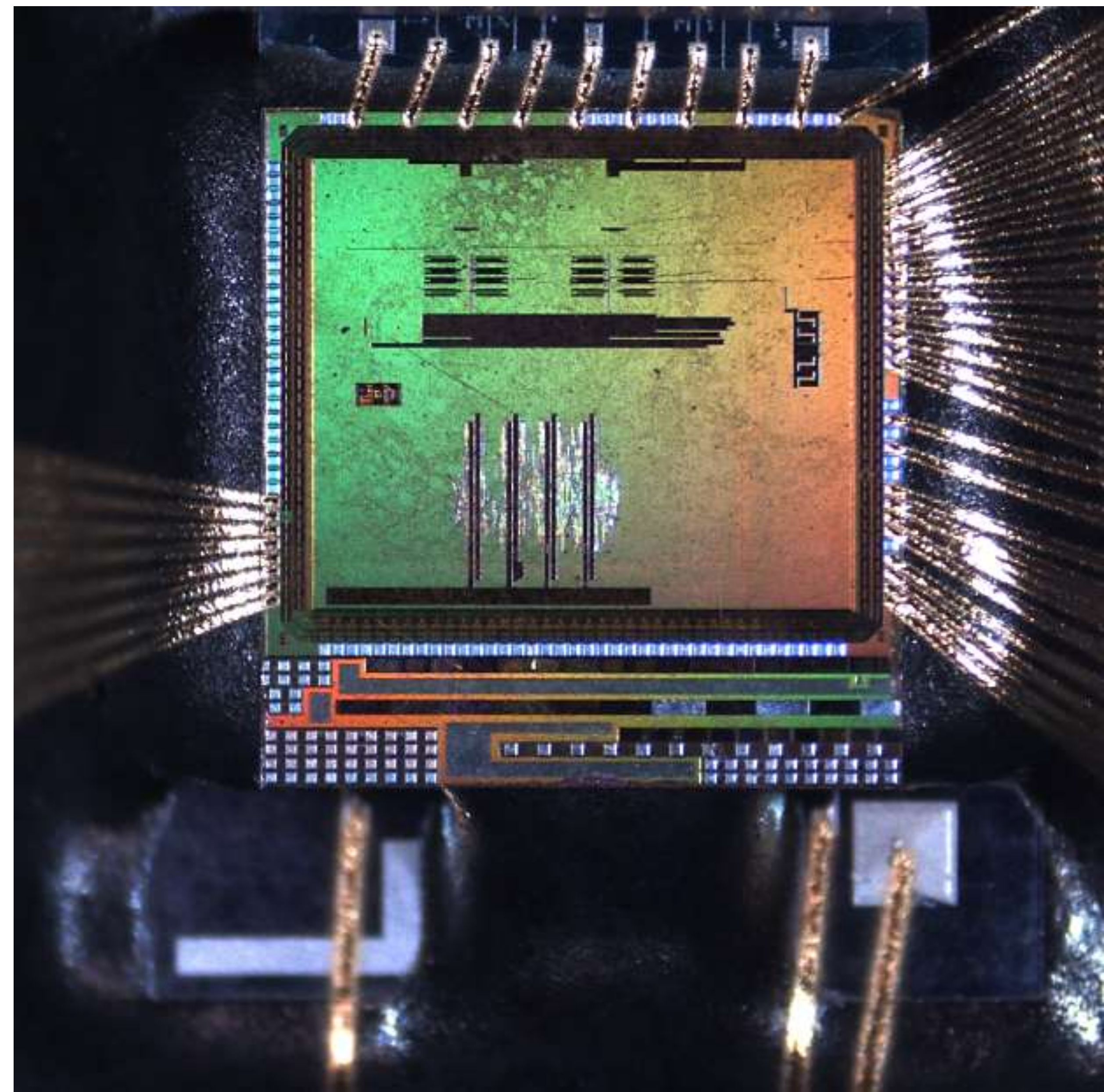

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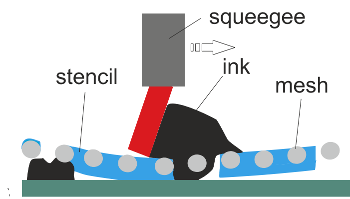
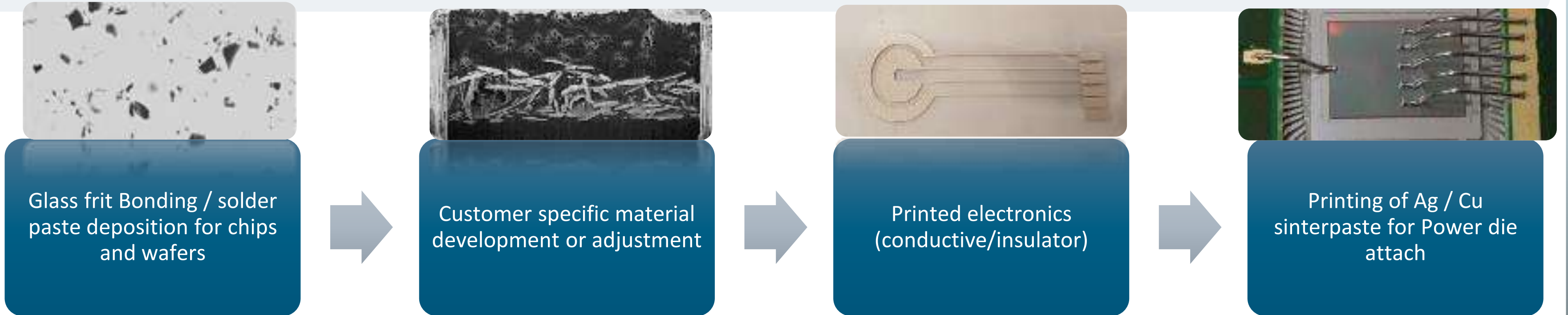
Focus on Technologies vs Application examples

Screen Printing

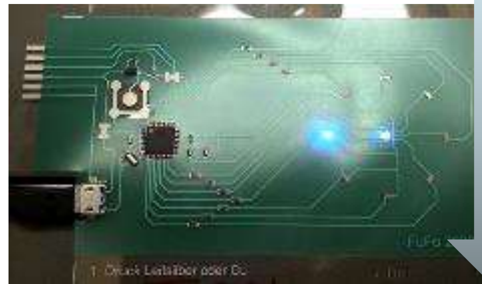
Screen / setncil printing

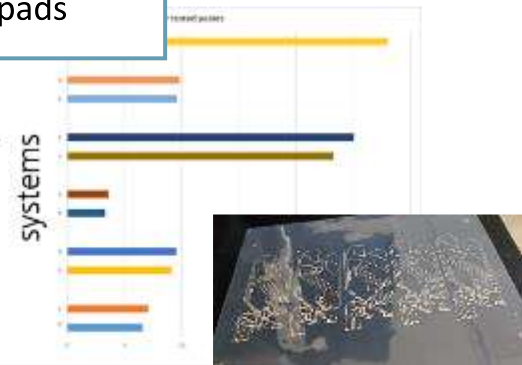




Products / Markets

Membrane Keypads





Medical wound patch

Multilayer (conductor/insulator) printing using Ag and Cu paste systems. Bechmark of different paste system
Achieved goal: printing on low cost polymer substrate and subsequent soldering / adhesive die attach for IC Integration

Medical patch for accelerated wound healing by external driven electrical fields
Achieved goal: Front and backside metallization with laser drilled vias, cell culture studies show improved healing.

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Focus on Technologies vs Application examples

Screen Printing of sinter paste materials and subsequent local heating by inductive principles

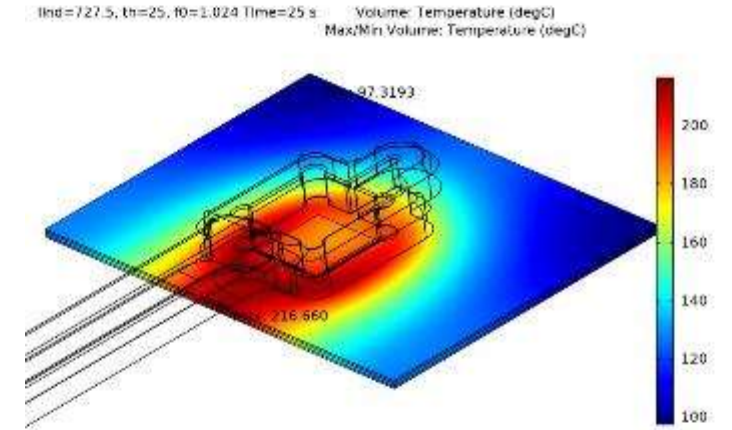
Sinter paste processed by stencil/screen printing on i.e. ceramic substrate / DBCs.

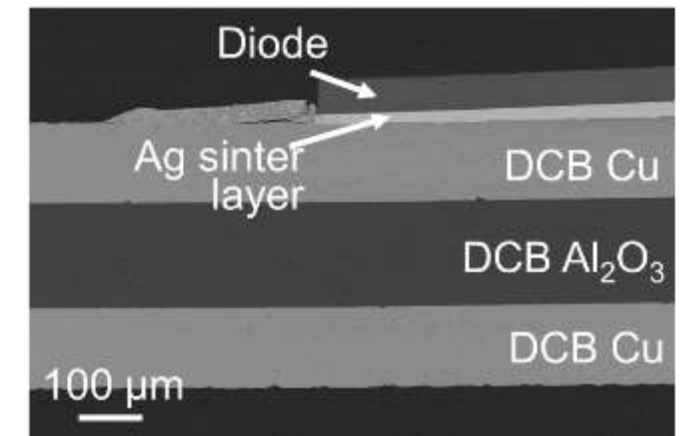
Selective Joining technologies are under development for bonding of microelectronic components by electro-magnetic field coupling in micro- and nano-scaled intermediate layers and resulting local resistance heating.

Target Application

- Power Electronics & heterogeneous Packaging
- D2D and D2W Bonding
- Waferlevel Bonding

Induction coil with pressure tooling (left), experimental test rig for sinter processes (right)





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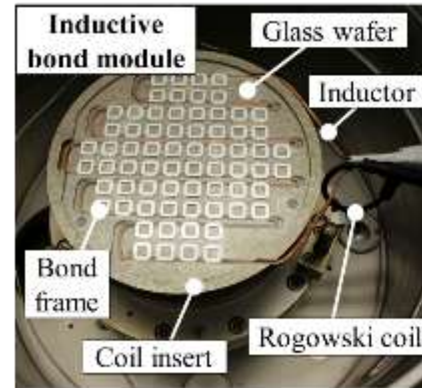
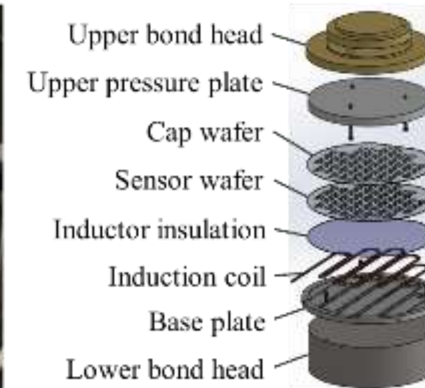
Focus on Technologies vs Application examples

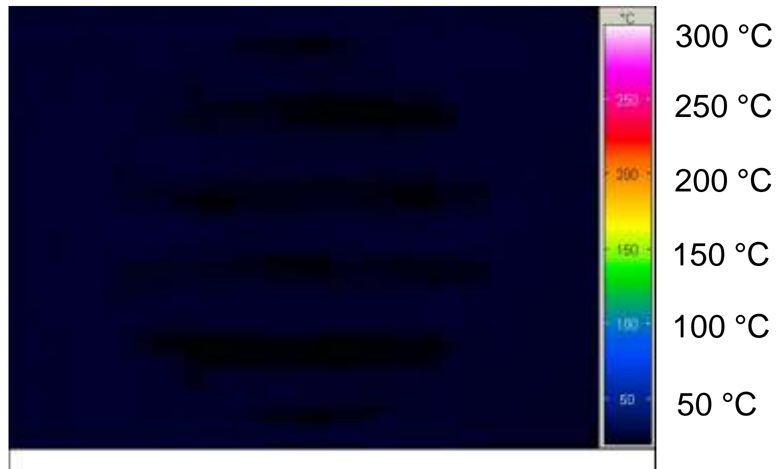
Inductive heating on waferlevel

- Heterogeneous substrate stack: Silicon - Borofloat® 33
- Tested bonding materials: Cu-Sn (TLP) and Au-Au (thermocompression)
- Maximum bond pressure: 2.2 MPa
- Bonding time (including heating and cooling): 120 s for Cu-Sn; 300 s for Au-Au

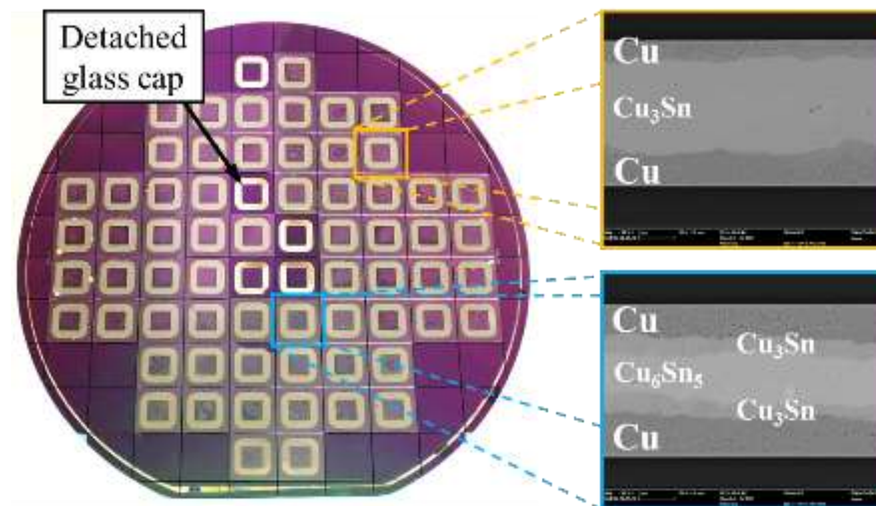




Assembly of the bond module with integrated inductor and Rogowski coil for RF current measurement



Real-time IR video of the inductive heating process



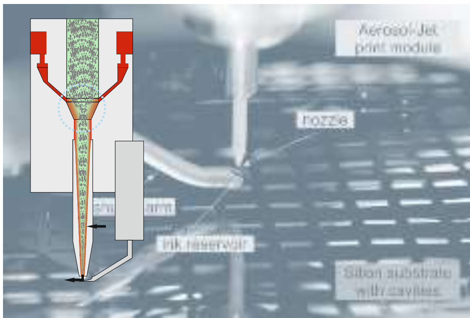
Si-glass wafer stack after inductive Cu-Sn SLID bonding

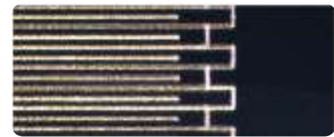
Focus on Technologies vs Application examples

Aerosol Jet Printing

Application portfolio

Aerosol-Jet Prnting

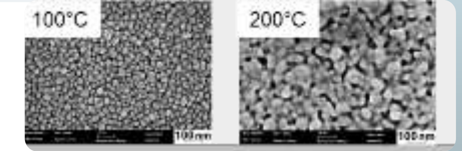




Fine line deposition down to 10µm

Rapid prototyping for printed electronics

2,5D deposition up to 8mm topography of conductive and insulating materials



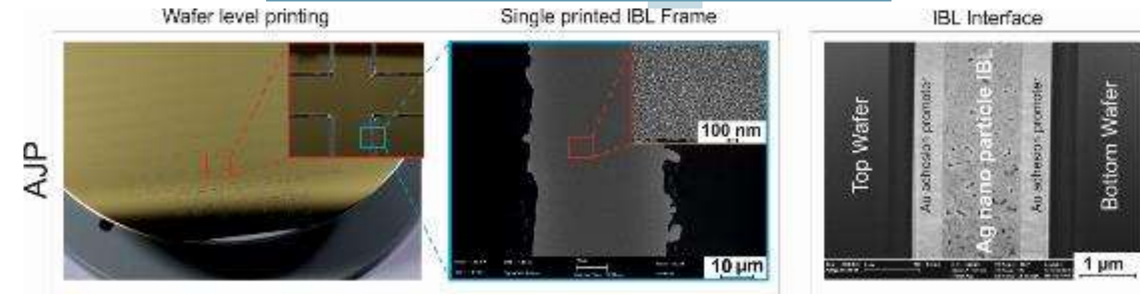
Material science, characterization of nanoparticle joint formation

Products / Markets

Printed Mulilayer RDLs

Multilayer RDL on injection moulded part (secure envelope). Left: Top View of printed Ag Nanoparticle mesh on 3D polymer substrate. Right: Microscopy and SEM of multilayer structure (Substrate-Parylene-Ag-Parylene-Ag) including laser vias.

Printed Nanoparticle interfaces



Wafer level nano particle deposition (Bond frames) i.e. on Au or Cu adhesion layers for subsequent low temperature bonding < 250°C. Technology enables post processing / deposition on fragile / sensible substrates due to digital nature / direct writing capability

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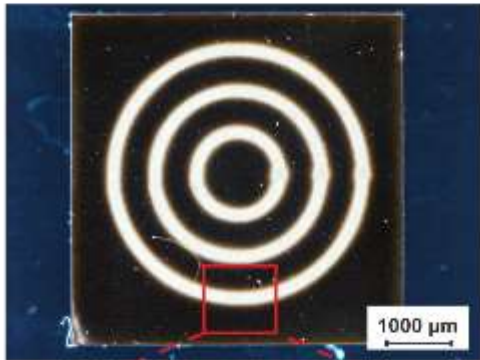
Focus on Technologies vs Application examples

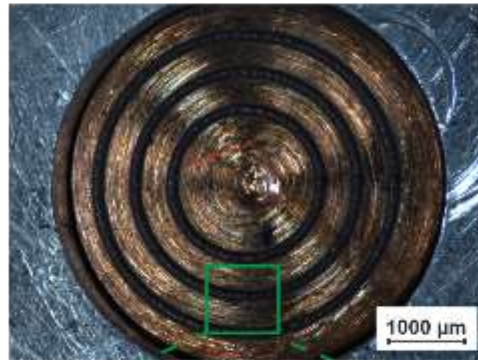
Aerosol – Jet Inflight Mixing of Cu and Sn Nanoparticles for adjustable solder composition

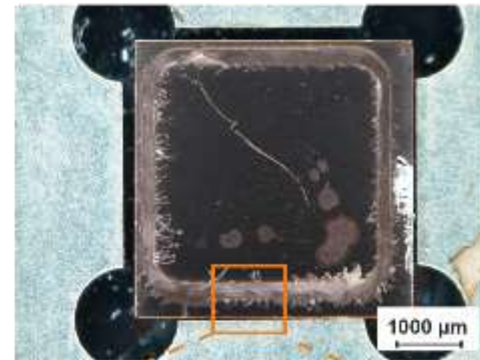
Inflight mixing of two different nanoparticle suspensions enable adjustable solder composition

Nano Sn | Nano Cu | Nano Cu + Nano Sn | CuSn EDX Map | Cu EDX Map | Sn EDX Map

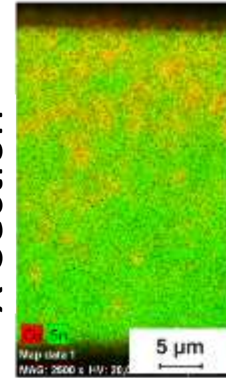
AJP

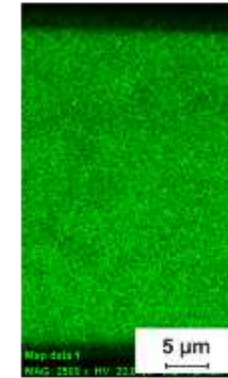


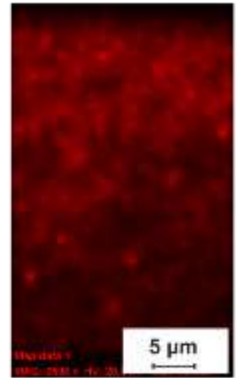




X-Section







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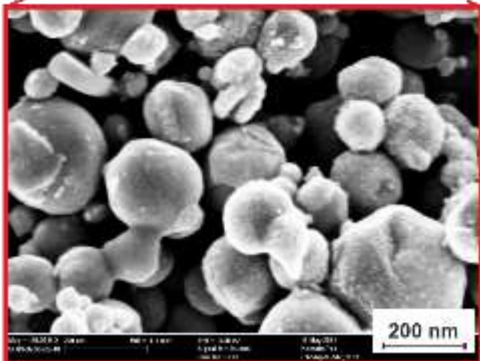
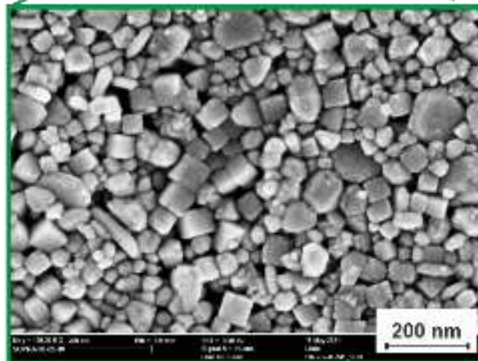
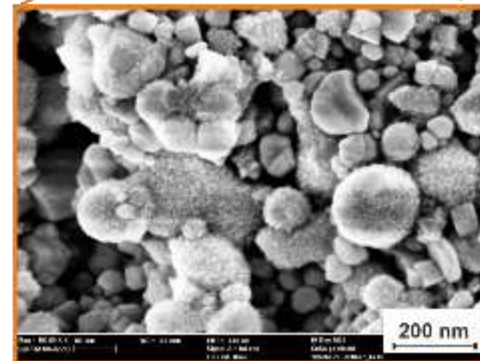
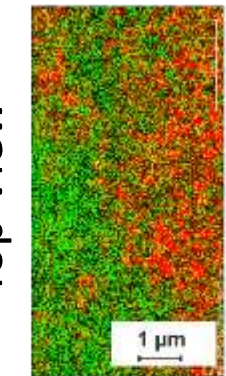
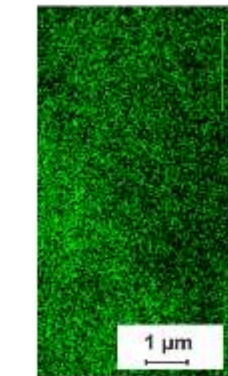


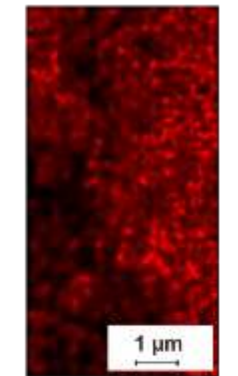




Top View







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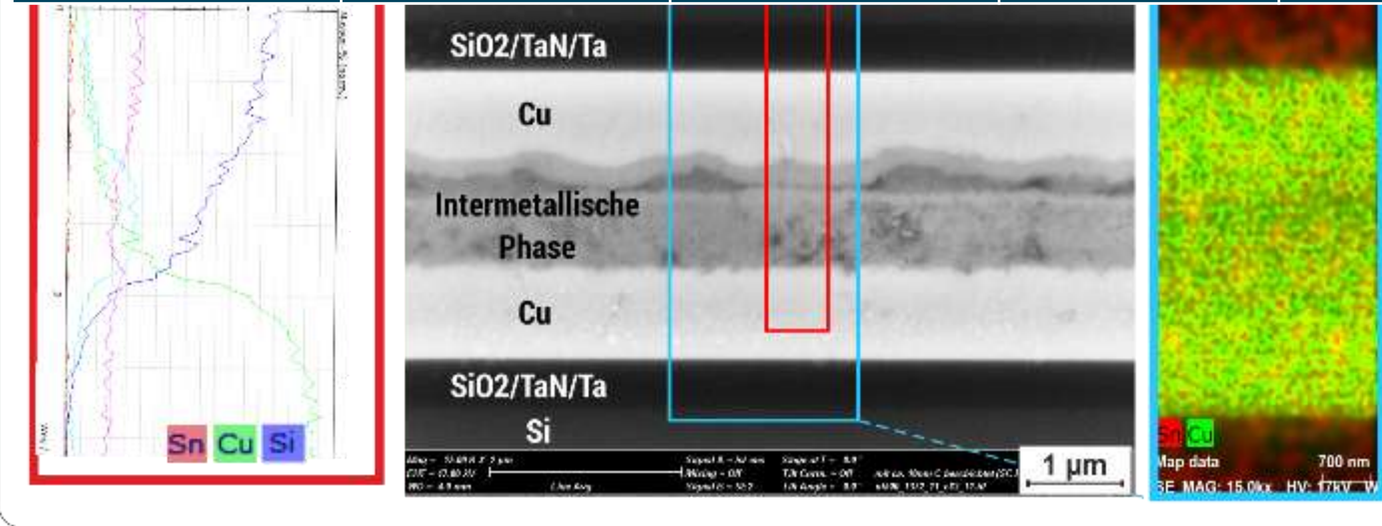
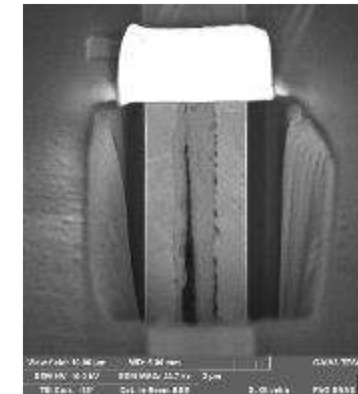
Focus on Technologies vs Application examples

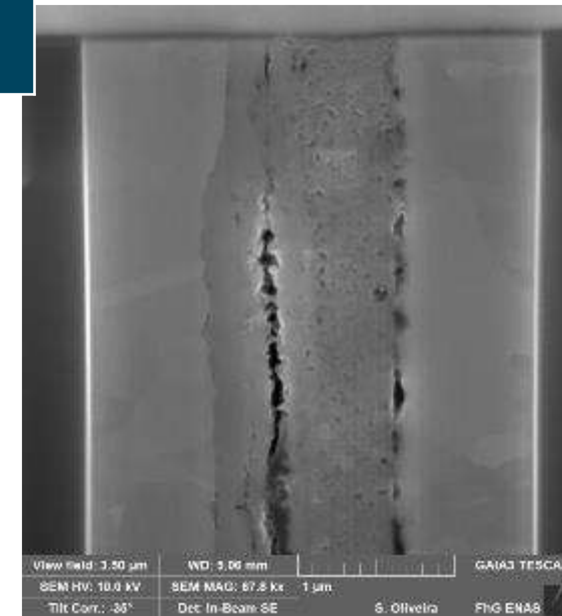
Aerosol – Jet Inflight Mixing of Cu and Sn Nanoparticles for adjustable solder composition

First partially achieved Chiplevel bonds, optimization regarding solder composition, deposition homogeneity and void formation

Adhesion layer	Printed material	Bonding Temp. [°C]	Bond Force [N]	Bond pressure [N·mm^{-2}]	Shear rate [N·mm^{-2}]
CU	CuSn - 4:1	320	50	14 ± 1	11 ± 1







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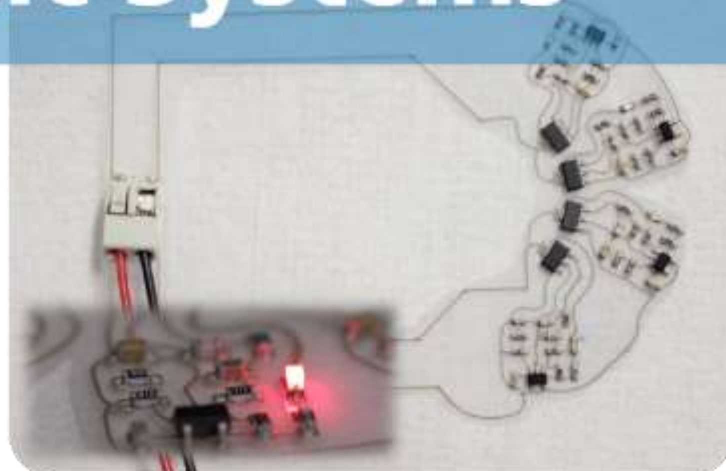
Focus on Technologies vs Application examples

Moving from 2D towards 3D

3D Electronic Systems

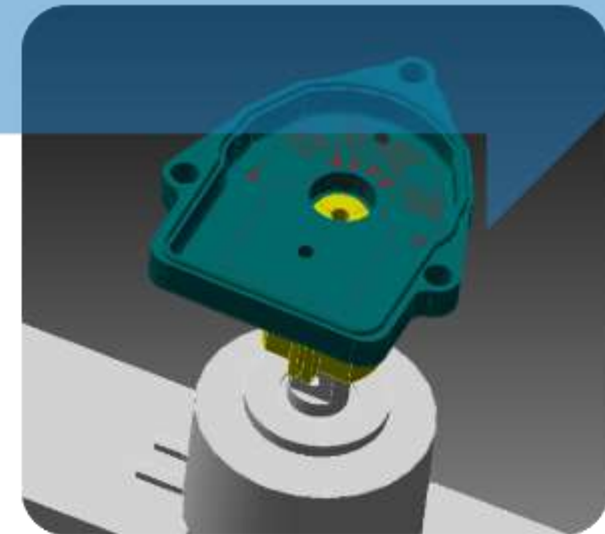
PCB based circuit (magnetic field sensors)

- Reflow solder die attach



Printed (PJ) circuit on flexible polymer (PEN) foil using 3D cluster tool

- Die attach by conductive glue



Designed (Dispensing/Jetting) circuit and CAD/CAM Strategy on injection molded 3D substrate

- R&D: Deposition, Integration Technologies, Reliability

Classical electronics | **Printed electronics** | **3D Electronic Systems**

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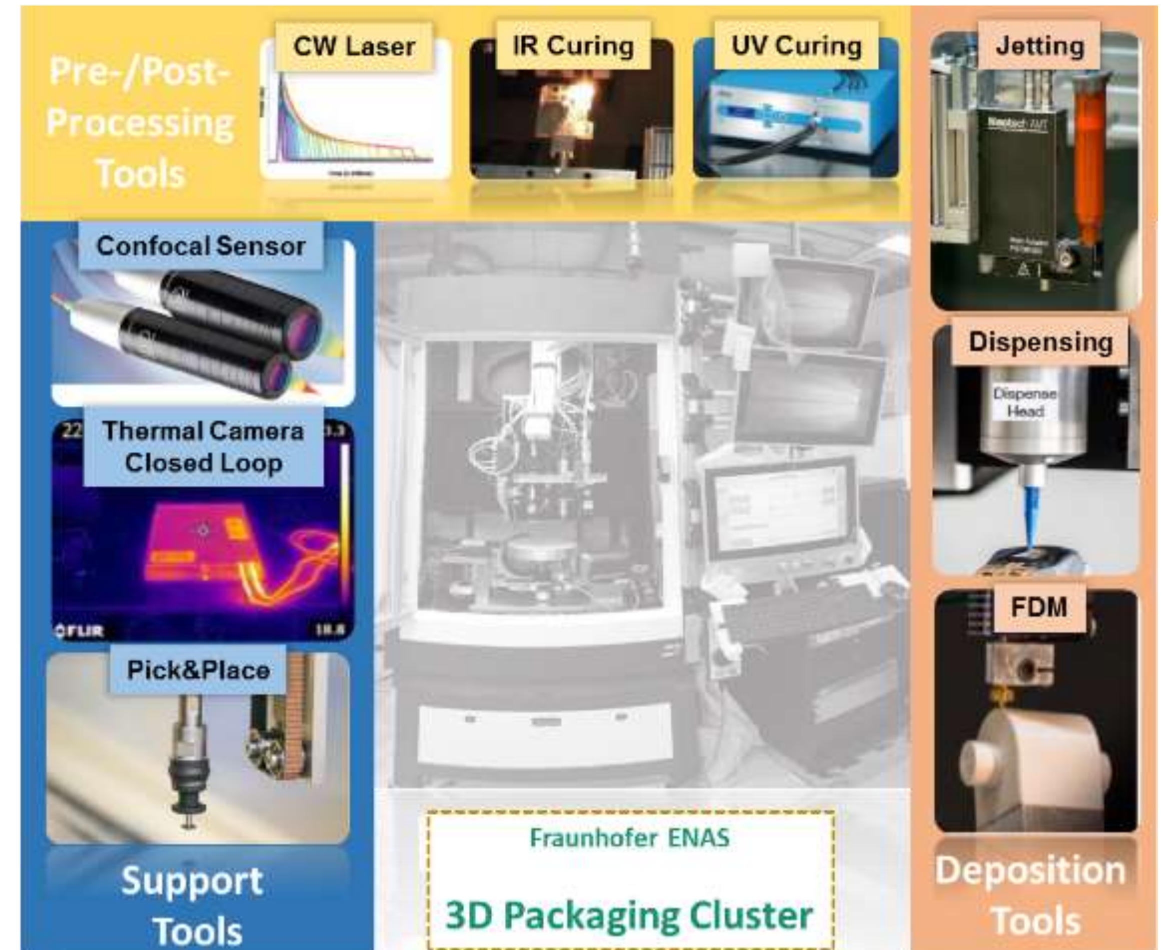
Focus on Technologies vs Application examples

Moving from 2D towards 3D

- 3D conformal functionalization for 2D and 3D substrate material (wafer, dies, 3D printed substrates, injection molded structures,…) combining deposition, pre- and posttreatment technologies with Pick&Place module
- Combination of digital deposition technologies (i) dispensing, (ii) jetting and (iii) fused deposition molding for the deposition of a wide variety of ink/paste materials (solder paste, silicone, ceramic paste, conductors (Ag, Cu, Au,…), insulators, conductive epoxy/smt glue, …)
- Integration of pre-/post processing modules (i) CW Laser, (ii) IR Curing System controlled by thermal cam and (iii) UV curing station
- Further supporting features include (i) Pick&Place, (ii) thermal camera and (iii) confocal sensor



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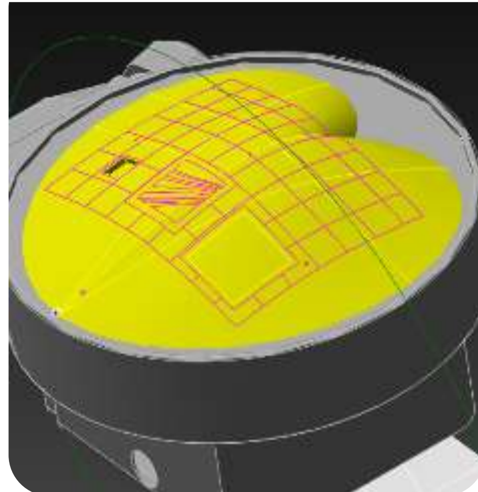
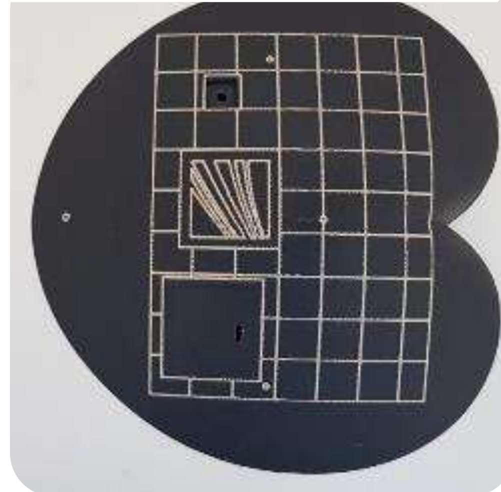
Focus on Technologies vs Application examples

Moving from 2D towards 3D

Layout → CAD/CAM strategy and simulation → Print on substrate



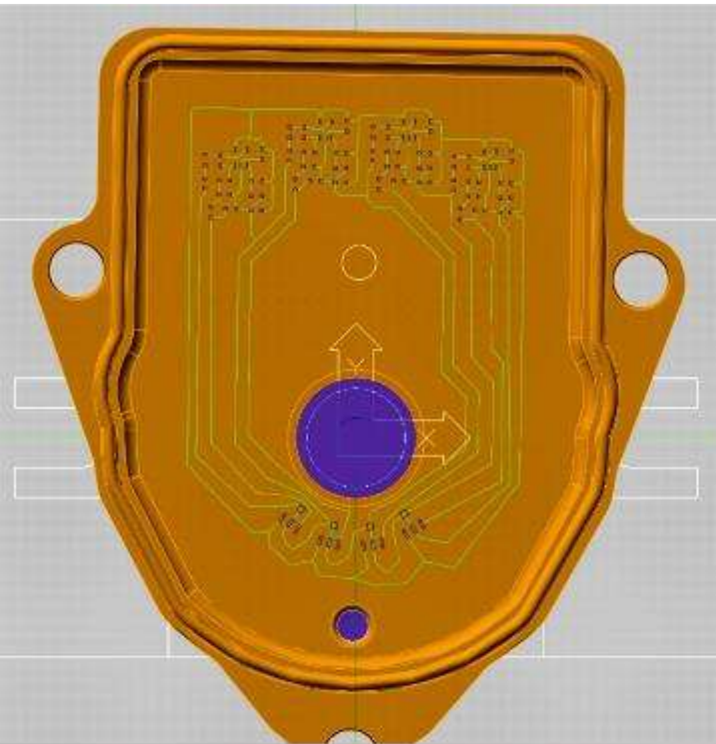


Digital manufacturing enables rapid prototyping / low volume use cases & individualization

Focus on Technologies vs Application examples

Moving from 2D towards 3D

- Functionalization of (todays mostly) passive parts of the system package using a wide variety of commercial available electronic grade materials (Ag paste (nano/micro), Cu paste, solders, adhesives, ceramic pastes, ….)

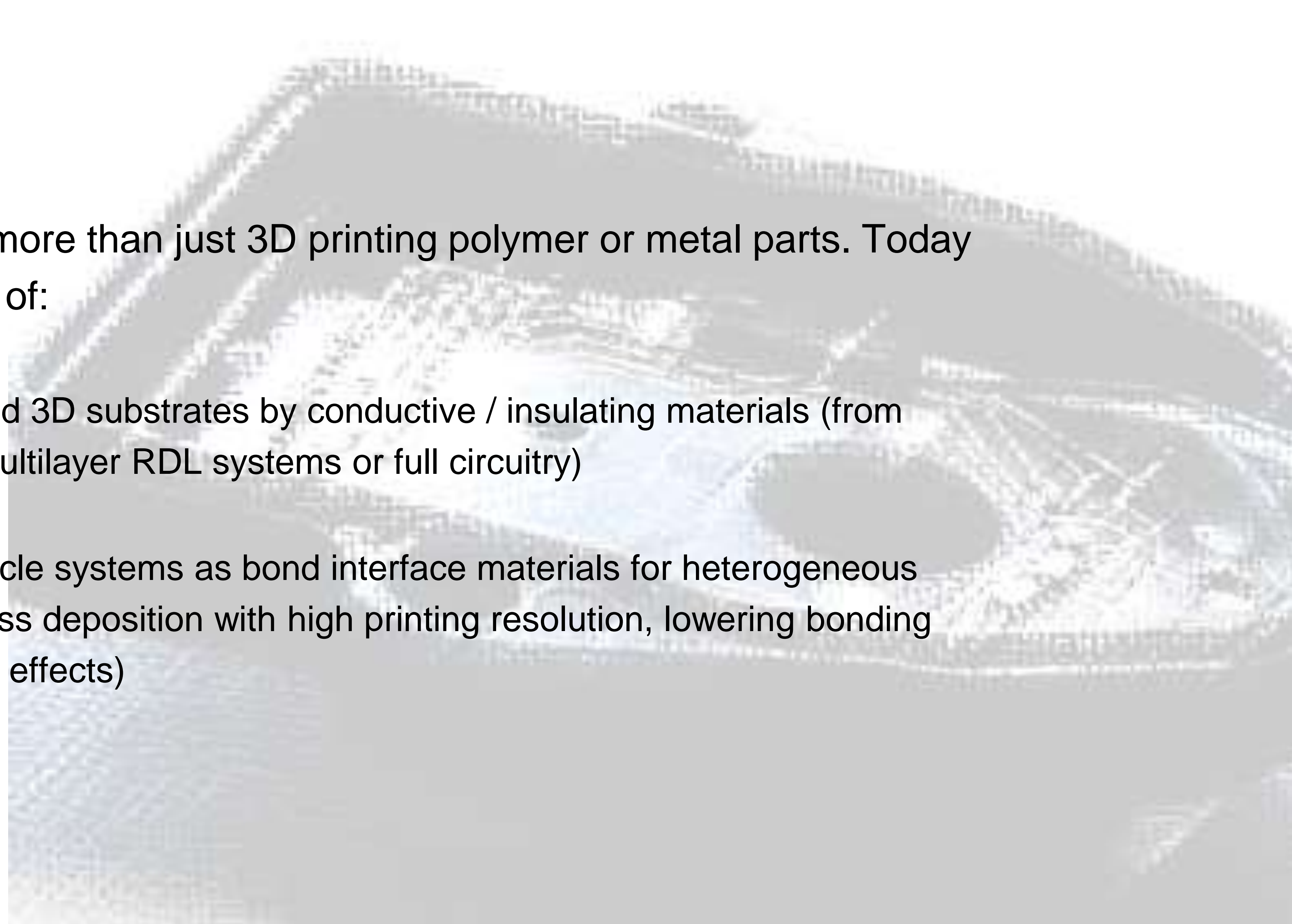


DESIGN

FABRICATED CONDUCTORS

PICK&PLACE & SYSTEM TEST

Conlusion



- Additive manufacturing is more than just 3D printing polymer or metal parts. Today the industry can make use of:
  - Functionalization of 2D and 3D substrates by conductive / insulating materials (from printed interconnects to multilayer RDL systems or full circuitry)
  - Utilizing micro / nano particle systems as bond interface materials for heterogeneous material joints (post process deposition with high printing resolution, lowering bonding temperature utilizing nano effects)

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