Presentation of the Institute FAPS

Electronics Production

Prof. Dr.-Ing. Jörg Franke

Institute for Factory Automation and Production Systems

Friedrich-Alexander University Erlangen-Nuremberg

Friedrich-Alexander-Universität
Technische Fakultät

FAPS

275 years of university history form the foundation for our success today

- 1742: Establishing of the University of Bayreuth by Margrave Friedrich von Brandenburg-Bayreuth
- 1743: Transfer of the university to Erlangen
- 1769: Renamed in "Friedrich-Alexander-University" in memory of Margrave Alexander of Ansbach and Bayreuth
- 1825: Move into the so-called "castle”
- 1966: First classical university with engineering sciences as an independent branch of education
- 1982: Foundation of the Department of Mechanical Engineering

FAPS

The School of Engineering of the University of Erlangen-Nuremberg is structured in five departments of different disciplines.

Friedrich-Alexander-University Erlangen-Nuremberg
~40,000 students ~6,000 employees ~600 professors

Schools

- School of Humanities, Social Sciences and Theology
- School of Law and Business Administration
- School of Medicine
- School of Science
- **School of Engineering**

Departments

- Artificial Intelligence in Biomedical Engineering – 10 Institutes
- Chemical and Biological Engineering – 13 Institutes
- Electrical and Telecommunications Engineering – 13 Institutes
- Computer Science
- **Mechanical Engineering** – **10 Institutes**
- Materials Science – 9 Institutes

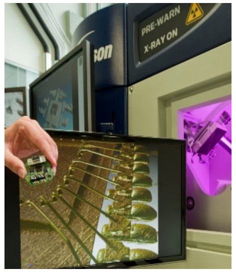
Institutes

- Engineering Design
- Engineering Mechanics
- Technical Dynamics
- **Factory Automation and Production Systems**
- Resource and Energy Efficient Production Machines
- Manufacturing Technology
- Institute of Metrology
- Plastics Engineering
- Photonic Technologies
- Casting Technology

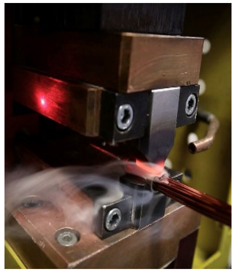
FAPS

The Institute for Factory Automation and Production Systems (FAPS) is researching the production and assembly of mechatronic products.

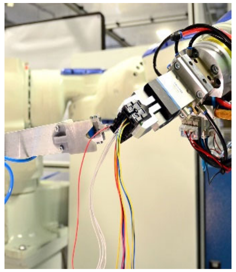
Electronics Production



Electro-mechanical Engineering



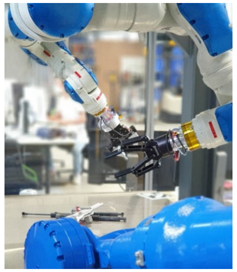
Signal and Power Networks



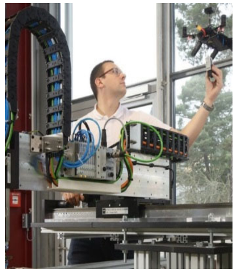
Home Automation

Medical Technology

Robotics



Automation Technology



Engineering Systems

Auf AEG Nuremberg

Technical Faculty Erlangen

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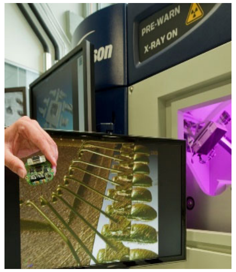
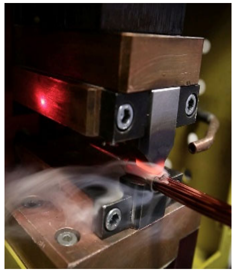
Electronics Production



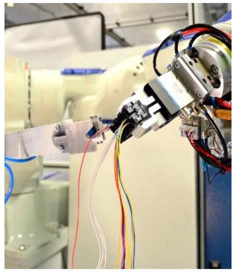
- Flexible printed circuits
- 3-D MID
- SMT-assembly
- Optoelectronic AVT
- Power electronics
- Quality assurance/ Reliability tests
- Structuring
- Printed electronics
- Additive manufacturing of mechatronics

Electro-mechanical Engineering



- Laser cutting
- Joining laminated core
- Magnet manufacturing, assembly, testing
- Winding technologies
- Impregnating
- Grouting
- Circuitry
- Test technologies
- Additive Manufacturing

Wiring Systems



- New topologies in Wiring systems
- Wire harness CAD
- Assembly and interconnection technologies
- 3D-MID antennas
- Automated assembly of wire harness
- Testing systems
- Assembly of control enclosures

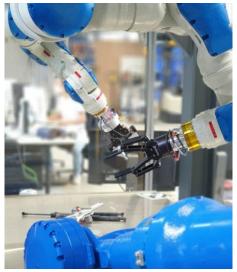
Home Automation

- Home automation
- Energy-management
- Comfort & safety
- Communication and Infotainment
- Decentralized energy production /storage
- Intelligent, efficient heating systems
- Synergy of mobility and smart home

Medical Technology

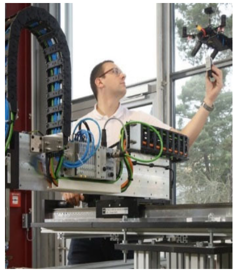
- (Partly) autonomous assistance systems
- Mechatronic implants
- Automation of medical diagnostics
- Digitalization in medical technology
- Compatible sensors and actuators
- Individualized manufacturing

Robotics



- Sensors for detecting the environment and for interaction
- New kinematics and drives
- Safe control architectures
- Learning systems for control, navigation and interaction
- Industrial and service robots
- Personal robots
- Mobile Robots

Automated Production Systems



- Industrial Smart Services
- Service-oriented architectures
- Condition and process monitoring
- Semantic technologies for machine interaction
- Cloud-based platform solutions
- Communication technologies
- Data Analytics and Machine Learning

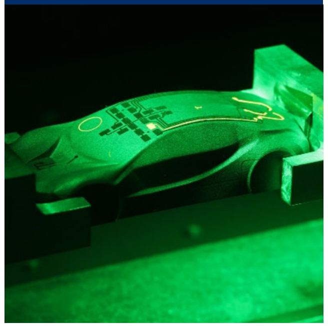
Engineering Systems

- Integrated Engineering
- Planning of production systems and intralogistics
- Development of digital process chains
- Process automation in engineering
- Engineering of resource-efficient production systems
- Human-Machine-Interaction (VR, AR)

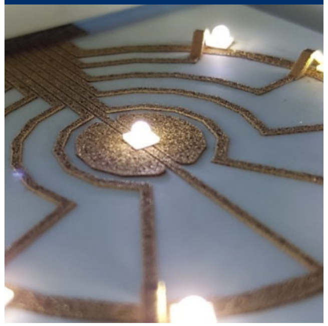
FAPS

Technology fields ensure an exchange of knowledge across research areas and promote specific technologies.

Mechatronic Integrated Devices (3D-MID)



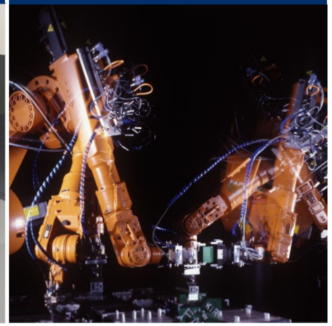
Additive Manufacturing



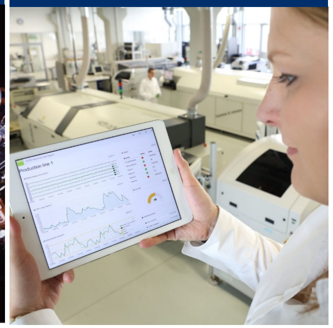
Construction and connection technology

Process control and Intralogistics

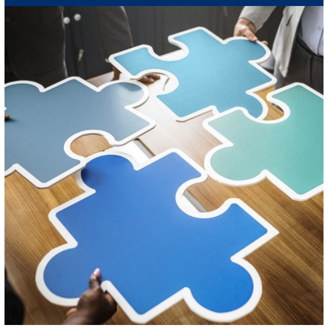
Handling technology



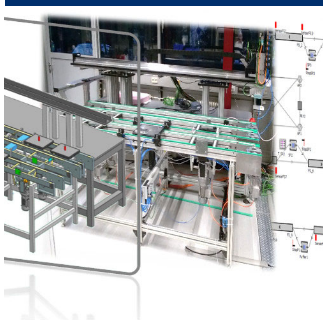
Artificial Intelligence & Machine Learning



Communication und Cooperation

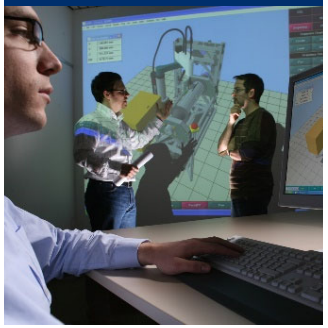


Planning and Simulation

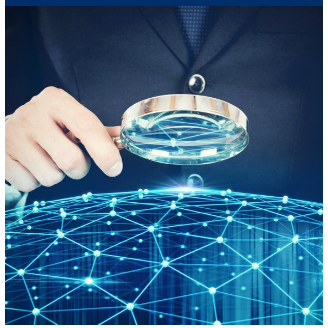


Energy Efficiency and Environmental protection

Software Engineering and Deployment



Quality and Management



FAPS

FAPS: The competent institute in automation technology and mechatronic systems.

VISION

FAPS is a recognized institute for teaching and research in the area of automation and mechatronic systems, with a interdisciplinary development of holistic optimization to serve the welfare of the people.

MISSION

FAPS creates innovations through the integration of knowledge from various disciplines, in particular

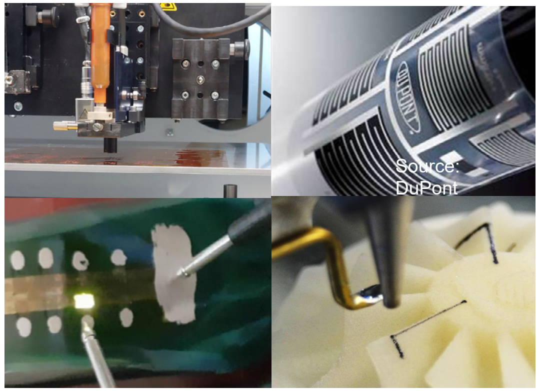
- the specialized disciplines in mechanical, electric/electronics, information technology, bionics and optics;
- levels of integration from the components to the system;
- automation components such as controllers, sensors and actuators;
- the entire product life cycle, from concepts, through to development, production, use and recycling;
- through university research and teaching, industry collaboration, technology transfer and the founding of new companies;
- through the human-machine interaction;
- through sustainable and efficient methods of production, distribution, usage, storage and reuse of resources.

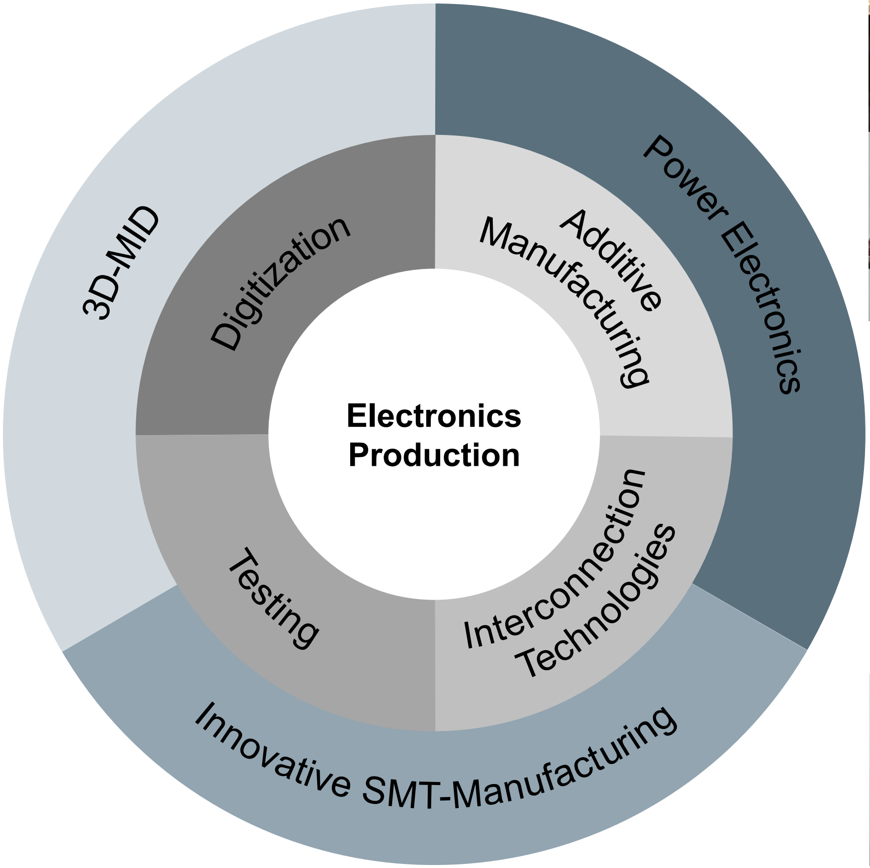
All employees set out on their activities based on commonly shared values at FAPS.

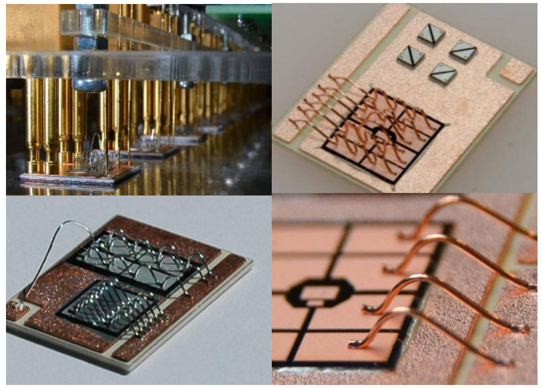
FAPS

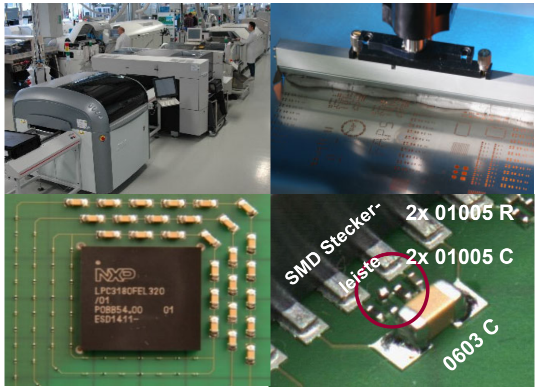
Responsibility	We work on tasks including research and teaching, which are the result of high-quality scientific practices. The aim of our work is to ensure value and to expand job opportunities in Germany.
Cooperation	Honesty, reliability and fairness are fundamental pillars of an effective collaboration with colleagues, industry partners and students. Such principles form the basis of proficiency, punctuality and open communication.
Future orientation	We continuously confront new multidisciplinary topics, and accordingly, develop relevant initiatives, ideas, and scopes developments in research and teaching. We give ourselves sufficient freedom for this.
Quality	The fruit of our labour is the result of high-quality work, which is carefully prepared and presented.
Embodiment	We define ourselves with goals and research fields of the institute.

The Research Sector Electronics Production focuses in three Core-Teams current challenges and new approaches for manufacturing mechatronic devices.









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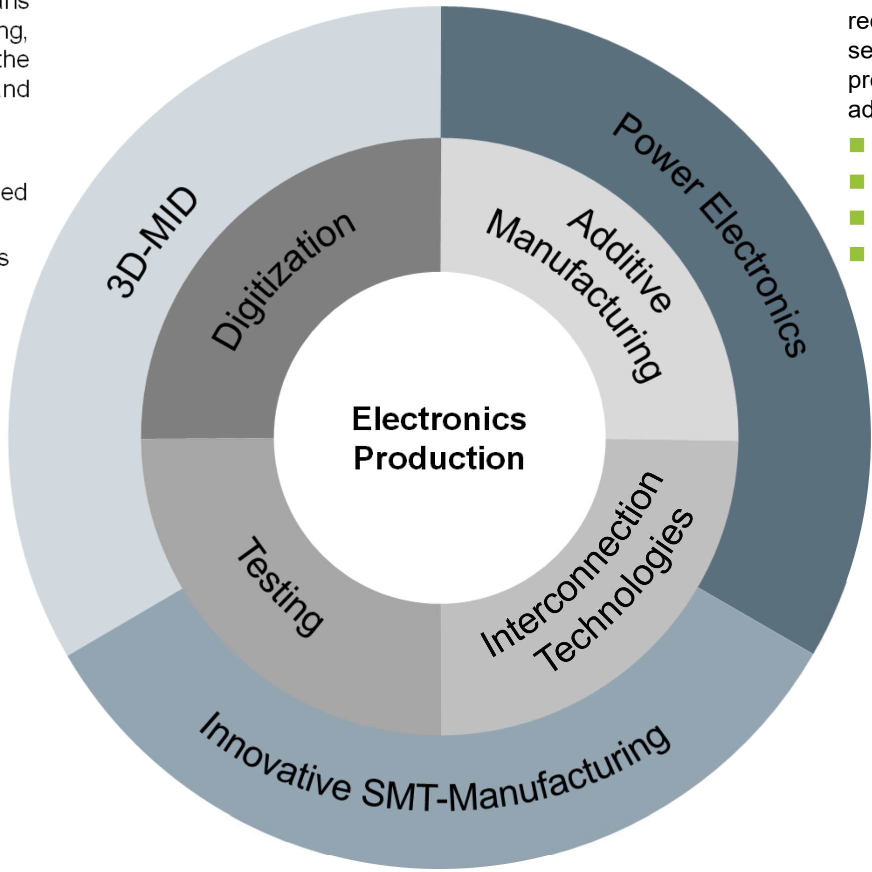
The Research Sector Electronics Production focuses in three Core-Teams current challenges and new approaches for manufacturing mechatronic devices.

Spatial circuit carriers offer potential for highly integrated and miniaturized assemblies. By means of modern processes such as AerosolJet printing, LDS or FDM printing, both the substrates and the circuit layout can be structured efficiently and flexibly

- Highly flexible structuring
- Mounting and connection technology for printed electronics
- Sensor technology through printing processes
- AI in printed electronics

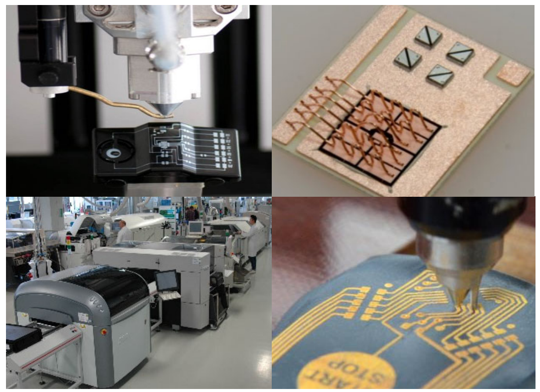
A high degree of automation and yield in conventional electronic module assembly require alternative interconnection technologies, simulation -based predictions for design rules and data-driven methods to realize further optimization.

- Optimized quality control using data-driven analysis methods
- Development of AI-based low-cost automation solutions for SMT/THT.
- Simulation-based design for manufacturing in the field of production of electronic modules



A high-performance assembly and connection technology is essential to meet the increasing requirements in terms of efficiency, reliability and service life. The use of additive manufacturing processes and materials makes it possible to address these trends.

- Substrate production via additive processes
- Bottom-Level Interconnection
- Top-Level Interconnection
- Testing technology

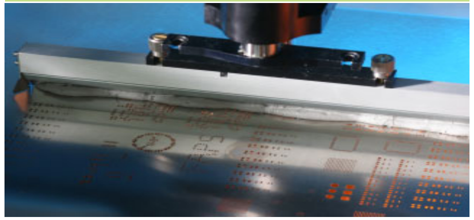


With data driven methods, flexible processes and improved quality control, FAPS investigates further advances in the already well-established manufacturing of 2D electronic assemblies.

Technologies

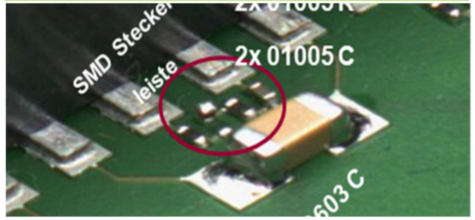
SMT

THT Wave Soldering



Alternative connection technologies

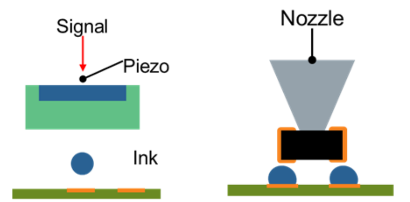
Testing Technologies



Methods

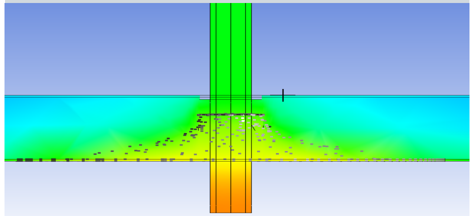
Design of Experiments

- Design for Manufacturing
- Process development
- Process optimization



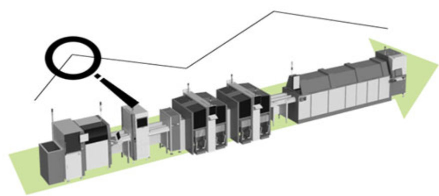
Simulation & Machine Learning

- Fluid dynamics
- High performance computing
- Computer Vision



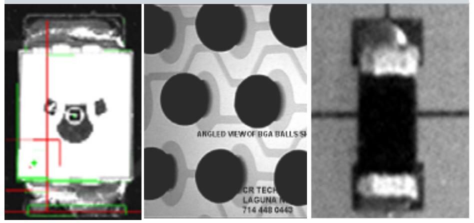
IIoT infrastructure

- Traceability
- Cloud-/Edge connectivity
- Automated data preparation



Production and testing systems

- Matrix production
- Test plan optimization
- Advanced quality control



Fluidsimulation of hole fill in selective wave soldering allows accurate quality prediction and design for manufacturing (DfM).

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Motivation & Objective

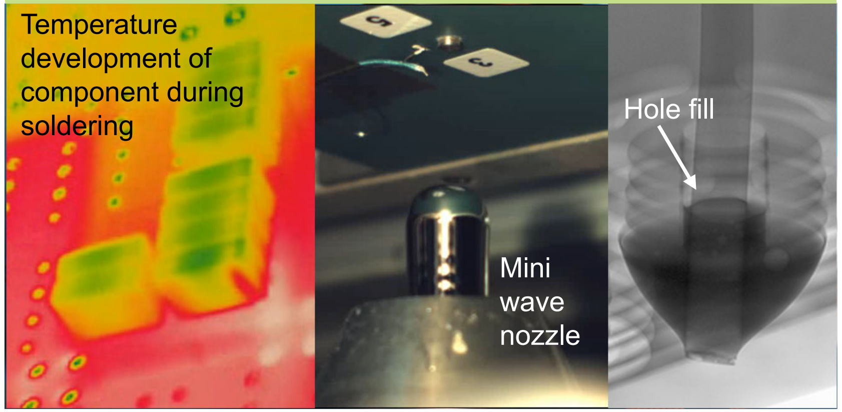
- Hole fill is the critical quality criterion in THT soldeirng
- Hole fill is primarily impacted by the solder joint copper layer design
- DfM requires reliable models to prevent manufacturing problems

Method

- Parametric definition of copper layer design
- Temperature dependent solder alloy material model
- CFD ANSYS Fluent with volume of fluid model (VOF) for hole fill calculation
- Prediction error ~10-15%

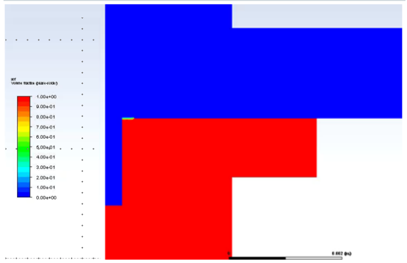
Technologies

THT Wave Soldering

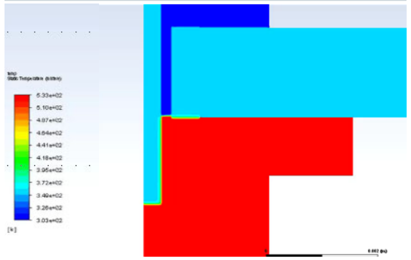


Methods

Hole fill simulation



Temperature distribution



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False calls of solder joints are a challenge in both SMT and THT manufacturing, which are addressed by a combination of multiple Machine Learning approaches.

Motivation & Objective

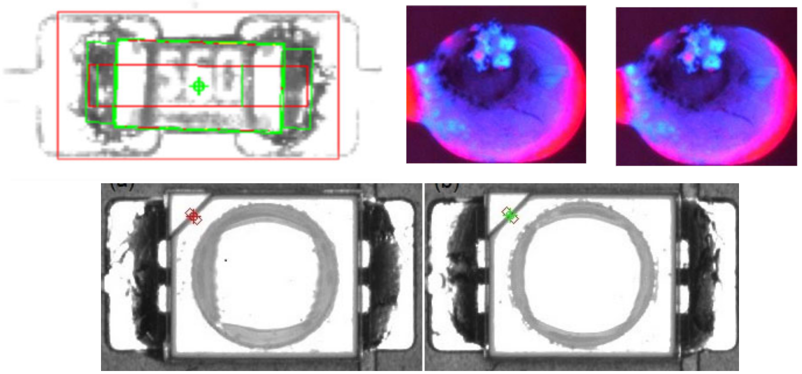
- False calls during quality control lead to additional manual inspection and unnecessary scrap.
- Accurate identification is necessary to prevent error slip.
- Ratio between false calls and true defects depends on technologies (SMT/THT), product and adjustment of conventional test routine.
- State-of-the-art Automated Optical Inspection machines need high investments.

Method

- Low cost camera systems to detect potential defects in early production stages
- Clustering data and AI-based classification and one-class-learning to identify either good solder joints and components, false calls or defects
- Enhancing datasets by generation of synthetic images of defects

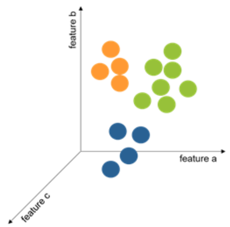
Technologies

Testing technologies



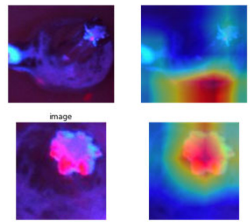
Methods

Clustering

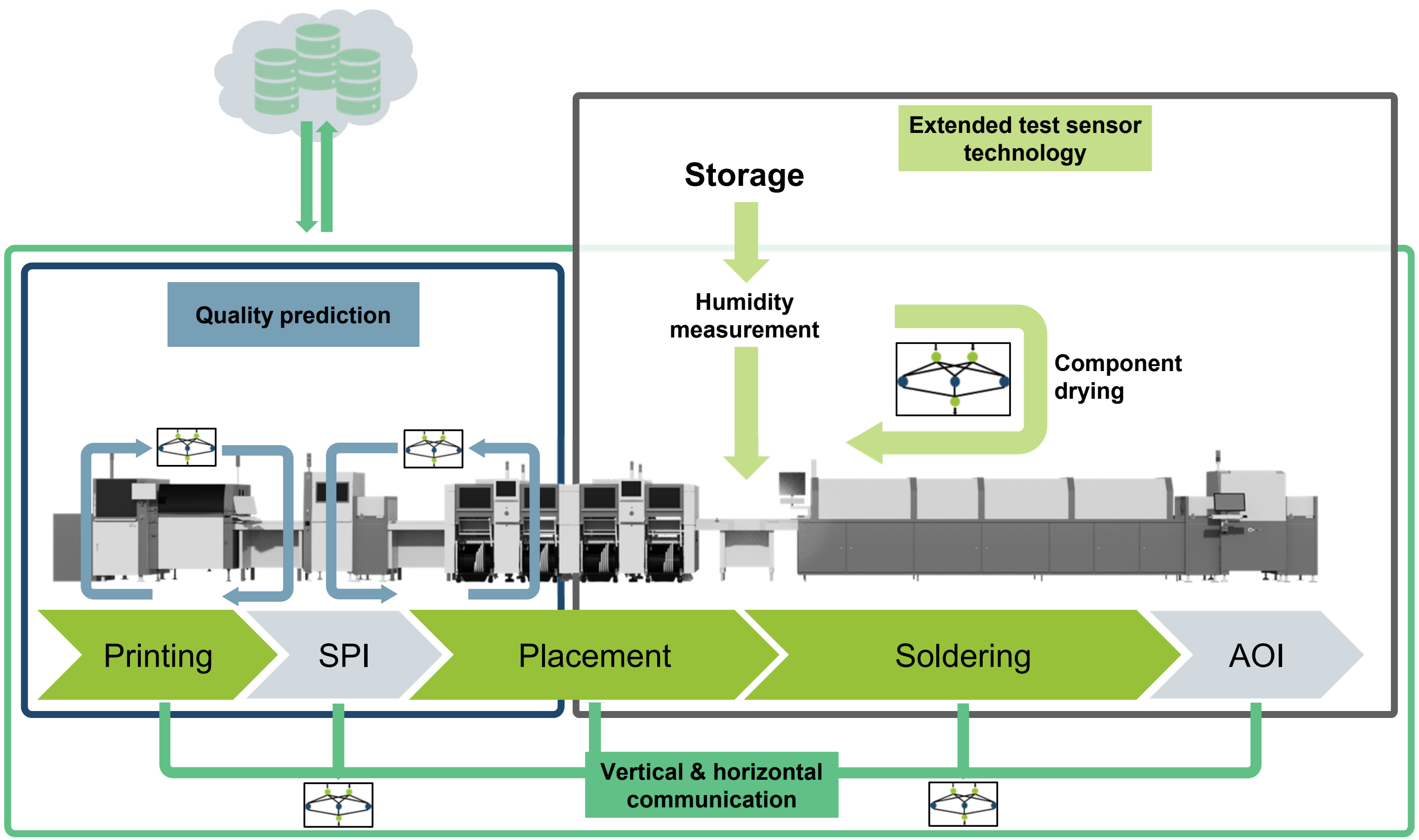


Deep Learning

Root Cause Analysis



By using AI in SMT manufacturing, measurement data from individual control loops can contribute to process and quality improvement across machines and lines.



Enhanced sensor systems

- Humidity measurements for components by new sensor systems
- Integration of new sensor data to existing information

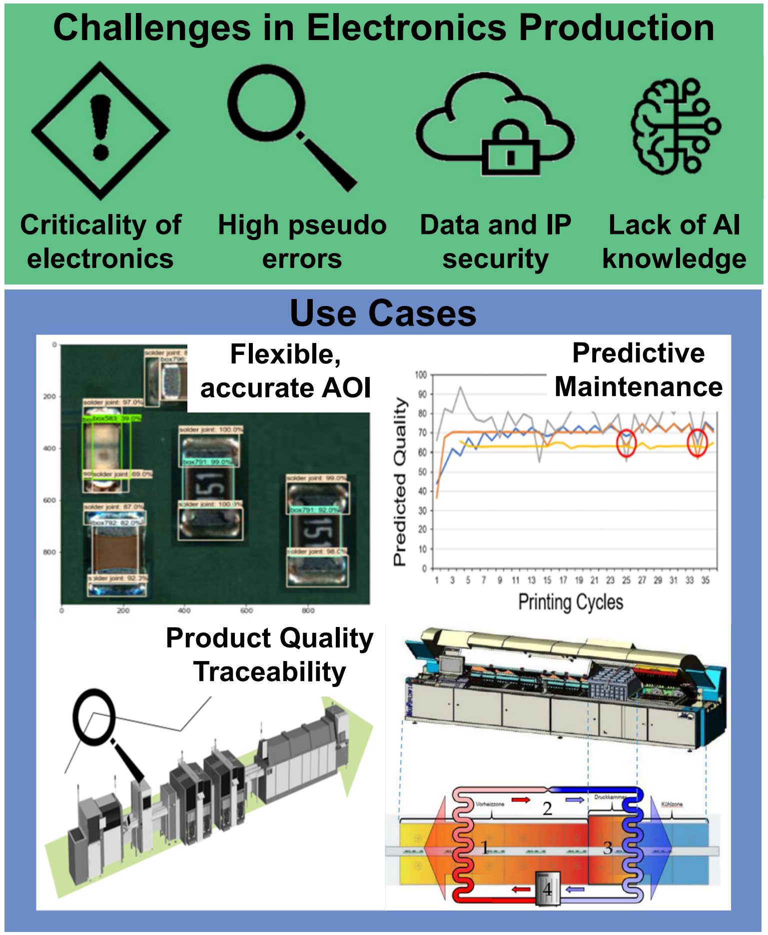
Quality prediction & control

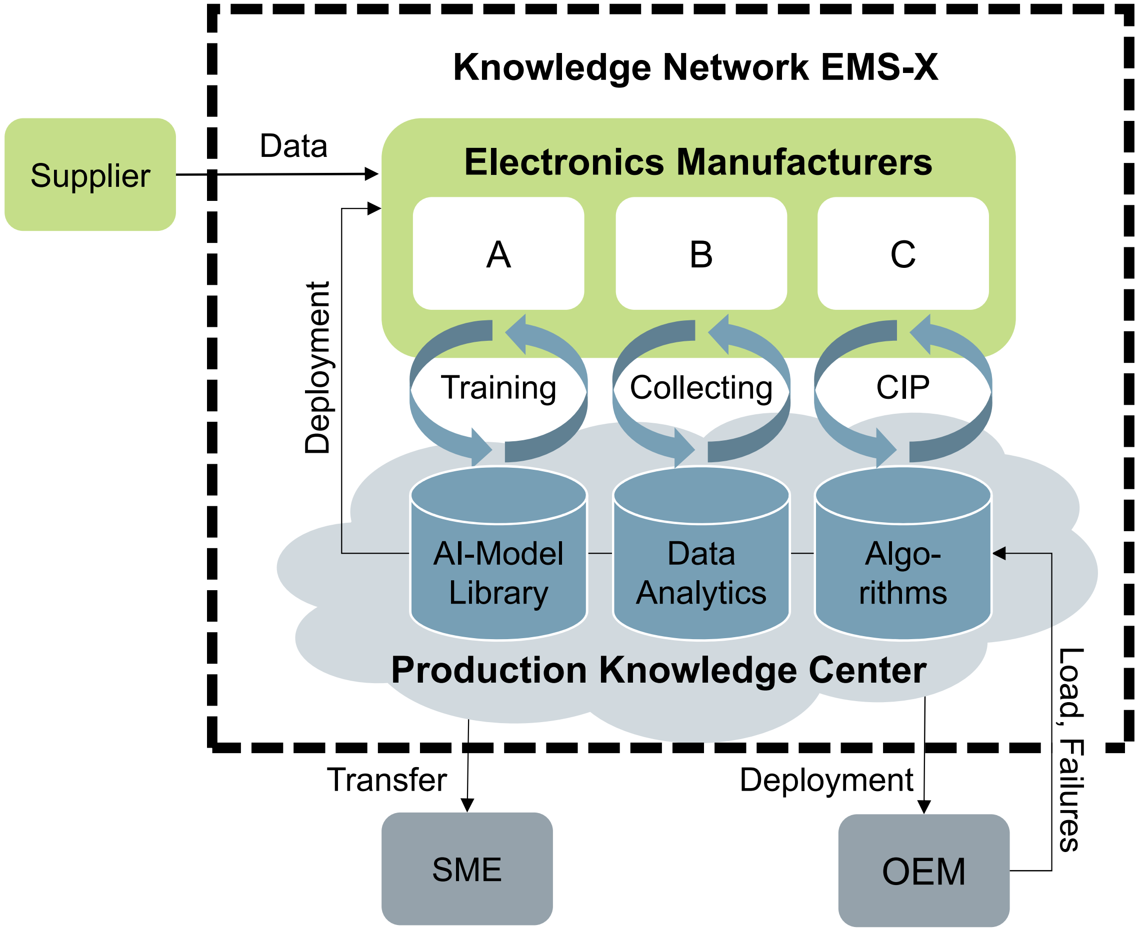
- Linking quality prediction and need for maintenance and adjustment
- Quality control to reduce manual inspection

Vertical & horizontal communication

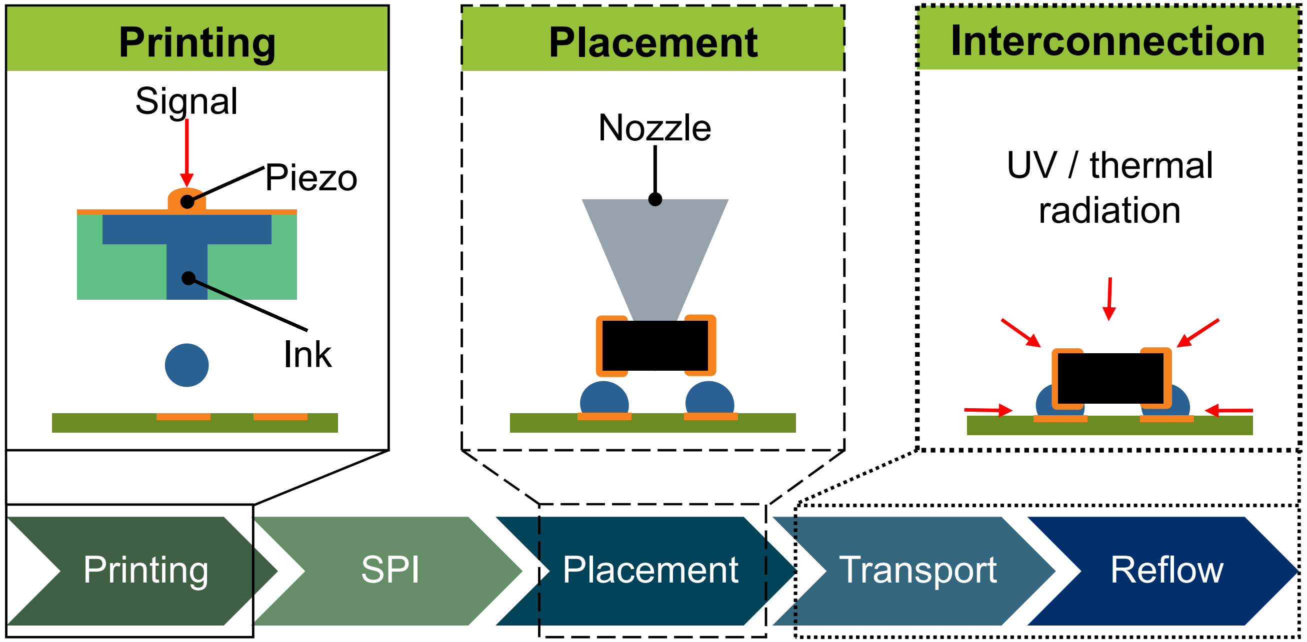
- Real time adjustment and monitoring of process and machine parameters
- Cross-line and transferable AI applications

Following the example of CATENA-X, FAPS is developing the platform EMS-X for the collaborative utilization of data in electronics production.



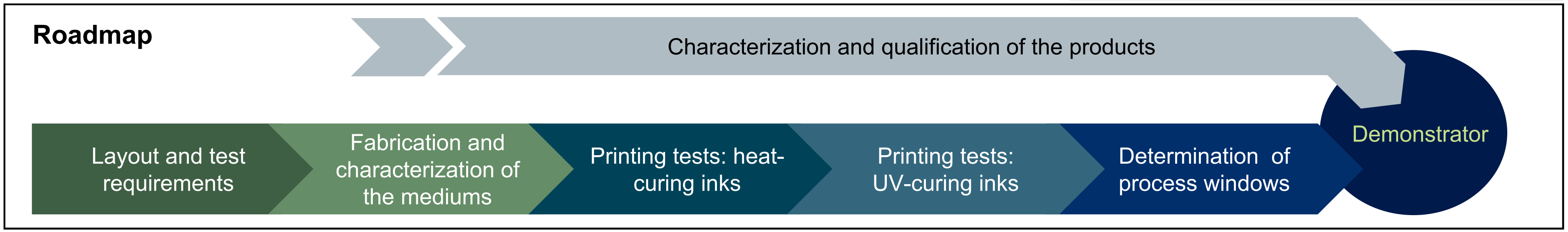


FAPS investigates the use of inkjet printing to apply conductive inks for interconnections if conventional technologies reach their limits.



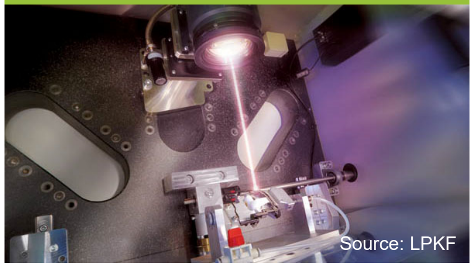
Goals:

- Realizing inkjet based interconnections for components ≤ 0402 (400 µm x 200 µm) and thermal sensitive components
- Development of a prototype for the line-integration of an inkjet system
- Construction of a demonstrator that can combine stencil and inkjet printing
- Determination of automatable testing methods



The institute FAPS investigates various additive manufacturing techniques for structuring 3D printed circuit carriers.

Laser Direct Structuring®



- Activation of additive through laser radiation
- Generation of micro-rough surfaces
- Chemical metallization to generate structures

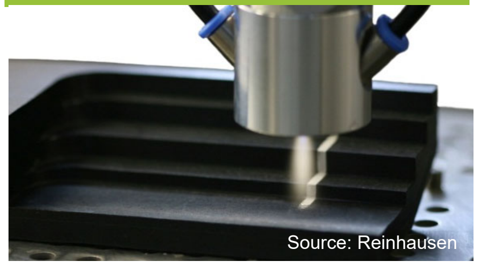
Usage of one or more laser scanning units for targeted deflection of laser and irradiation of the surface

Laser Powder Bed Fusion

- Powder based additive manufacturing
- Selective melting of the powder to generate structures
- Flexible geometries

Usage of one or more laser scanning units for targeted deflection of laser and irradiation of the surface and powder

Plasma Powder Coating



- Additive metallization
- Flexible geometries
- Continuous conveying and application of the coating powder

Production of structures by relative movement of nozzle to substrate or substrate to nozzle.

5-Axis Printed Electronics

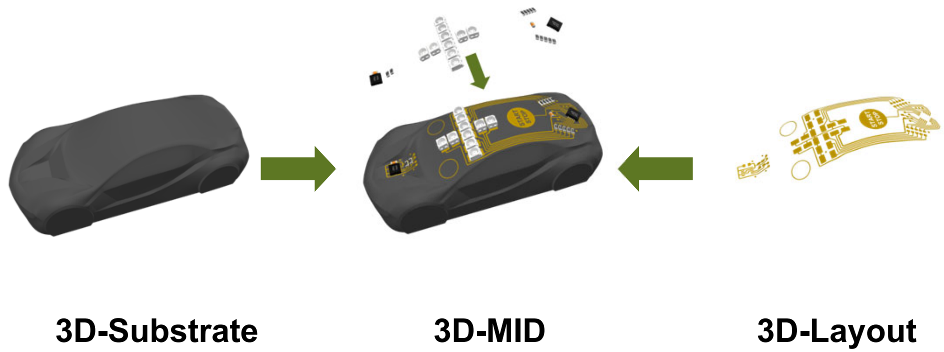
- Printing technologies for applying functional inks
- Flexible and fine structures
- Miniaturized 3D-Assemblies

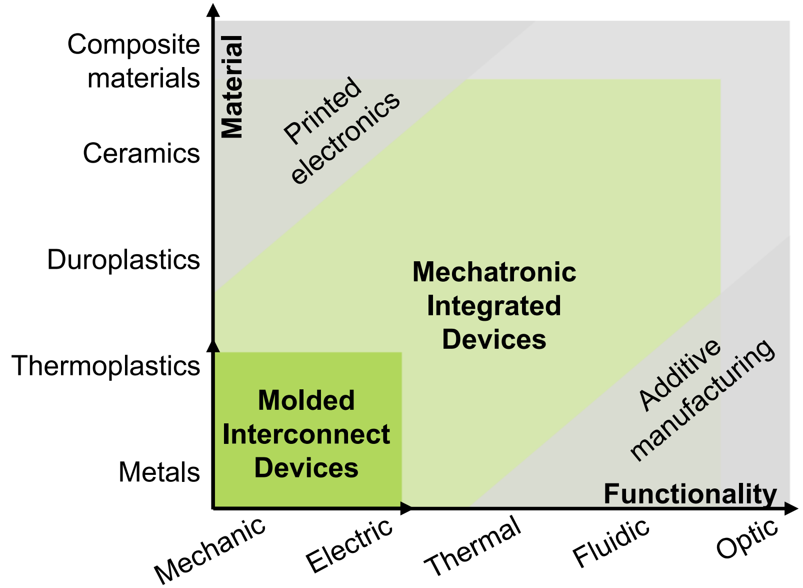
Production of structures by relative movement of nozzle to substrate or substrate to nozzle.

FAPS

MID – from Molded Interconnect Devices to Mechatronic Integrated Devices.

MID-basic principle





Molded Interconnect Devices

- 3D-MID are spatial *injection molded* parts with integrated conductor tracks.
- The technology allows the combination of *mechanic* (injection molding) and *electric/ electronic* (selective metallization) functionalities in one device.

Mechatronic Integrated Devices

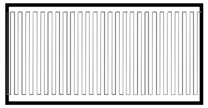
- 3D-MID are mechatronically functionalized spatial parts.
- The technology allows the combination of *mechanic, electric/ electronic, thermal, fluidic and optic* functionalities in one device.

The manifold integration capabilities of the MID technology offer big potentials for innovative product solutions.

Antennas

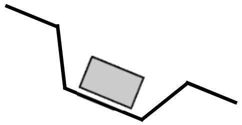
Mounting elements

Shielding / Security structures



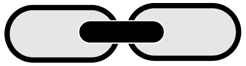
HARTING Mitronics

Orientation of components



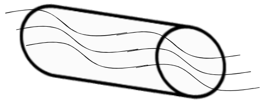
HARTING Mitronics

Contacting elements



HARTING Mitronics

Fluid channels



2E mechatronic

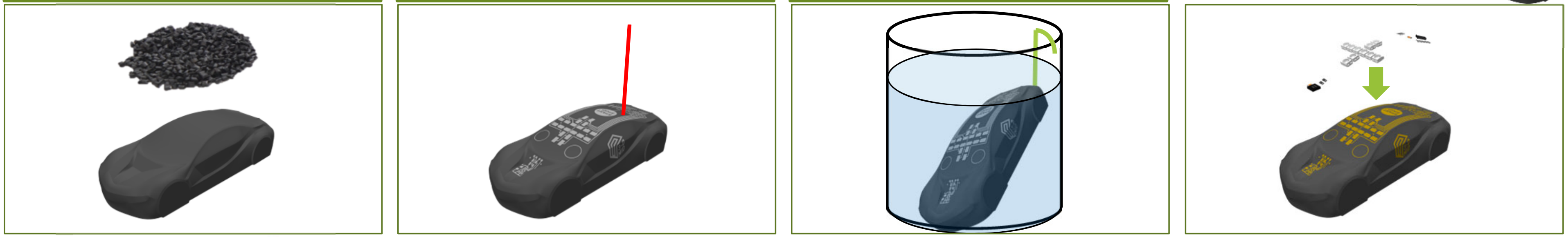
- Design freedom
- Reduction of components
- Increased functional density
- Weight reduction

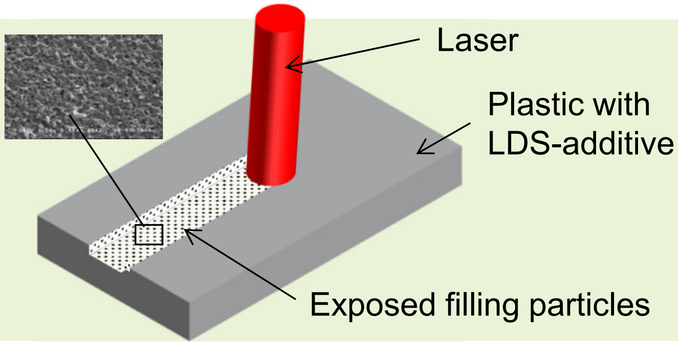
The classical process chain for manufacturing MID by Laser Direct Structuring (LDS) consists of injection molding, laser structuring and chemical metallization.

Production of the MID circuit carrier | Mounting of SMT components

Substrate Production → **Generation of circuit tracks** (Structuring, Metallization) → **Assembly**

Injection molding	Laser structuring (additive)	Chemical Process



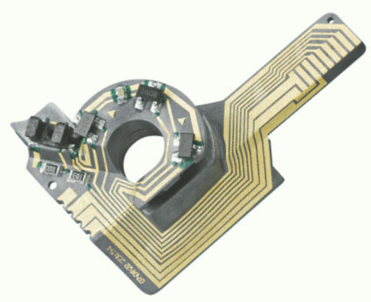


- Thermoplastic material filled with laser activatable additive
- Laser structuring causes ablation and activation of the additive on the substrate surface
  → micro-rough surface with catalytic nuclei
- Metallization in electroless copper bath
  (typical layers: Cu-Ni-Au)

Many examples of successful LDS-based serial applications prove the wide application field in different industries.

FAPS

Adaptive Cruise Control

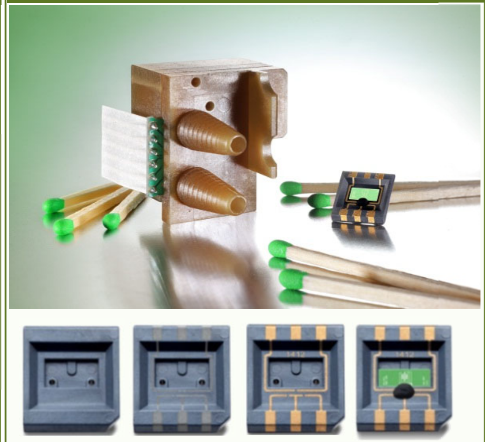


Industry: Automotive
Technology: LDS
Manufacturer: HARTING Mitronics / 2E mechatronic
User: Continental
Start: 2010
Quantity: ca. 800.000 p.a.

Lighting module

Industry: Industry automation
Technology : LDS
Manufacturer: HARTING Mitronics
User: SICK
Start: 2007
Quantity: ca. 5.000 p.a.

Flow sensor



Industry: Climate technology
Technology: LDS
Manufacturer: 2E mechatronic
User:
Start: 2012
Quantity: ca. 25.000 p.a.

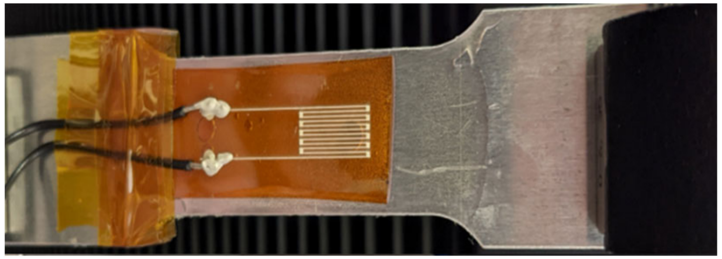
Caries diagnosis tool

Industry: Medical technology
Technology : LDS
Manufacturer: HARTING Mitronics
User: KaVo Dental
Start: 2013
Quantity: ca. 2.500 p.a.

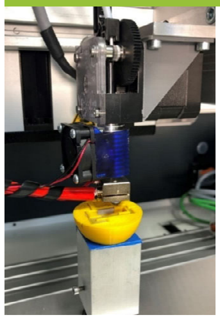
(Sources: HARTING Mitronics, Continental, 2E mechatronic)

The combination of printed electronics, additive manufacturing and AVT technologies of discrete electronics serves to create mechatronically integrated assemblies.

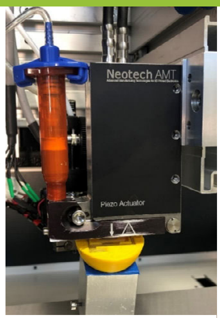
Printing of strain gauge elements



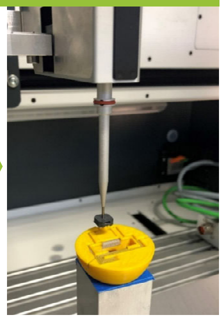
Production of complete mechatronic products by one machine



FDM



Piezojet

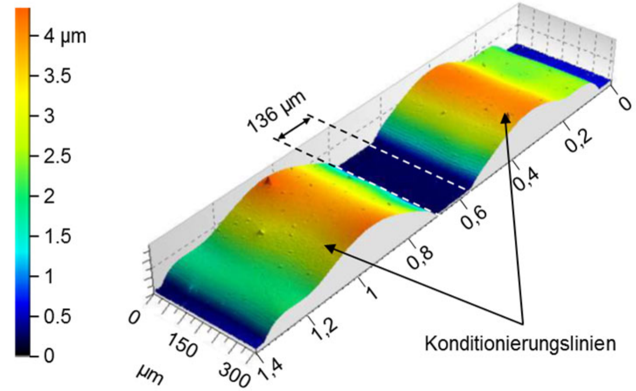


SMT

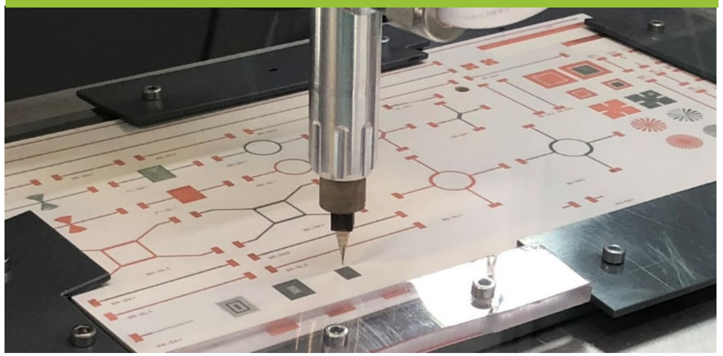
3D Printed Electronics

- Printing technologies for contactless application of functional inks and pastes (several millimetres working distance)
- Electrical and optical signals
- Printing of
  - Conductor tracks (20µm - 1mm)
  - Resistors
  - Capacitors
  - Sensors
  - Fibre optic cables
  - Antennas
  - Contacting of SMTs
- Light sintering system for curing the printed structures

Customised production of polymer optical fibres by flexo and aerosol jet printing



Development of methods and guidelines for the print production of HF applications



Additive Manufacturing of ceramic materials in combination with printed conductive inks leads to flexible production of functional 3D electronic assemblies in harsh environments.

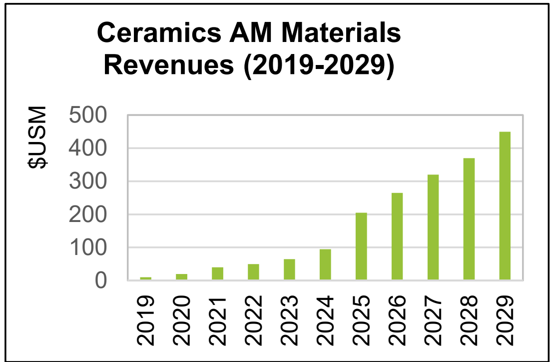


Fig. 01: Prediction of Ceramics AM Materials Sales, Source: Smartech Analysis (2019)

Fused Filament Fabrication (FFF)

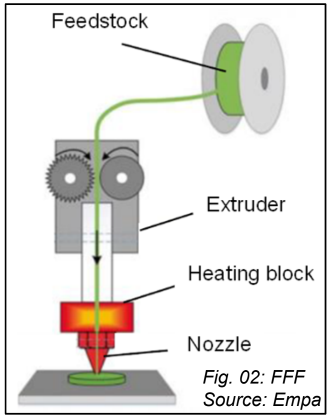


Fig. 02: FFF Source: Empa

Ceramic green body production through parameter studies

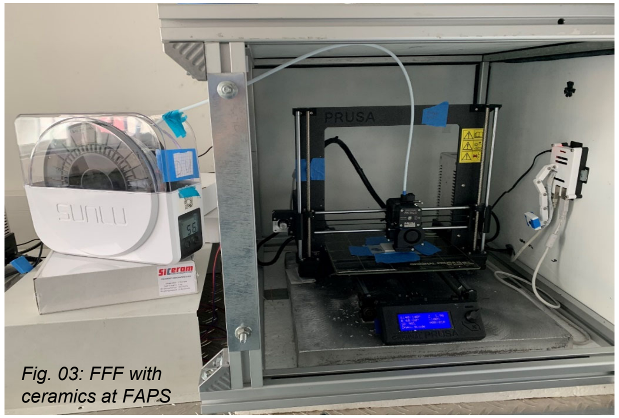


Fig. 03: FFF with ceramics at FAPS

Debinding by chemical and thermal processes

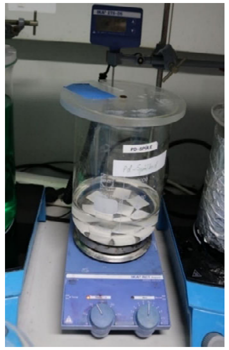


Fig. 04: Bodies debinded in Aceton bath at FAPS

After sintering in high temperature furnace, complex 3D ceramic bodies are ready for metallization

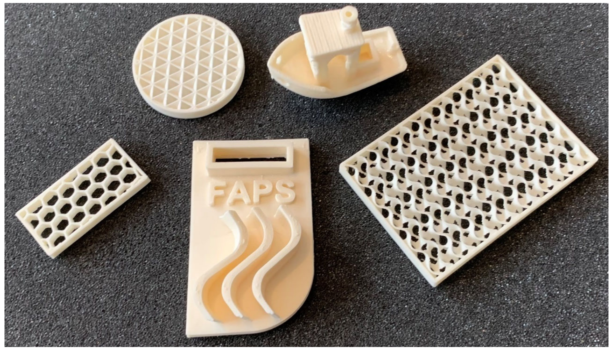


Fig. 05: Ceramic specimens with complex 3D shape, printed with FFF, debinded and sintered at FAPS

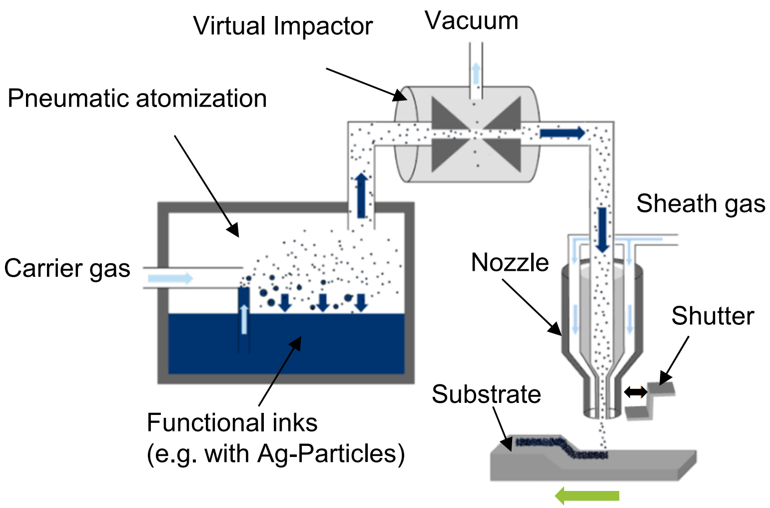
Using piezo-jet technology, conductive structures can be printed flexibly on ceramic substrates

FAPS

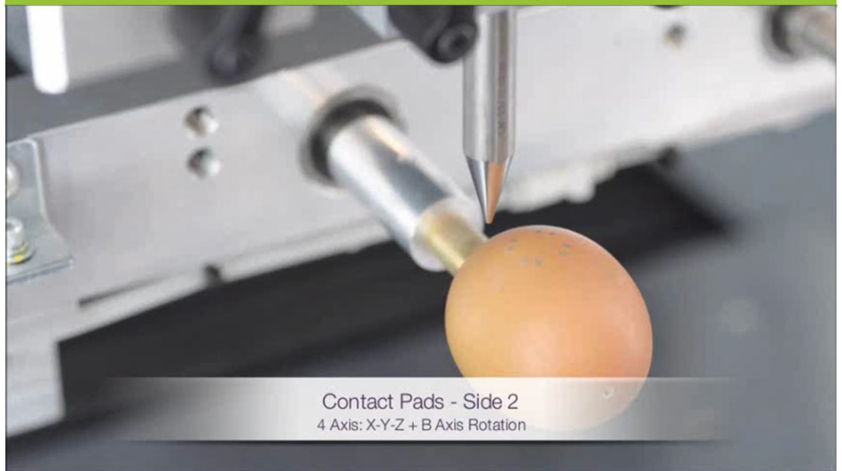
Digital printing processes allow the printing of 3D objects with electrically functional inks.

Aerosol Jet

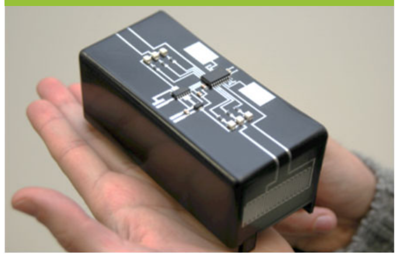
- Serial contactless printing process
- Structures smaller than 10 µm up to 10 mm with varying nozzle geometries realizable
- Large working distance through elongated focus of aerosol beam
- Wide spectrum of material properties of the used medium
- Printing of functional elements like conductive patterns, resistors, isolation layers, capacitors, etc.



Aerosol Jet printing on an egg with a 5-axis motion system



Printed circuit layout with capacitive sensors for 3D-MID



Printed antennas for mobile applications

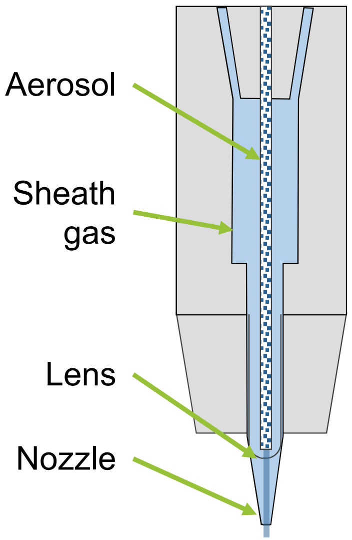
Source: Neotech

FAPS

The Nanojet process enables the generation of fine structures which are required for high-frequency applications.

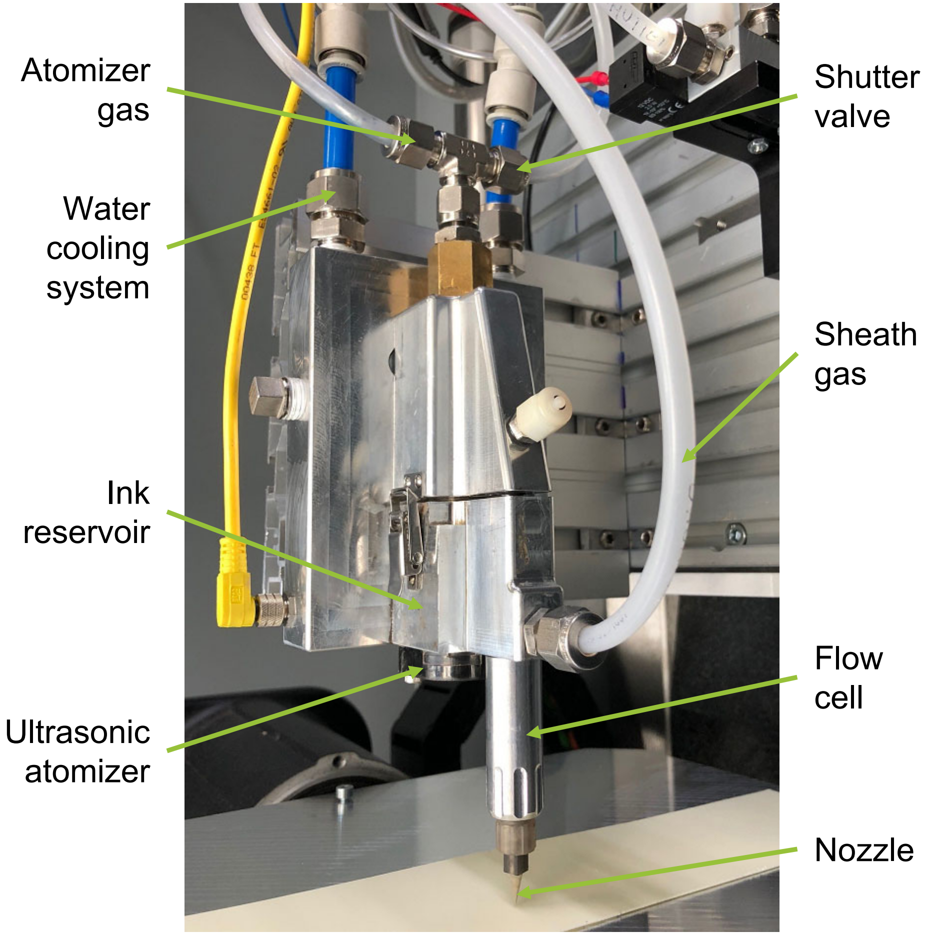
Nanojet

- Simplified system compared to Aerosol Jet (no bubblers, heaters or solvent add-Overview)
- Aerosol generation by ultrasonic atomization of functional ink
- Aerodynamic lenses focus the aerosol
- Changeable nozzles allow line widths from 20 µm to 1 mm
- Particle focusing in flow cell by lens and sheath gas
- Ink viscosities < 20 mPas



Process parameter	Value
Atomizer voltage	28 V
Chiller temperature	22°C
Aerosol flow rate	8 sccm
Sheath flow rate	50 sccm
Lens diameter	750 µm
Nozzle diameter	233 µm

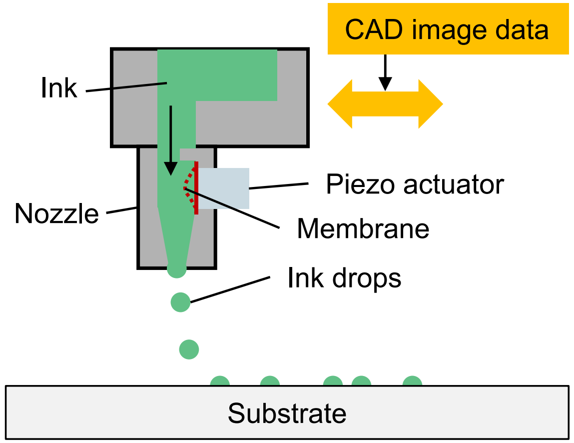

Helix antenna

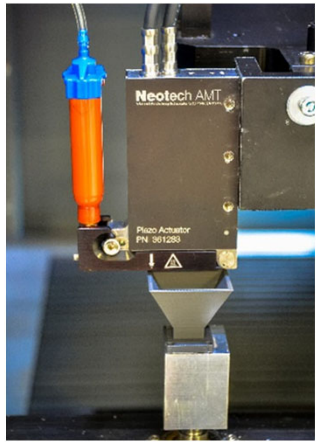


The Piezojet printhead can process a wide range of ink viscosities with a high stand-off distance.

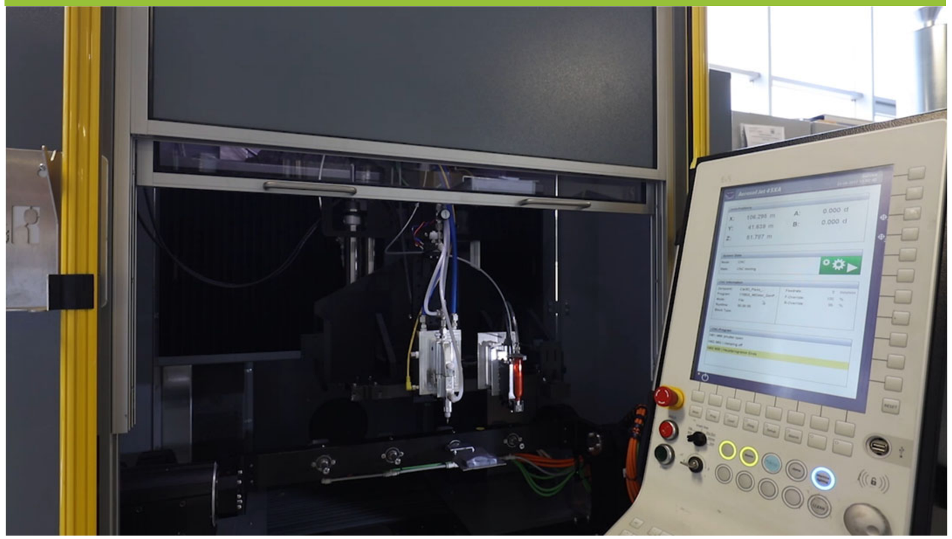
Piezojet Drop-on-Demand:

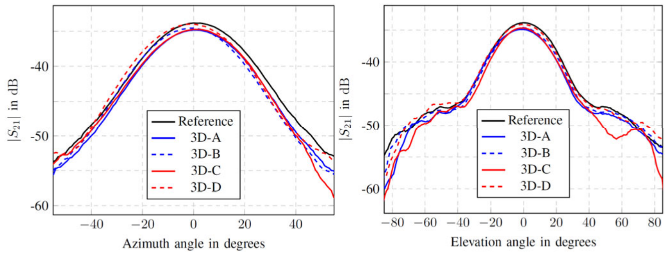
- Functional ink is passed from the reservoir into the nozzle
- Piezo actuator is deformed by a voltage signal
- Pressure pulse ejects an ink drop onto the substrate
- Printhead is moved according to CAD image data
- Viscosities up to 200,000 mPas and 250 µm – 1 mm line widths





Printing on a MID demonstrator with a
5-axis motion system with Piezojet and Nanojet

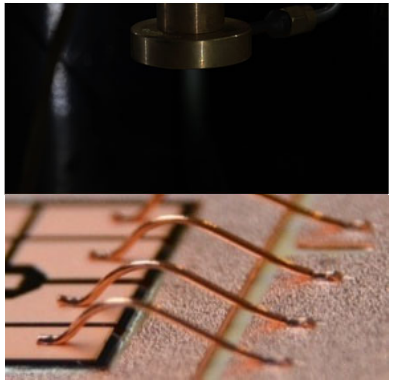




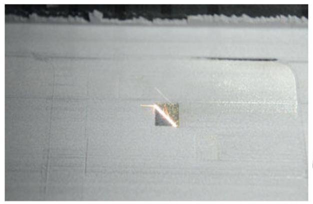
Additive horn antenna

Innovative manufacturing technologies for assembly and connection technology significantly influence the performance of electronic modules.

Top-Level Interconnection
- Increase of power density through optimized bondlayout
- Increased efficiency through the use of copper
- Development of chip-buffer systems



Integration of additive manufacturing
- Integration of optimized heat sinks by addressing hot-spots
- Production substrates in small lot sizes through flexible processes

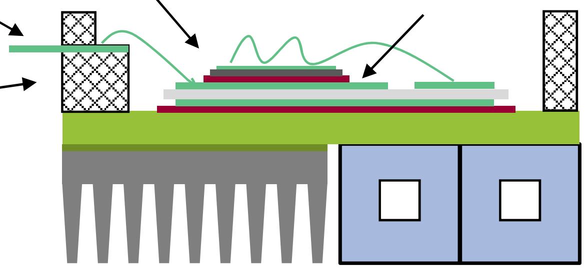


Top-Level Interconnection
- Aluminium wires
- Copper wires
- Chip-Buffer Systems

Bottom-Level Interconnection
- Silver pasts
- Copper pasts

Connection

Housing

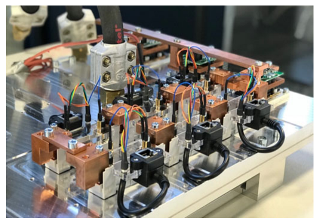


power module

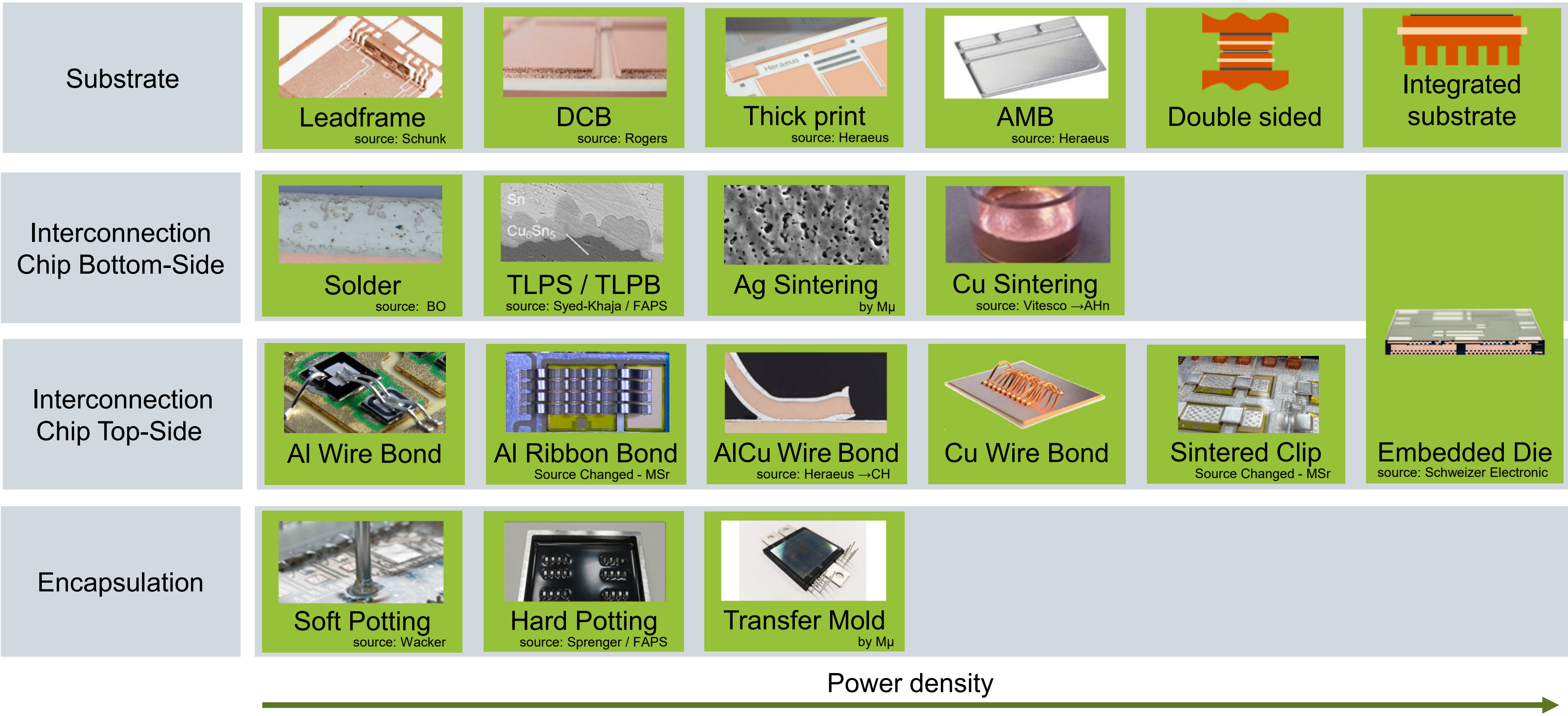
Heat sink
- Active/passive
- Additively manufactured

Bottom-Level Interconnection
- Qualification of Ag und Cu Pasts
- Packaging optimization via transient liquid phase soldering

Testing & Qualification
- Definition of effect-equivalent testing methods
- Active & passive lifetime testing e.g. Power cycling, H3TRB, Thermo cycling

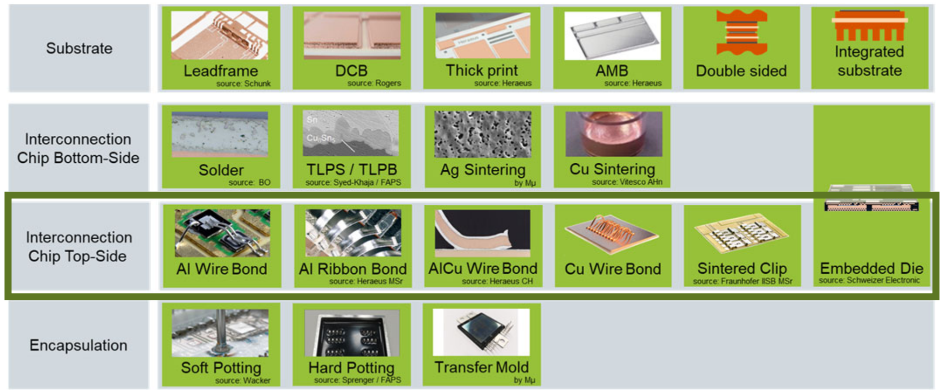


Advances in power electronics packaging enable increased reliability and power density.

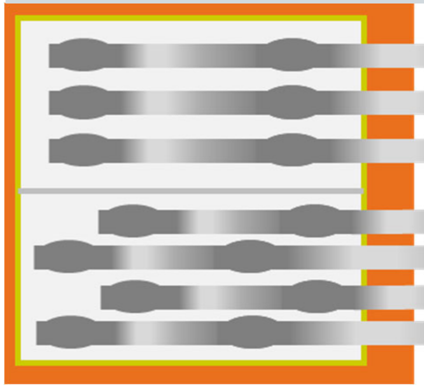


In the field of Die Top-Side Interconnection Copper Wire Bonding, Bond Layout Optimization and Selective Metallization by Plasma Spray is investigated at FAPS.

FAPS

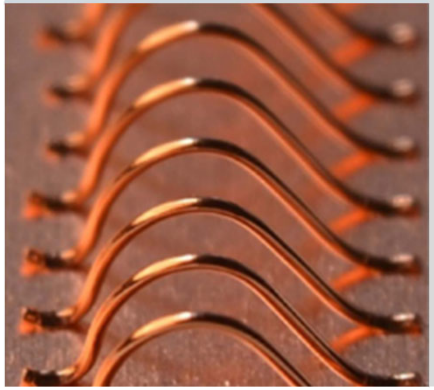


Optimized Bond Layout



- Increase in power cycling capabilities without changes to existing production facilities
- Design-Guide for wire bond layouts to estimate reliability during development of new power modules
- Improved correlation between simulation data and application

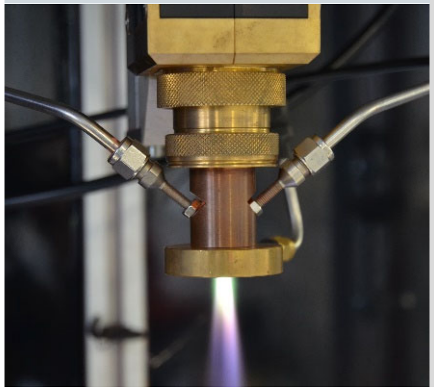
Cu Wire Bonding



Compared to Al wire bonding:

- Better CTE match at bond interface
- Improved thermal cycling stability
- Lower electrical resistance
- Higher thermal conductivity

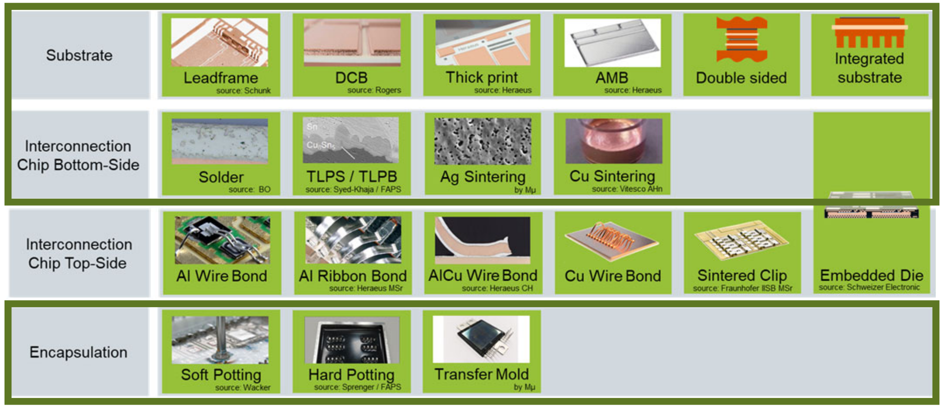
Plasma based Cu Coating



- Freedom of design
- Flexible metallization of various substrate materials and semiconductors, allowing for Cu wire bonding
- Generation of high conductive circuit path (up to 60% of Cu)
- High-Temperature applications

FAPS

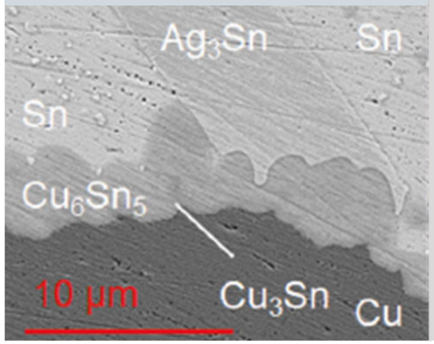
Other investigated technologies are additive manufacturing of metal-ceramic-substrates, transient liquid phase soldering and advanced encapsulation techniques and materials.



Hard encapsulation by potting or transfer molding

- Reliability enhancement by replacement of soft encap-sulation with hard encapsulant
- Advanced enapsulants for wide band gap temperature operation range
- Cost reduction potential by integration of function into the molded structures

High temperature interconnects



- Silversintering, Cu-Sintering

Compared to Sn-soldering:

- Better thermal performance
- Higher homologous temperature, higher operational temperature

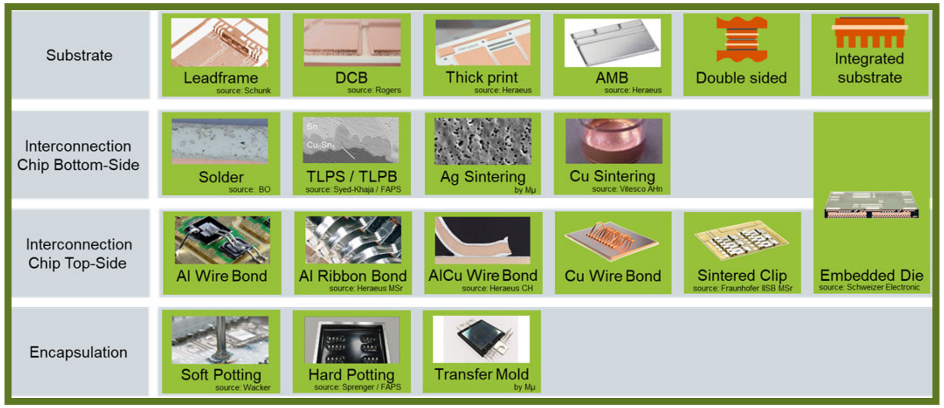
Compared to sintering:

- Less complex tooling

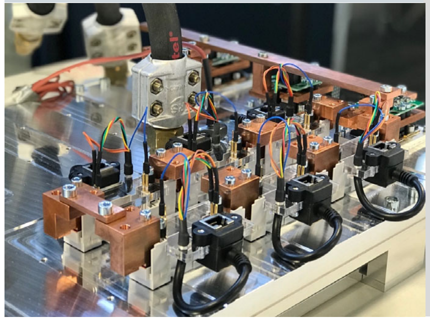
SLM-based metal-ceramic substrates and heatsinks

- Integration of cooling structures directly into the substrate (integrated substrate)
- Design freedom, flexible adaption of layer stack up

Accelerated lifetime testing allows for reliability assessment of different power electronic packaging technologies.

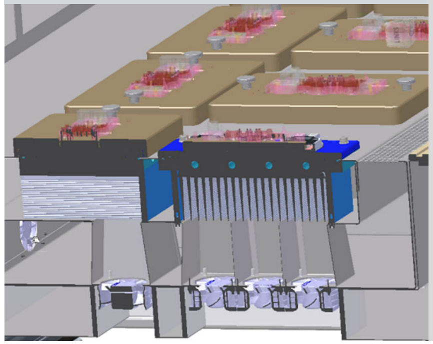


Active Power Cycling



- Accelerated lifetime test for power electronic modules
- Thermomechanical stress distribution comparable to application
- Evaluation of reliability of chip and substrate interconnections

H3TRB



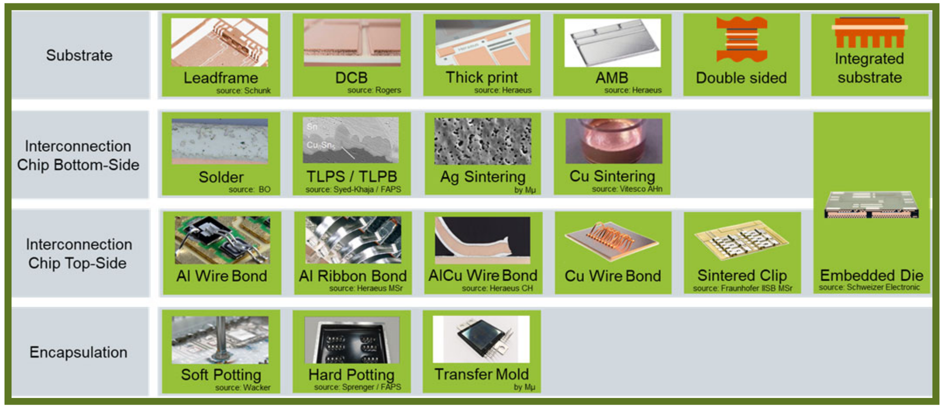
- Application of field voltage of max. 3.3 kV
- Indication of failure mechanisms by leakage current
- Simultaneous test of 60 DUTs
- Integrated Curve Tracer

Environmental Testing

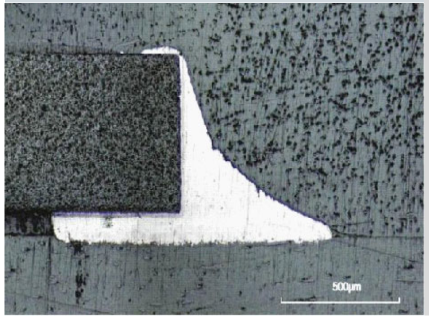
- Temperature shock testing (air to air)
- High temperature storage
- Vibration test
- Salt spray test

Cross sections combined with focused ion beam and high resolution electron microscopy or mechanicals tests allow for in-depth analysis of the interconnection technologies.

FAPS



Metallography

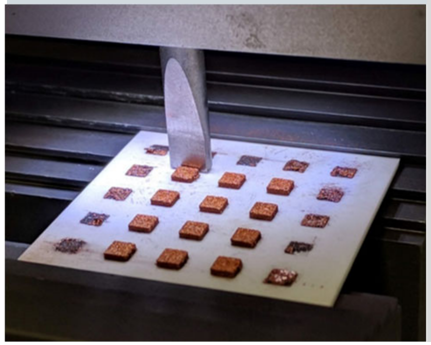


- Cross-section of micrographs
- Sawing, Embedding, Etching, Grinding, Polishing
- Microscope Inspection

SEM

- Detectors, manipulators and possible analysis
  - EDX
  - EBSD
  - Raman-Spectroscopy
  - Plasma-FIB

Mechanical Testing



- Bending Tests
- Shear Testing
- Hot-Pin-Pull-Test

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Technische Fakultät

THANK YOU