ESA Strategy on Advanced Manufacturing of EEE components

Game-changing applications for faster development of electronics

Nano Dimension User Forum

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ESA ECSAT

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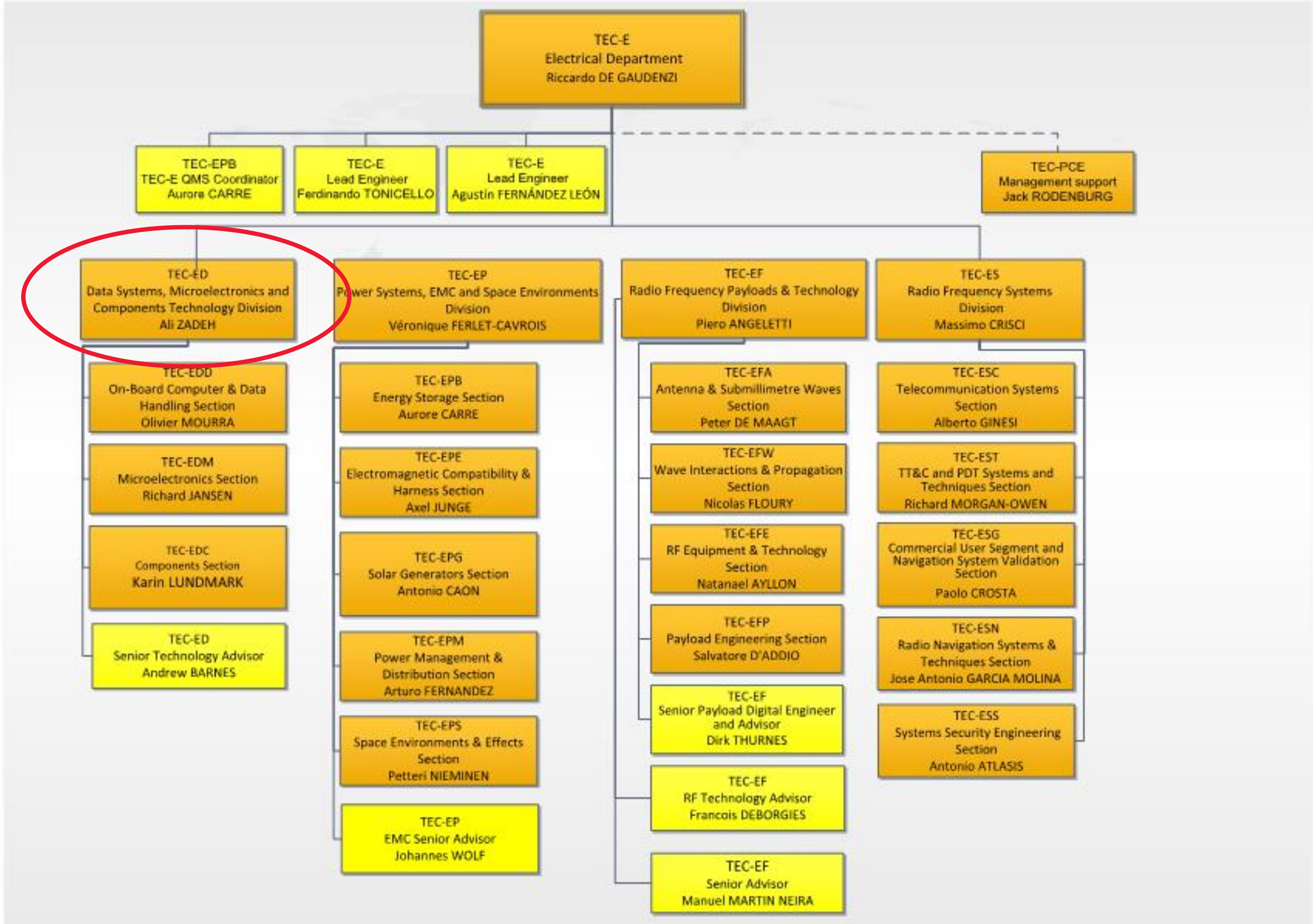
ECSAT, UK

The European Centre for Space Applications and Telecommunications (ECSAT) is ESA’s facility in the United Kingdom.

It is based at the Harwell Campus in Oxfordshire.

Data Systems, Microelectronics and Component Technology Division (TEC-ED)
Electrical Department (TEC-E)
Directorate of Technology, Engineering and Quality (D/TEC)



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Project introduction 01

AM activities at ESA 02

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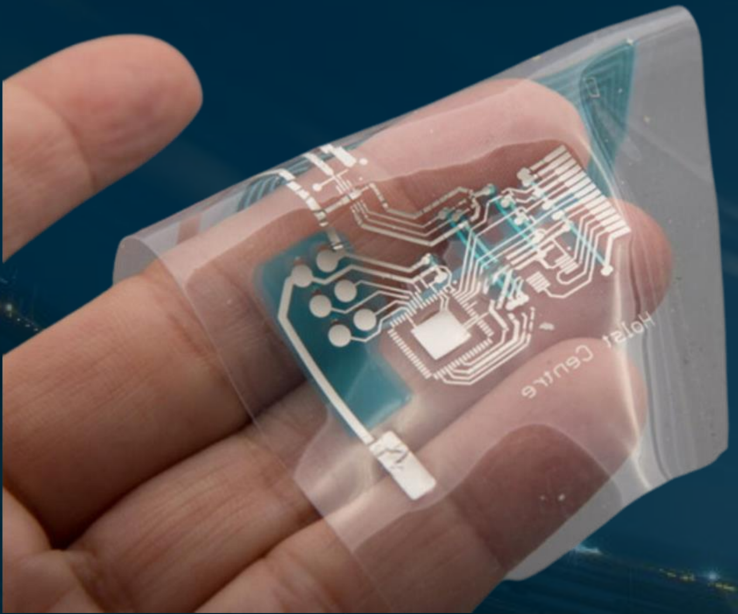
Aim of the project

To develop a strategic roadmap to introduce
Advanced Manufacturing of EEE components in space.

By investigating AM techniques for potential game-changing applications that could be used in space
from individual EEE component functions
through to complete subsystems.



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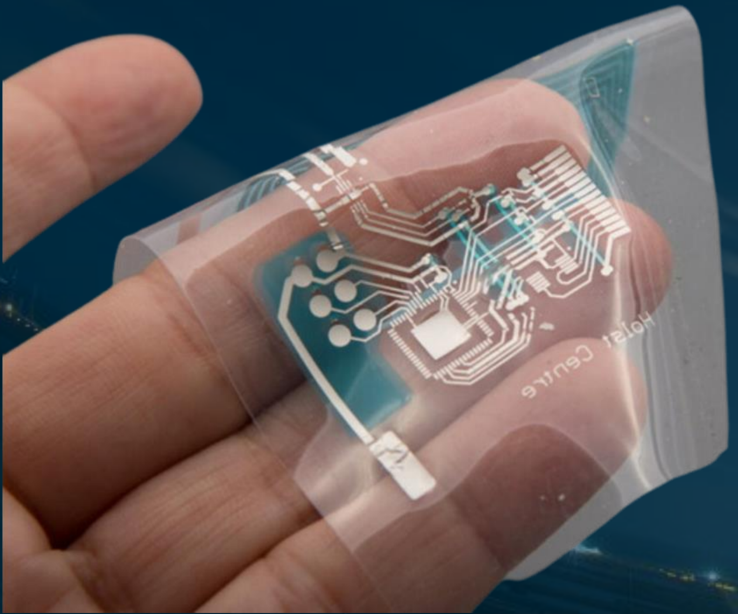


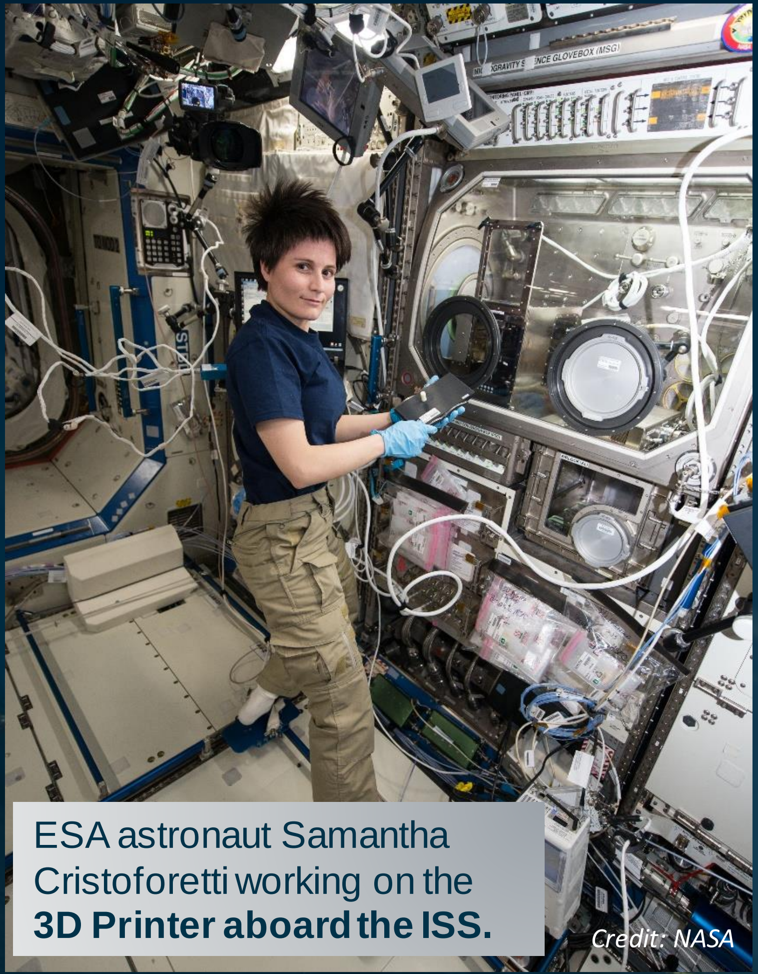
The strategy is holistic and across directorates, to have a coordinated and shared roadmap.
It ensures that technology development programmes across directorates work together without overlap.

Objectives

1. To understand the **supply chain segmentation** in Europe and overseas, identify business trends, map out current and future **state of art and emerging directions** in this field.
2. To have an across-directorate ESA **working group** on AM EEE components (TEC, EOP, CSC, HRE) and explore **space applications.**
3. To have a clear **strategic investment plan** that prioritises the most promising directions.
4. To explore **basic printed functionalities** through Early Technology Development projects to assess any issues preventing AM EEE components from being used in space.

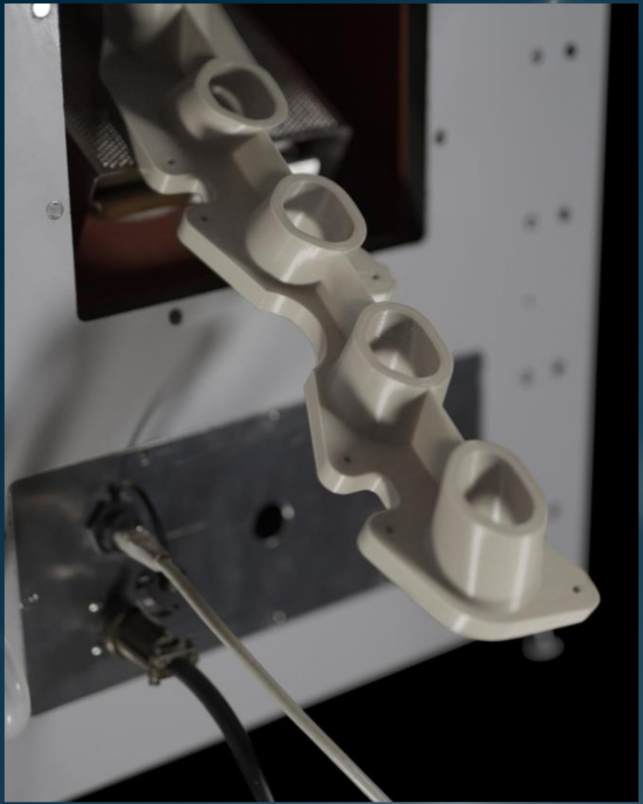
AM and printed electronics in space

3D printing for polymers has been proven and used on the International Space Station for years.



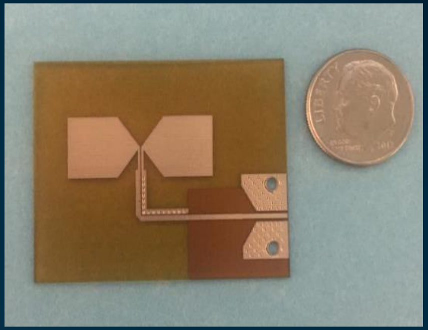
ESA astronaut Samantha Cristoforetti working on the **3D Printer aboard the ISS.**

Credit: NASA

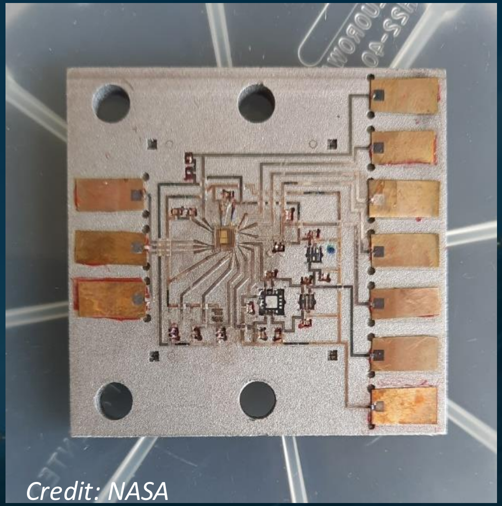


ESA IMPERIAL 3D printer, designed for use in space by a Europe-wide industrial consortium, can print **polymer parts of unlimited size along one dimension.**

Nano Dimension **3D printed integrated radiofrequency circuit**, in collab with L3Harris, flown to the ISS for space effects studies.

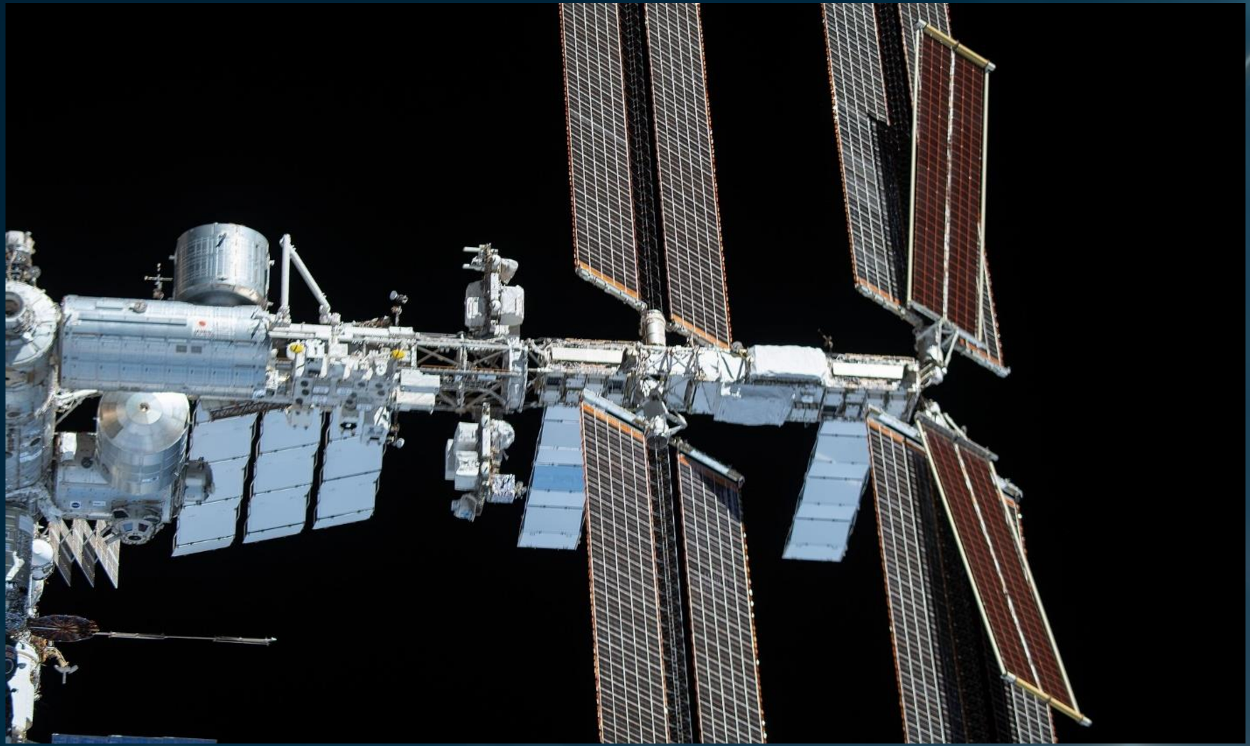


NASA Hybrid Printed Circuit tested in a sounding rocket flight in 2023.



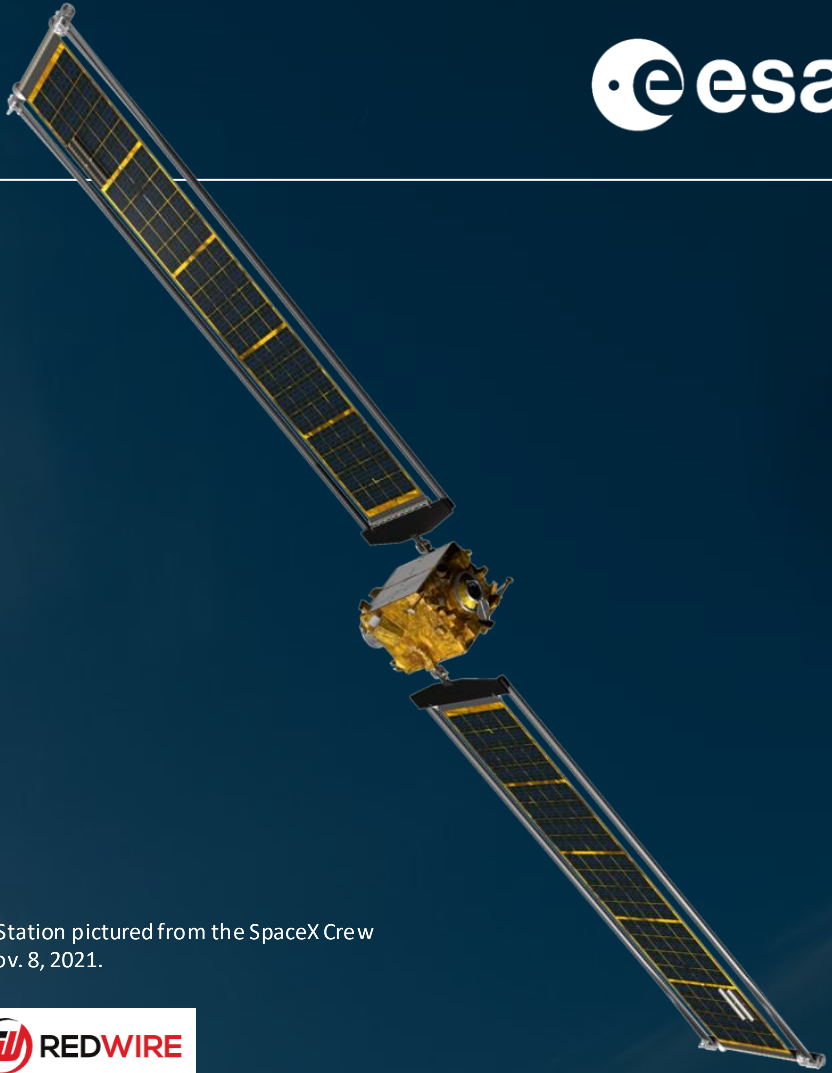
Credit: NASA

AM and printed electronics in space



NASA/Crew-2

The International Space Station pictured from the SpaceX Crew Dragon Endeavour on Nov. 8, 2021.



DART satellite showing its ROSA fully deployed

NASA’s ROSA and ISS Roll Out Solar Array (iROSA) REDWIRE

- **20% lighter** (mass of 325 kg) and **¼ the volume** of rigid panel arrays with the same performance.
- Six iROSAs on the ISS increased the station’s power generation by over 30% (more than 250 kW).
- Used on **DART** and the **Power and Propulsion Element on Gateway.**

AM aligns with ESA Agenda 2025 targets…


ESA'S TECHNOLOGY STRATEGY
Version 1.2, September 2022

To achieve the **green and digital agendas targets,** the Technology Strategy aims to:


30%

30% IMPROVEMENT IN SPACECRAFT DEVELOPMENT TIME BY 2023

30% improvement in spacecraft development time by 2023 by developing technologies that digitalise workflows, advancing technologies for increased flexibility, scalability and adaptability and developing processes that quickly introduce terrestrial technology into missions.

10X

10X IMPROVEMENT IN COST EFFICIENCY

A one order of magnitude improvement in cost efficiency with each new generation by reducing the cost per useful bit transmitted by telecommunications satellites, providing 100% service availability of positioning, navigation and timing services and making systems resilient to spoofing attacks, improving the resolution, accuracy revisit time and product delivery time of remote sensing missions and enabling transformational science and increased science performance.

2030

2030 TARGET FOR INVERTING EUROPE'S CONTRIBUTION TO SPACE DEBRIS

Inverting Europe's contribution to space debris by 2030 by ensuring that all ESA missions are environmentally neutral by 2020, developing the technologies necessary for the successful active removal of space debris by 2024 and enabling all ESA missions to be risk neutral by 2030.

30%

30% FASTER DEVELOPMENT

30% faster development and adoption of innovative technology by focusing on technologies that enable new space-based capabilities and services investing in joint lab facilities with industry and research centres for faster spin-in from terrestrial sectors to space and increasing opportunities for technology demonstration and verification payloads.

… and with ESA’s Journey to Sustainable Electronics

ESA'S JOURNEY TO SUSTAINABLE ELECTRONICS

TOWARDS A GREENER SPACE

Studies at ESA have revealed that electronics play a significant role as an environmental hotspot in space missions. ESA is exploring alternative manufacturing processes, **including the utilization of printed electronics**.

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AM of Electronics Activities at ESA

- **ARTES AT 5C.499** (> 500 KEURO) European chip inductor for point of load converters in telecommunication satellites (Technology domain: EEE Components and Quality) – Status: Tender Action Issued.
- **ARTES AT 7C.074** (> 500 KEURO) Phased array antennas based on flexible ultra-light materials and printed RF components (Antenna and Sub-Millimetre Waves section) – Status: Tender Action Issued.
- **ARTES AT 7C.083** (> 500 KEURO) Printed circuit board technology for automotive conformal antennas (Technology domain: RF Systems, Payloads and technologies) – Status: Tender Action Issued.
- **ARTES AT 4E.073** (200-500 KEURO) Direct Printing of mechanical and thermal Sensors onto Spacecraft hardware. Strain and temperature sensors on batteries and tanks (CSC) – Status: Evaluation
- **ARTES AT 4A.078** HighPEEK - Conductive Plastics for Satellite Parts. Structural parts and housings (CSC) – Status: Completed 2023-01-23.
- **TDE T706-702EF** Advanced Packaging for RF Modules (Technology domain: RF Systems, Payloads and technologies).
- **TDE Activity number: 1000035672** (200-500 KEURO) Printed Structural Electronics - Expro+ (TEC-MSP) – Status: Awarded.

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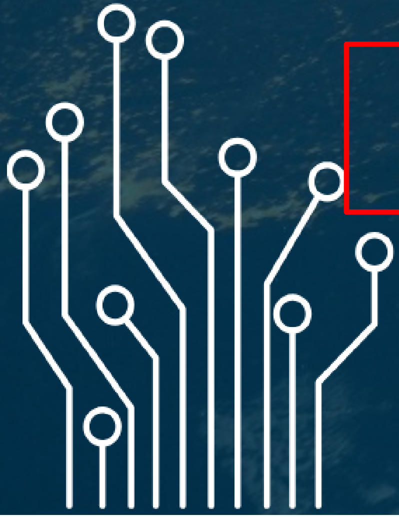

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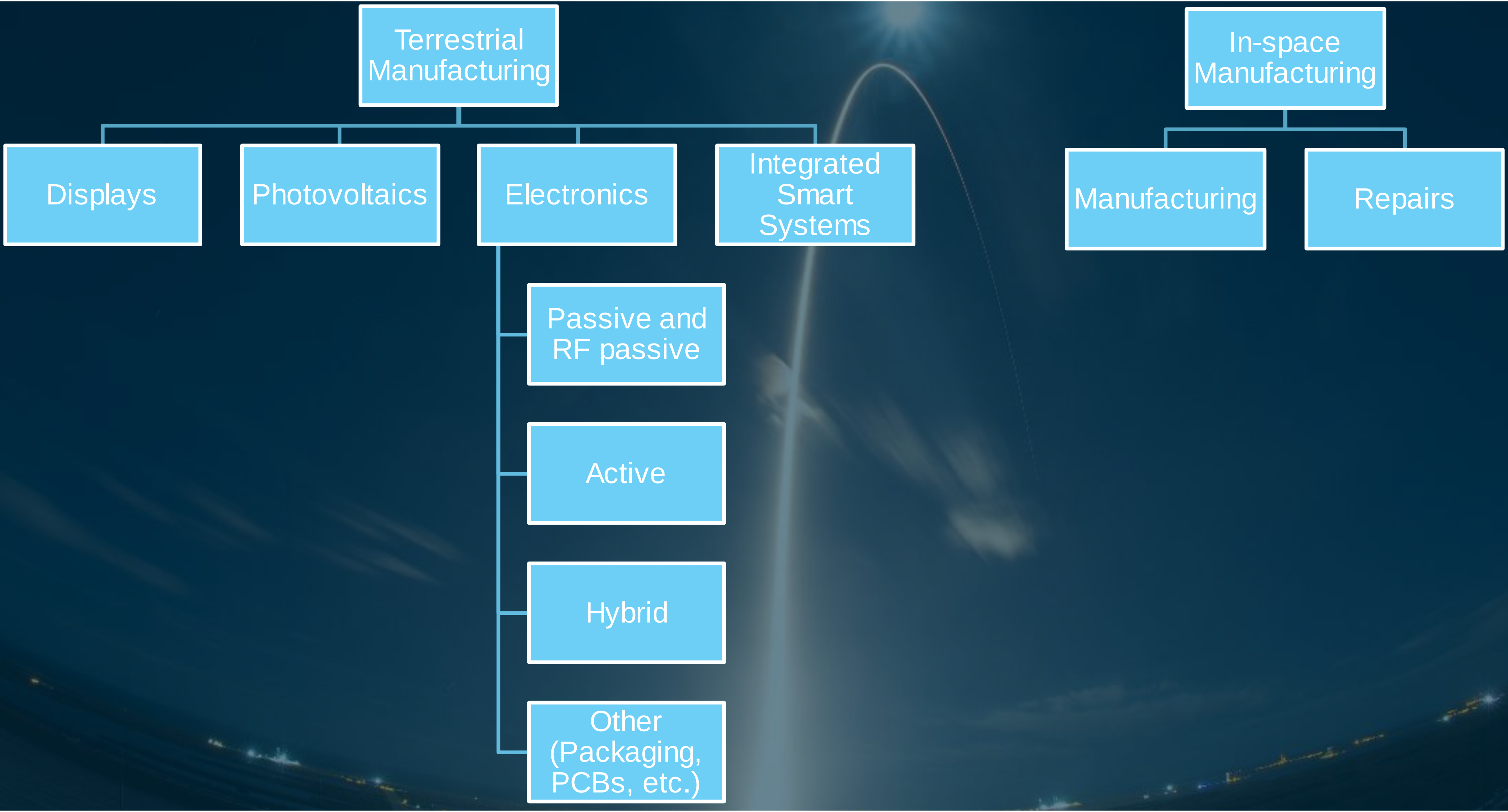
Our goal is to have a shared, holistic strategy roadmap



- Terrestrial Manufacturing
  - Displays
  - Photovoltaics
  - Electronics
    - Passive and RF passive
    - Active
    - Hybrid
    - Other (Packaging, PCBs, etc.)
  - Integrated Smart Systems
- In-space Manufacturing
  - Manufacturing
  - Repairs

Strategic plan

Short-term (target outputs expected in the next 2-3 years)

1. Investigate through market analysis and R&D activities in:

  a. Passives (e.g., sensors, conformal electronics, harness)
  b. Packaging (e.g., SiP)
  c. Initial focus on hybrid techniques, possible move to discrete actives
  d. Understand the main factors to monitor for reliability and repeatability of materials, processes, and final products for standardization.

2. If initial R&D activities are promising, investing in resources to develop ESA internal know-how through and gain independent access to the capabilities of emerging technologies.

Strategic plan

Medium-term (target outputs expected in the next 5-10 years)

Hybrid Printed Electronics (HPE):

- ➢ Establish a consortium to go through development cycles of specific products.
- ➢ **Develop industrial capability for space compatible hybrid electronics applications. Collaborate with partners to develop high throughput digital printing and/or setup a bureau service.**

Other :

- ➢ Develop recipes (including indications on e.g., size of particles, materials utilized in the ink formulation, printed pattern, sintering process) to create space standards that ensure reliability and repeatability of final products performances.
- ➢ R&D on e.g., flexible photovoltaics, transition from hybrid techniques to fully printed.

Strategic plan

Long-term (target outputs expected in the next 10+ years)

- **Provision of individual EEE component functions and complete subsystems through a qualified AM process.**
  - Fundamental **change of business model for EEE procurement** (e.g., European, simplified, local and sustainable, one-stop-shop supply chain)

- **In-space manufacturing** on the ISS/the Moon for repair and fabrication.

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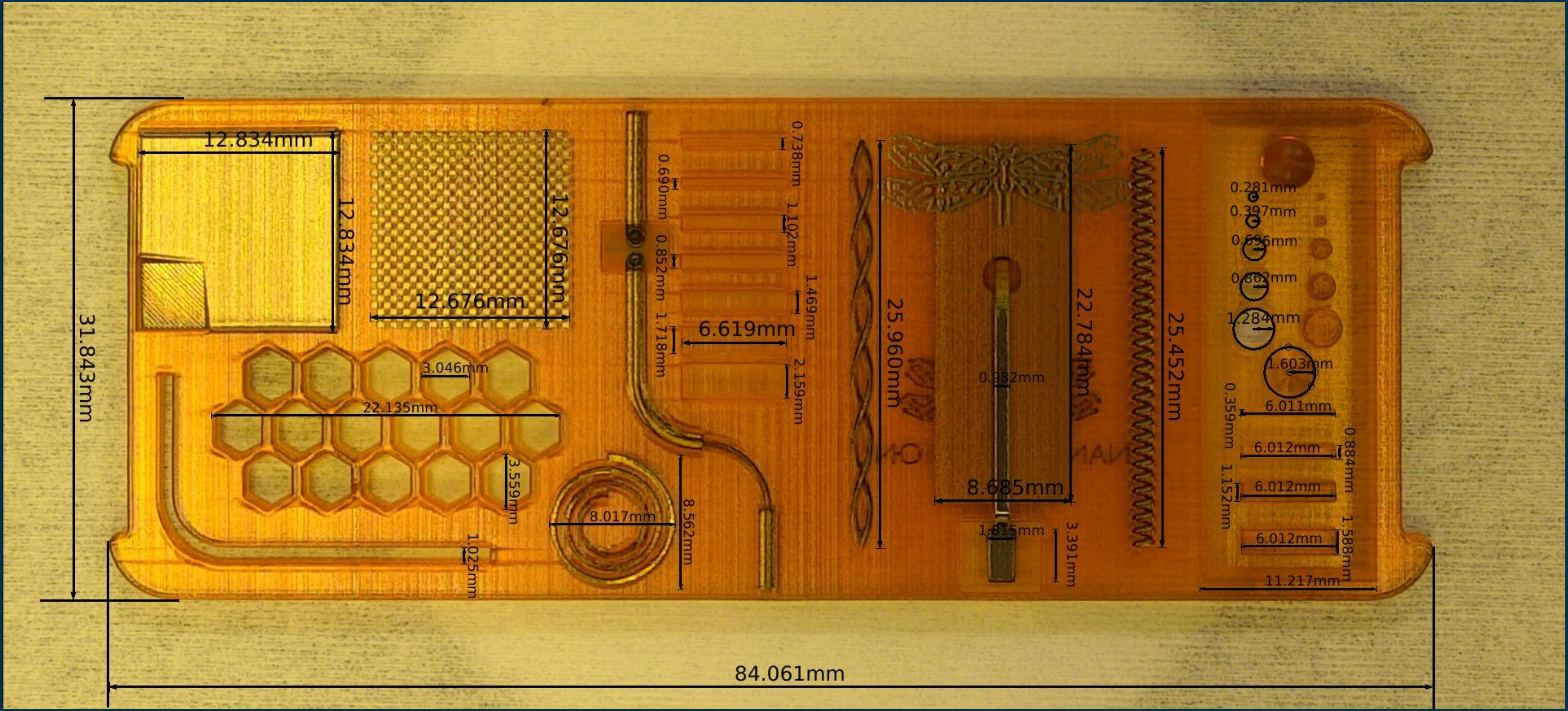
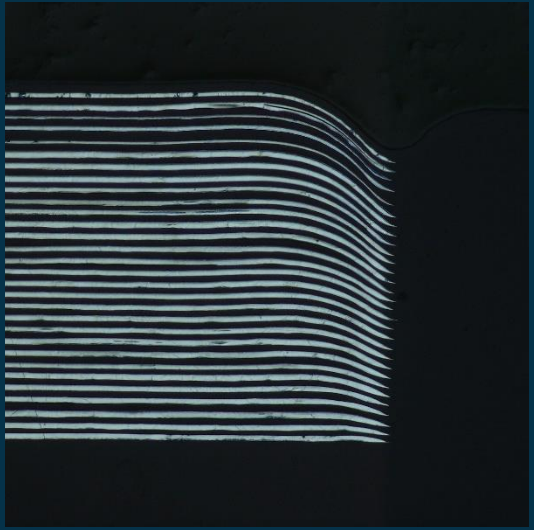
Optical inspections on Nano AME coupon



Micro sectioning
Plates – Section 1 (direction parallel to printing)

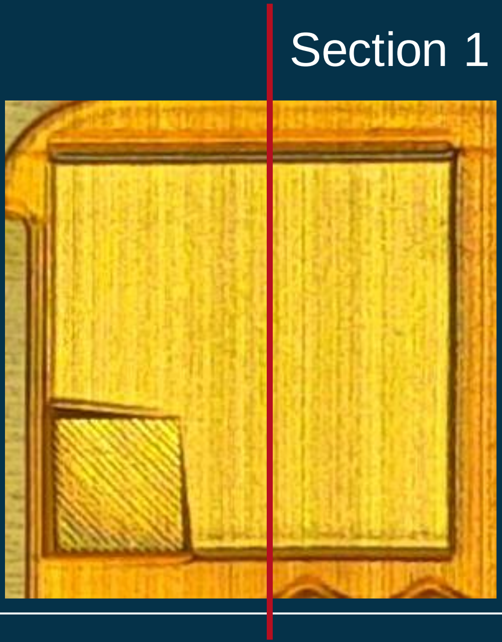


Plates thickness

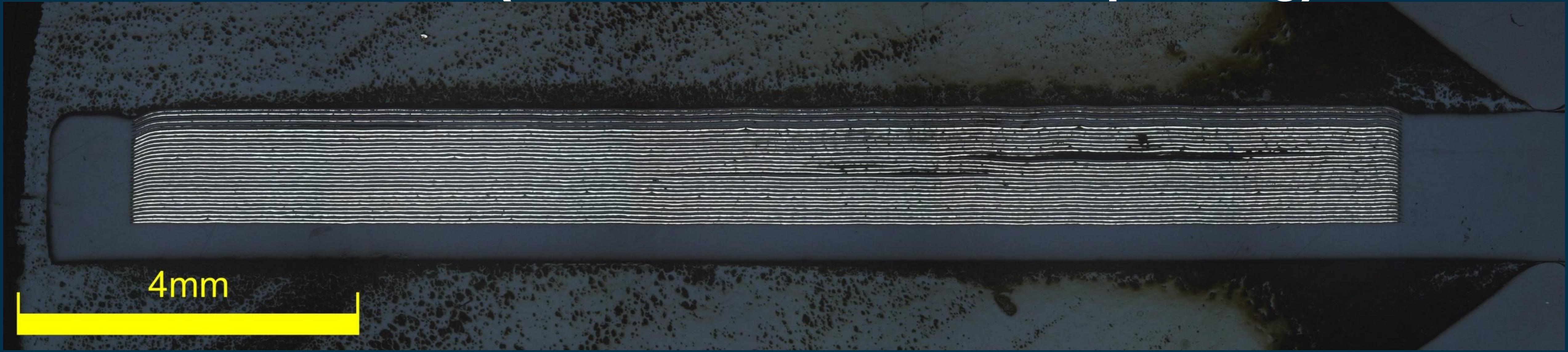
$$\mu = 28.5\ \mu m$$
$$\sigma = 4.69\ \mu m$$
$$CV = 16.5\%$$

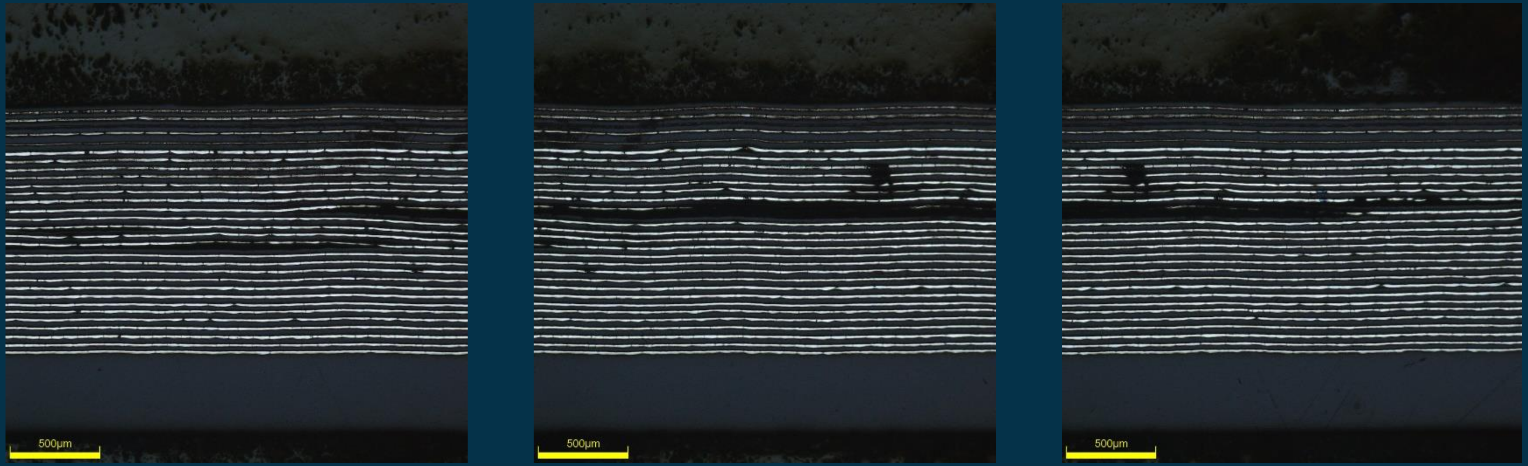
Plates distance

$$\mu = 16.6\ \mu m$$
$$\sigma = 5.12\ \mu m$$
$$CV = 30.8\%$$

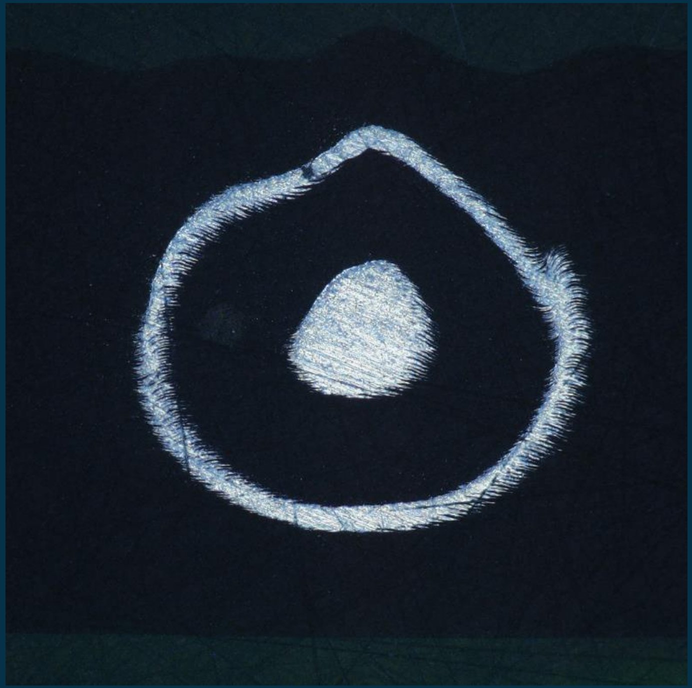


Micro sectioning
Plates – Section 2 (direction transversal to printing)

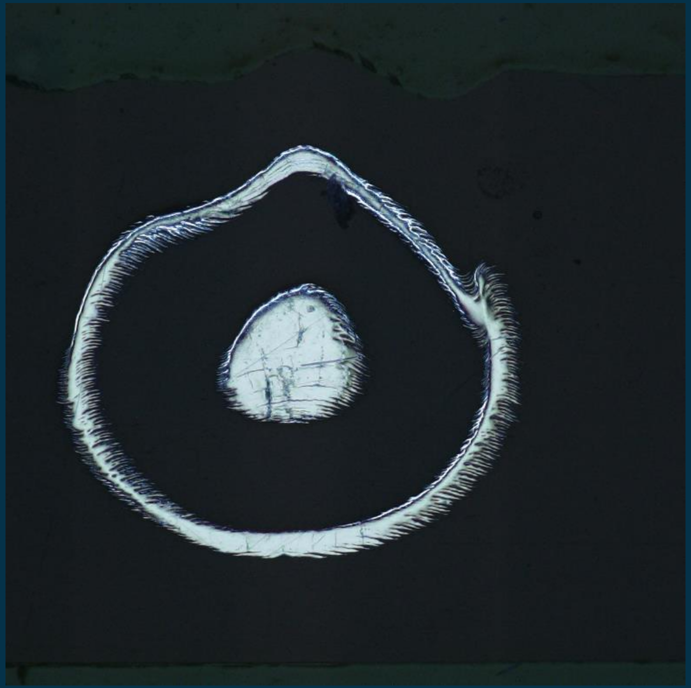




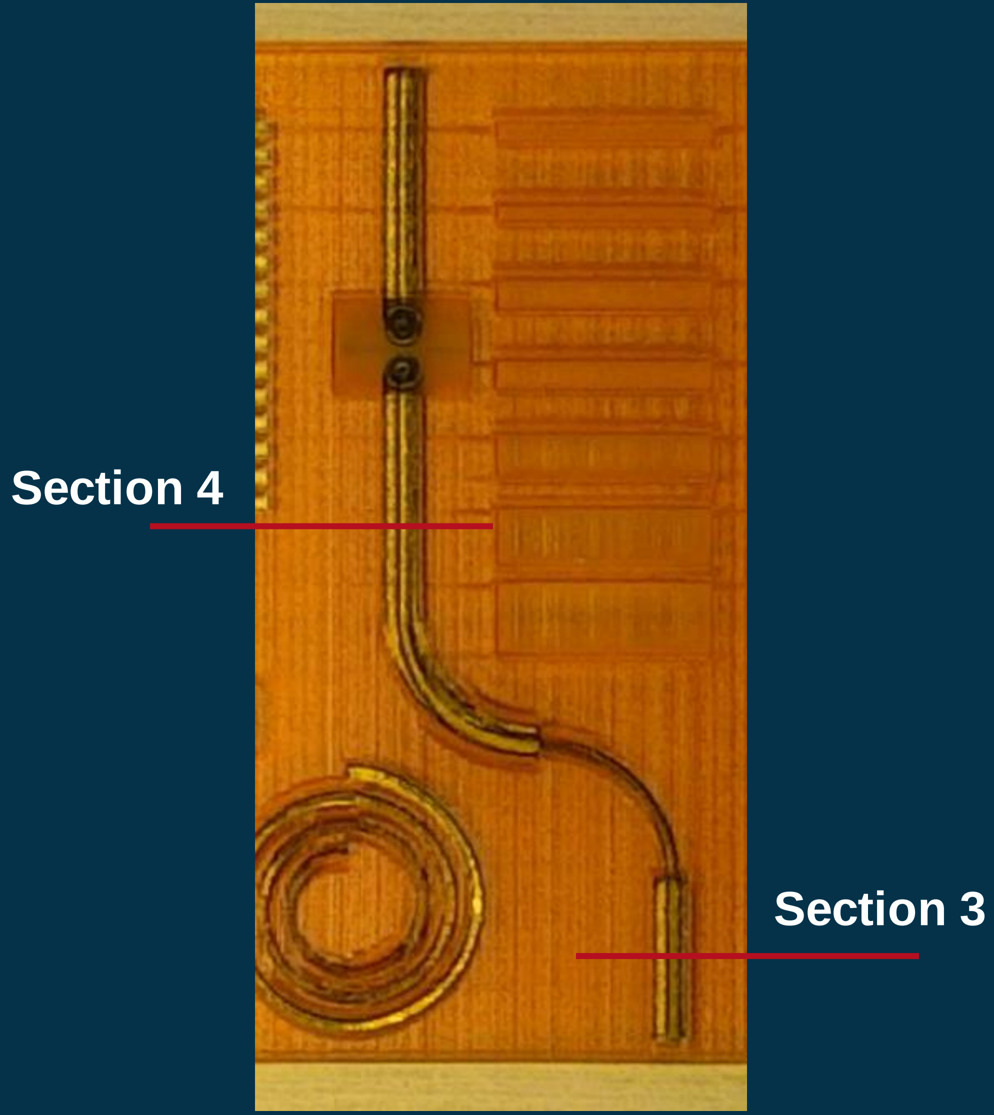
Micro sectioning
Coaxial line



Section 3 – after grinding, before polishing



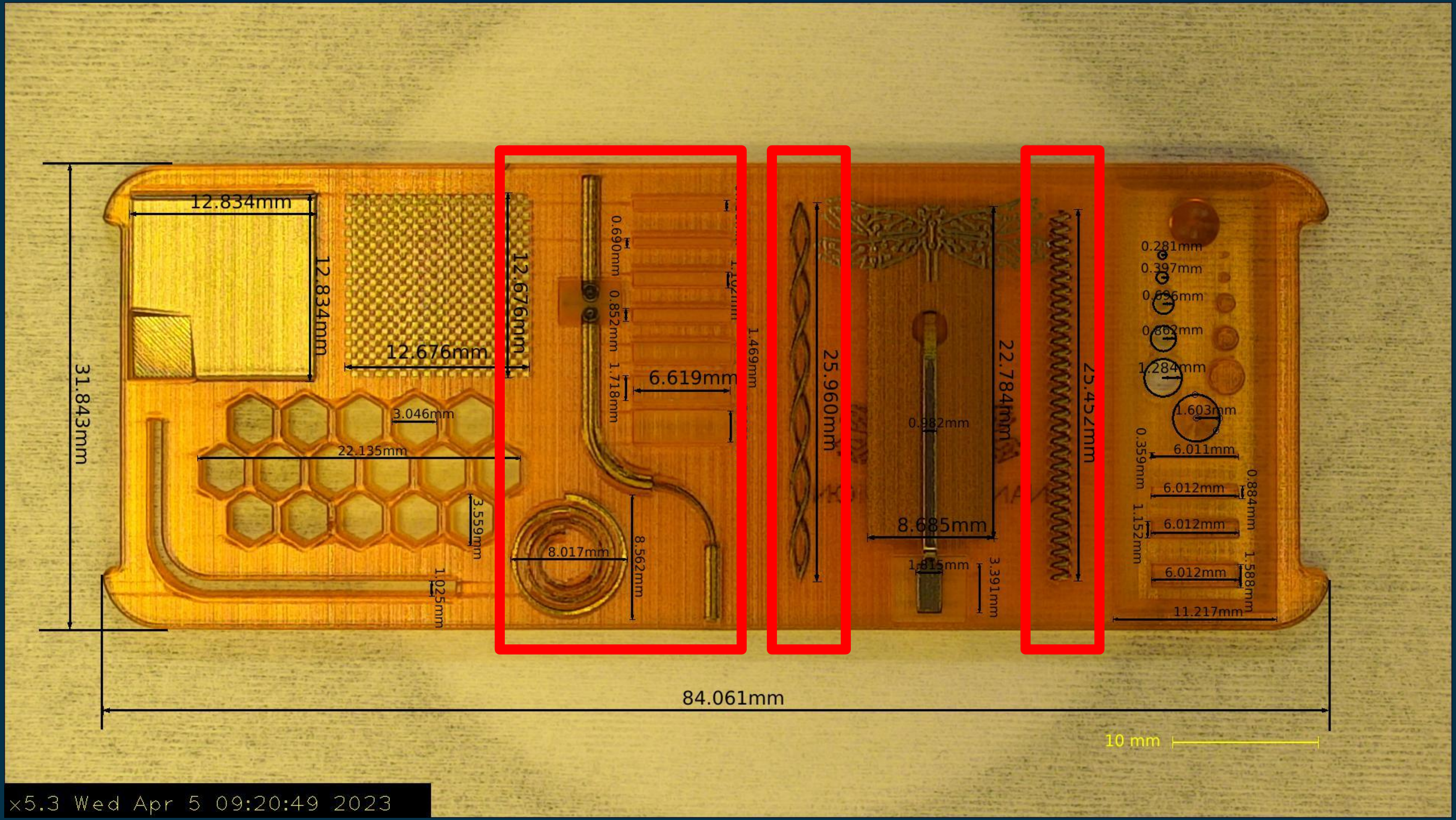
Section 4 – after polishing



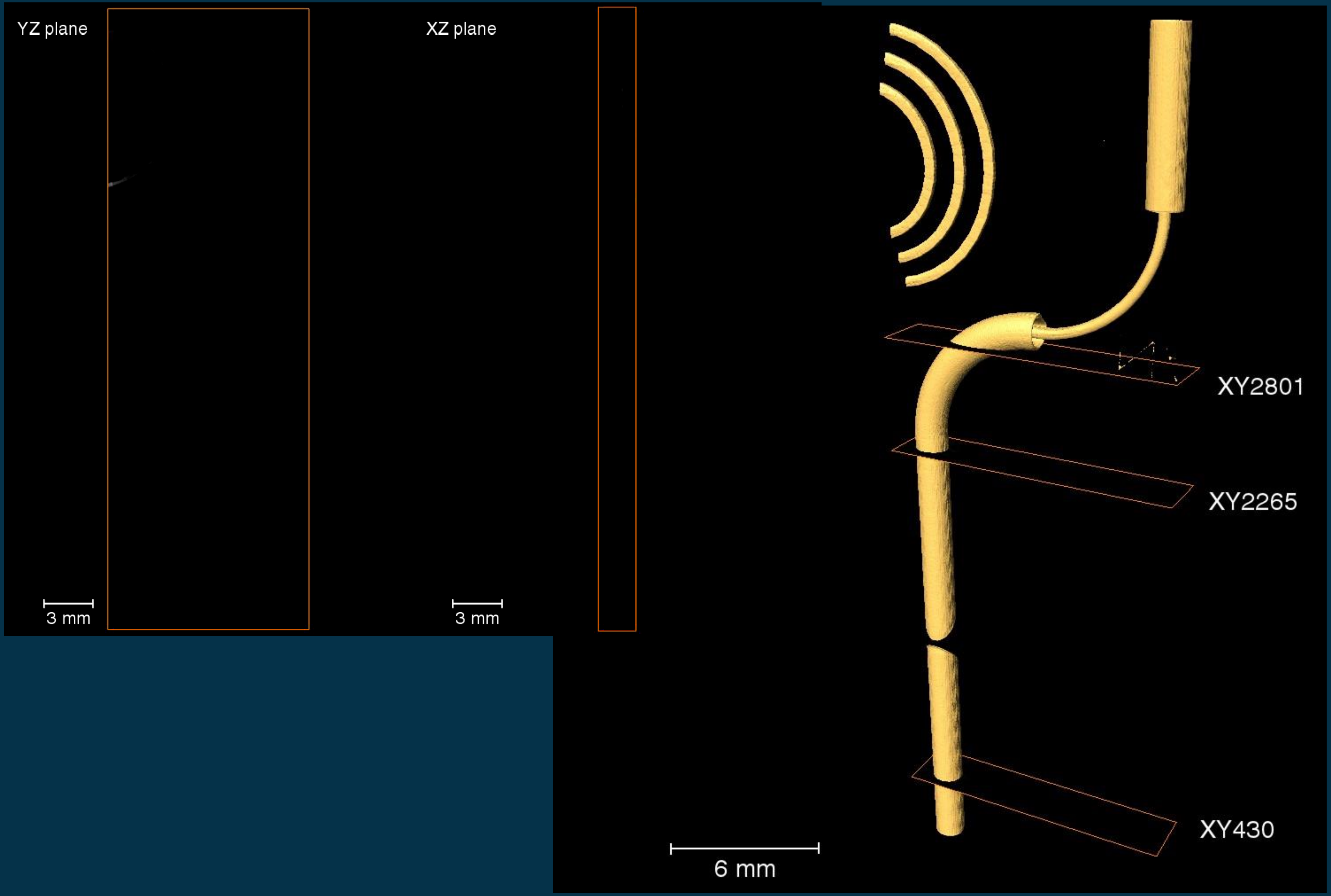
X-Ray Scanning Analysis

Components:
- coaxial line
- twisted cable
- coils

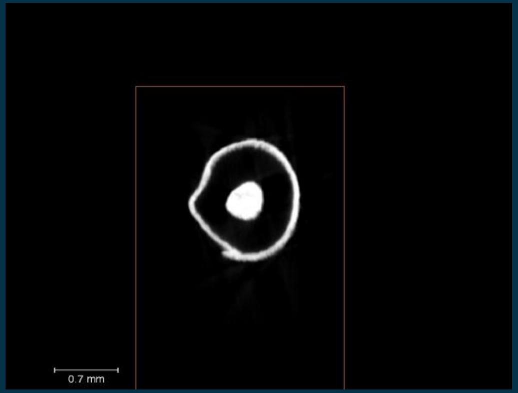
Voxel size:
8.198 um



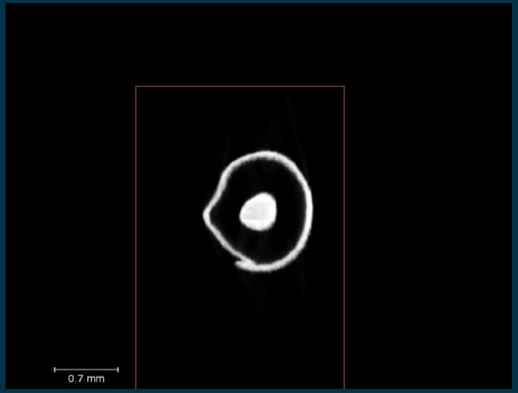
X-Ray – Coaxial line



XY 2801

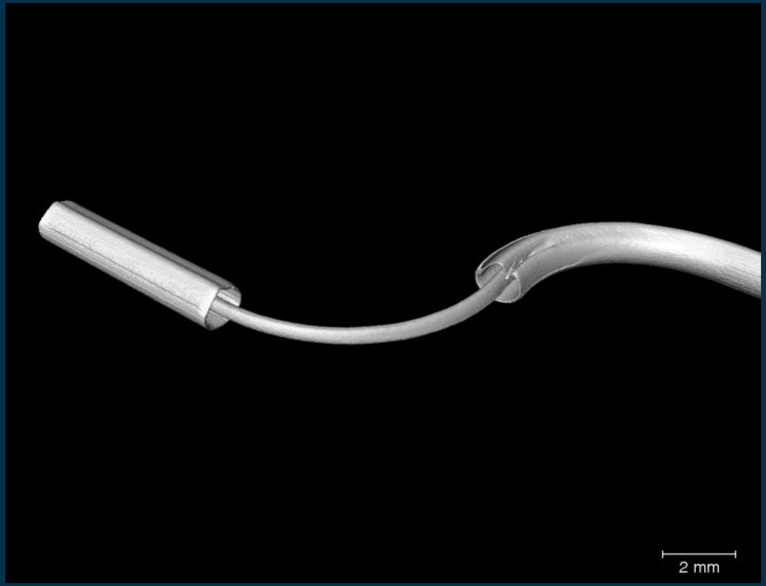


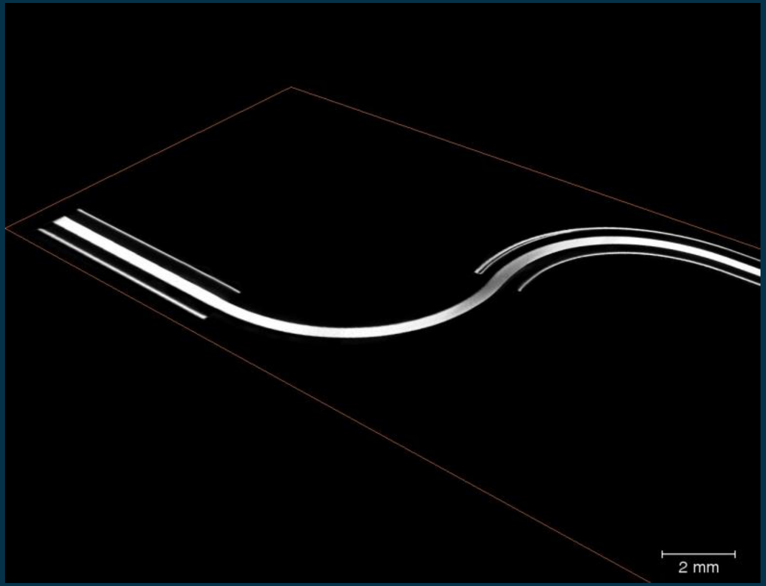
XY 2265

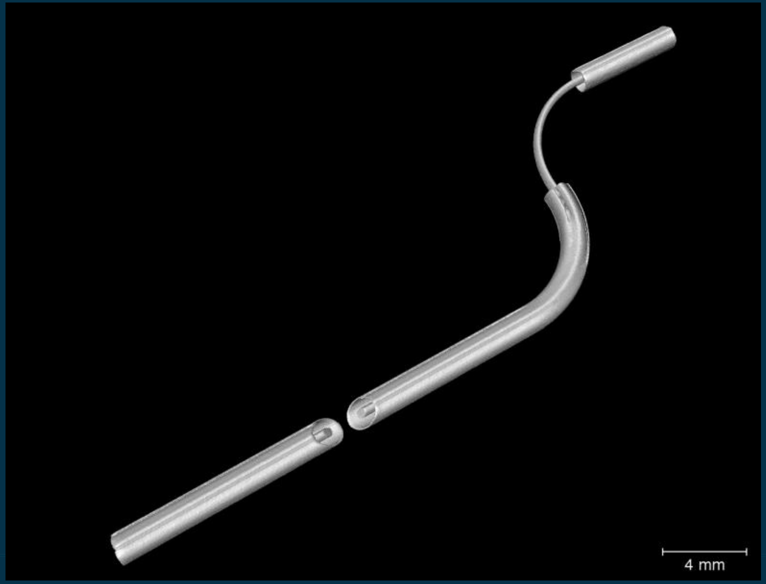


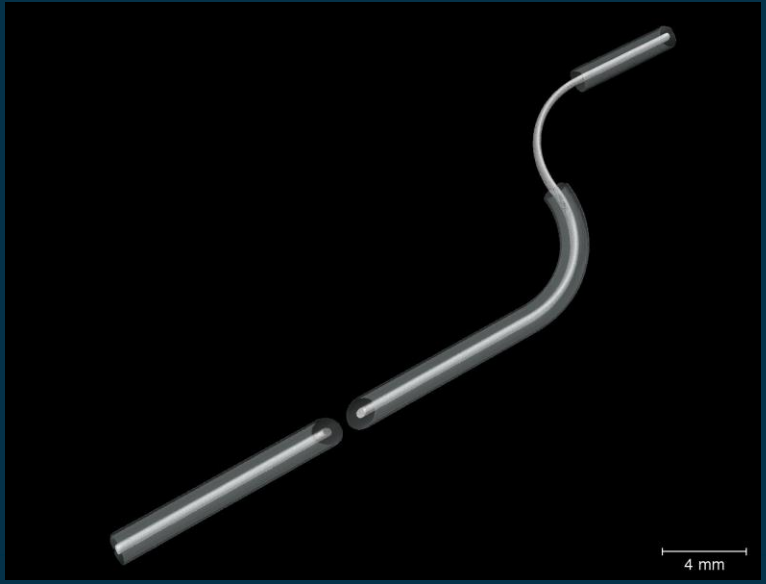
XY 430

X-Ray – Coaxial line

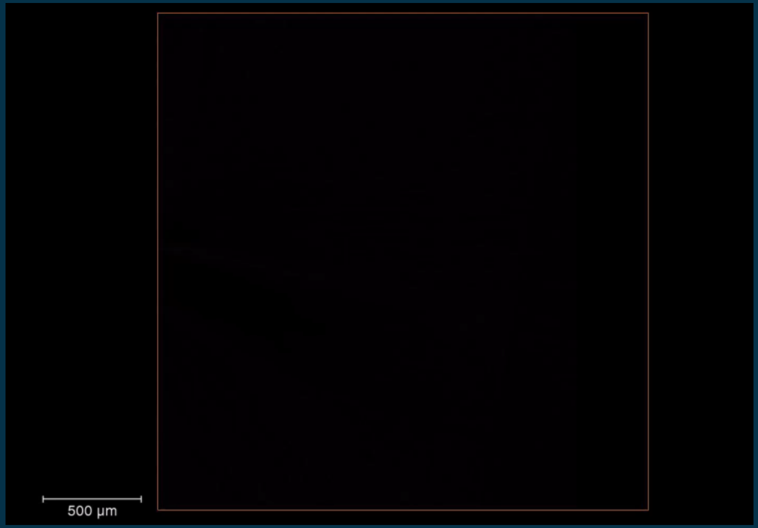


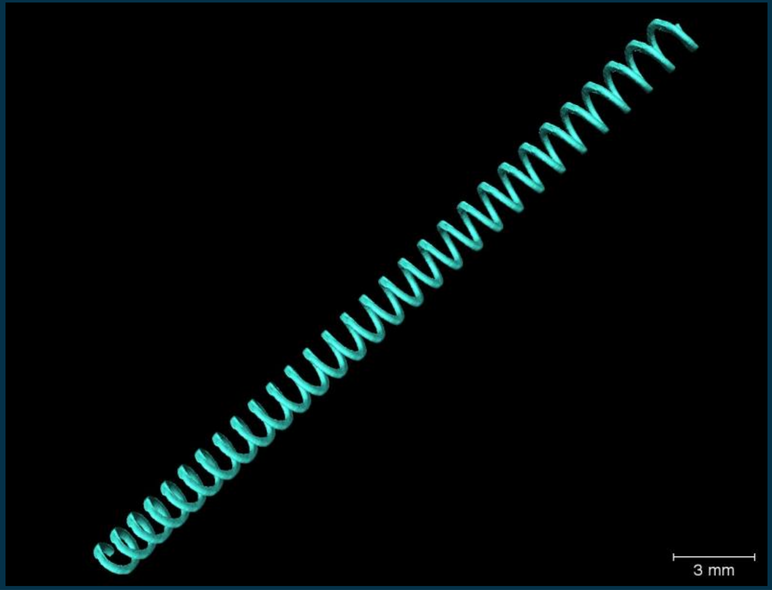


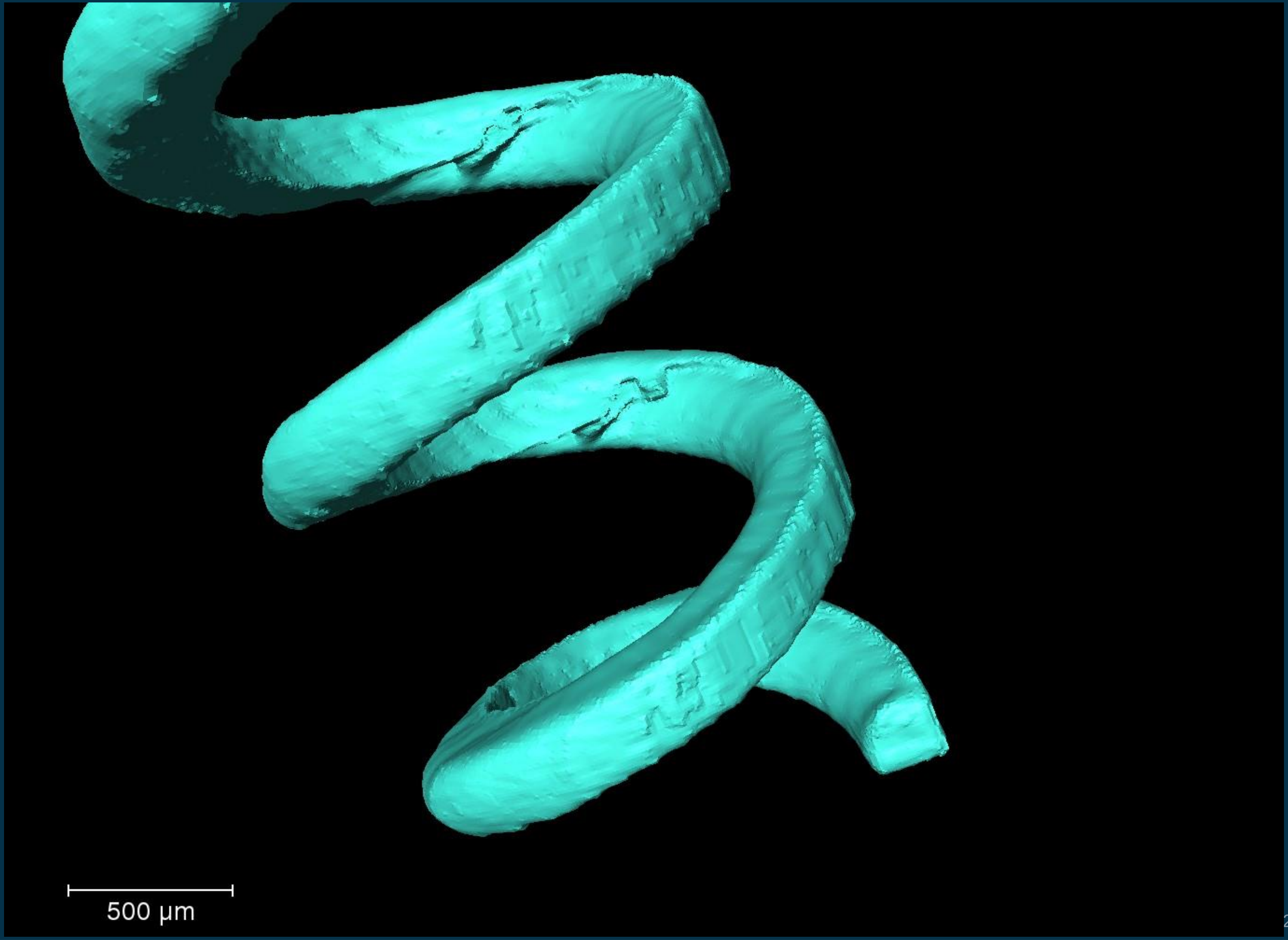




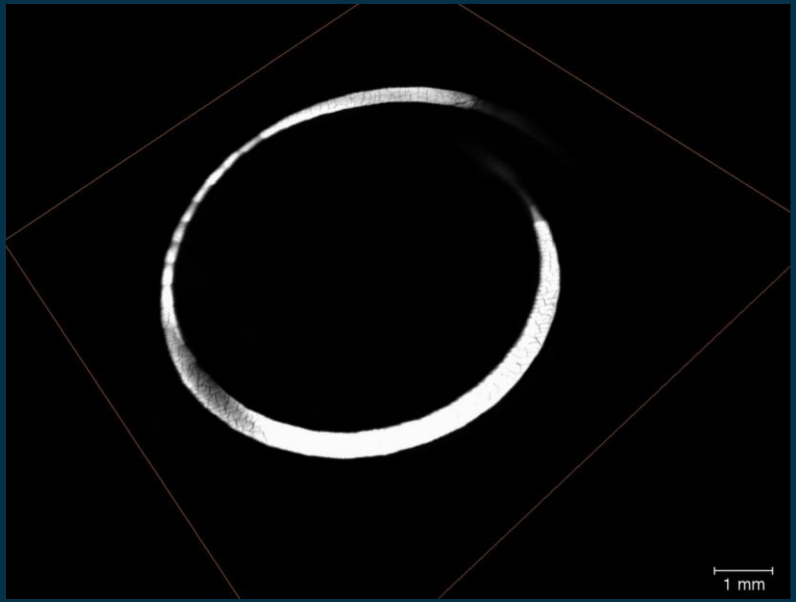
X-Ray – Horizontal Coil

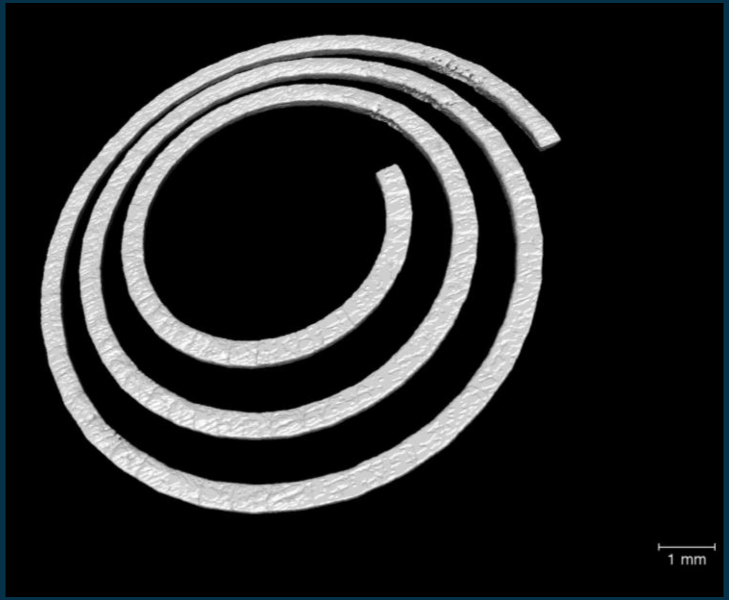


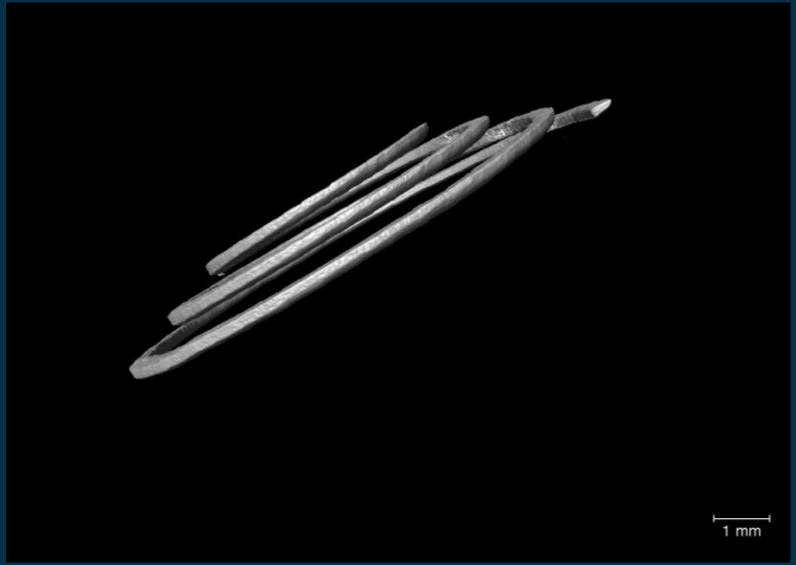


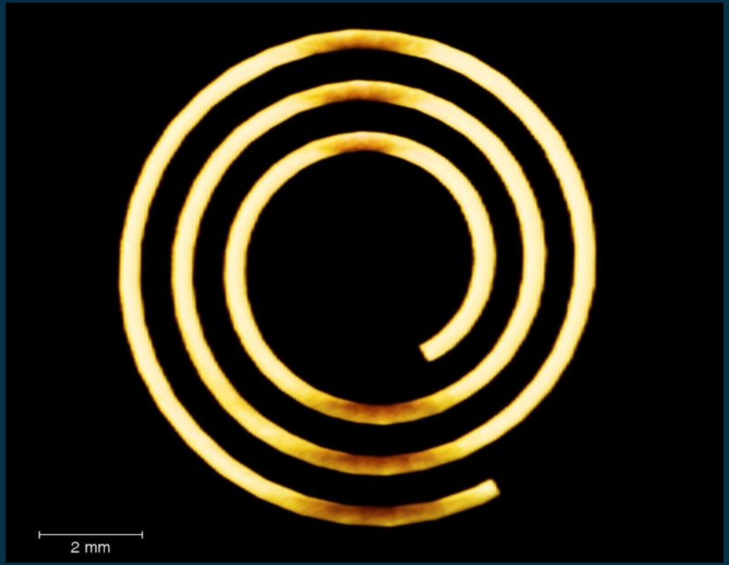


X-Ray – Vertical Coil

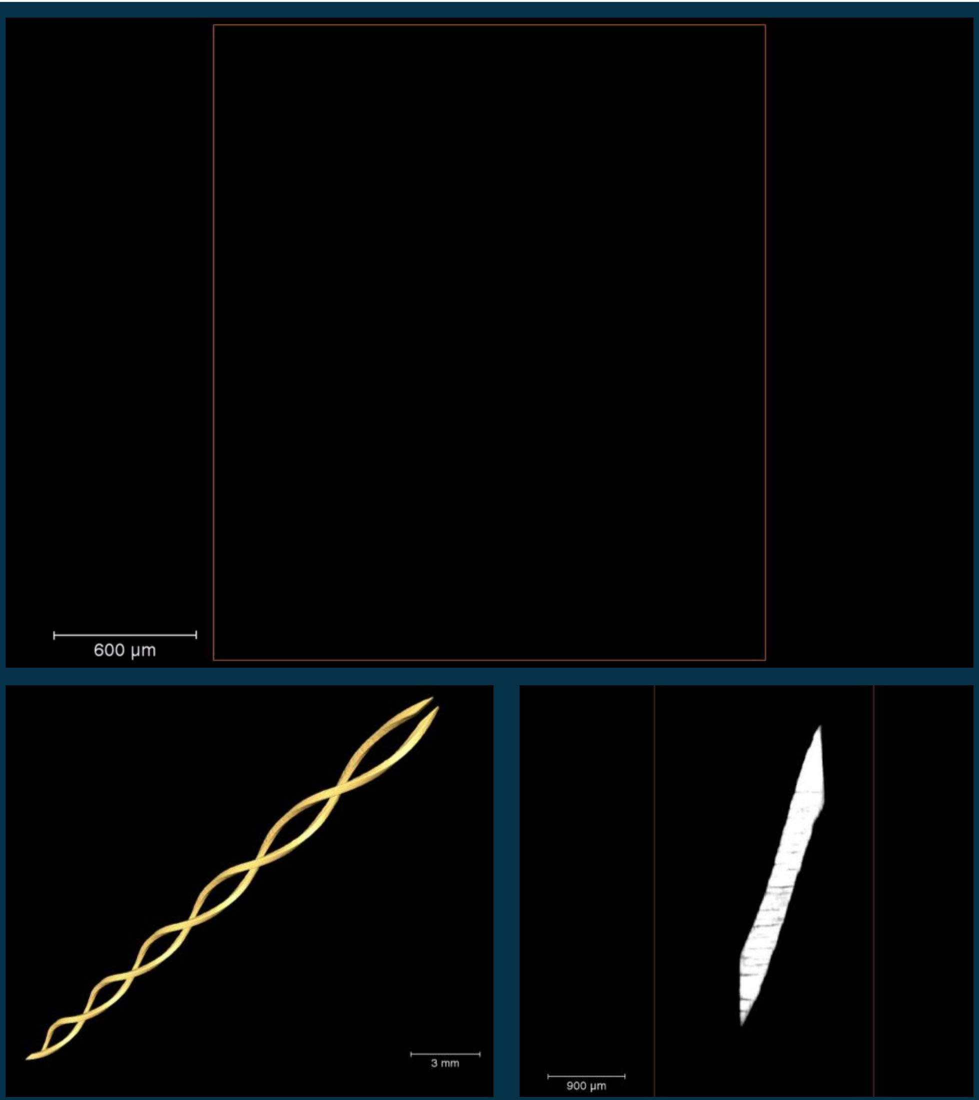






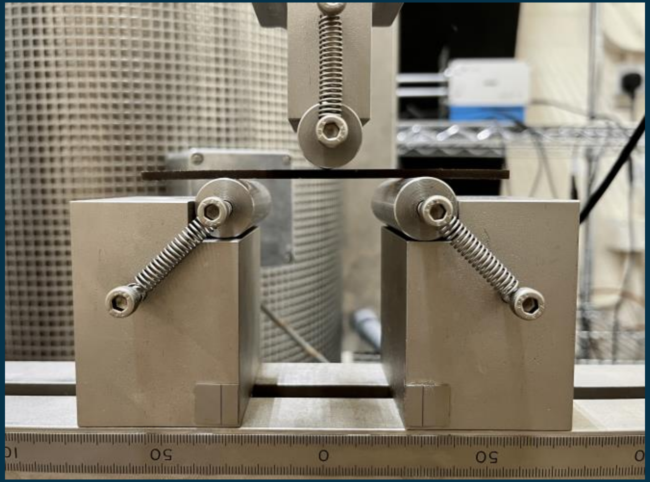


X-Ray – Twisted cable

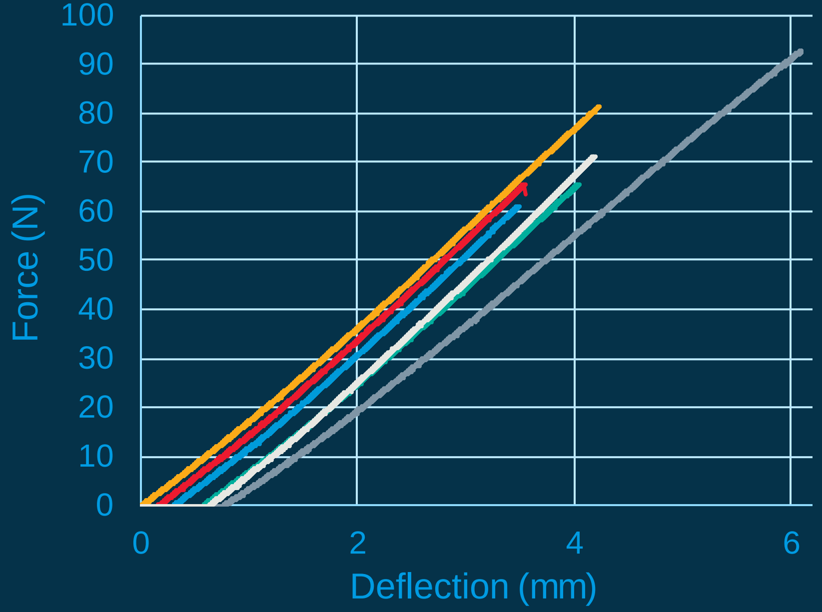


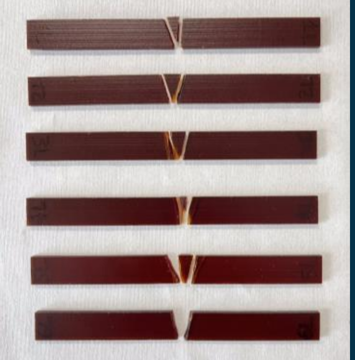
Mechanical Characterization

3 Point Bending, ASTM-D-790-2017

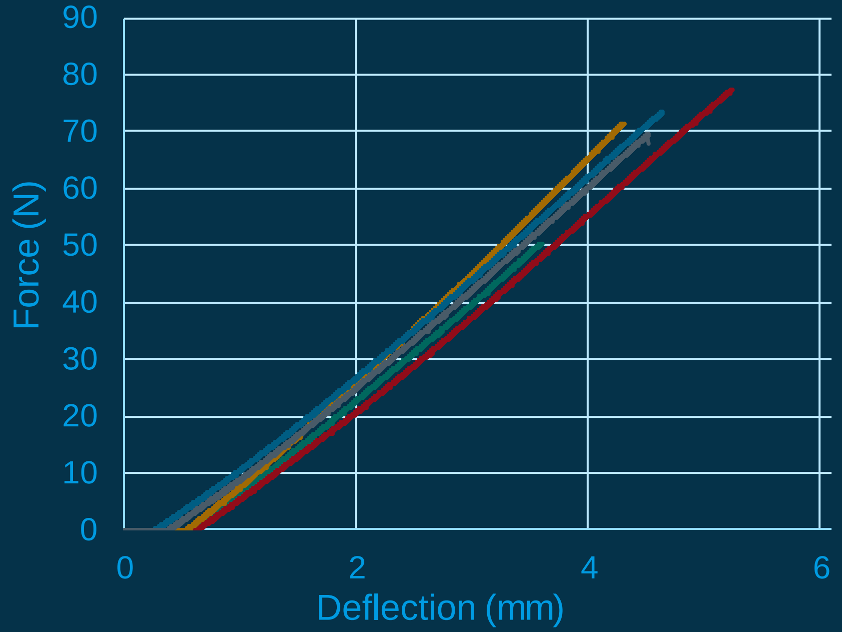


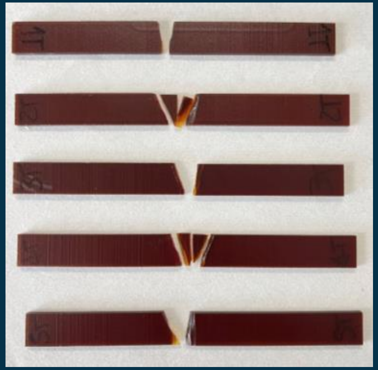
LONGITUDINAL TO PRINT





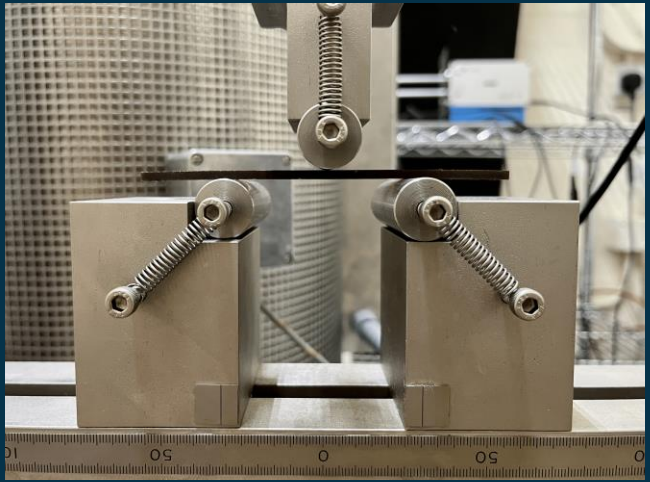
TRANSVERSAL TO PRINT





Mechanical Characterization

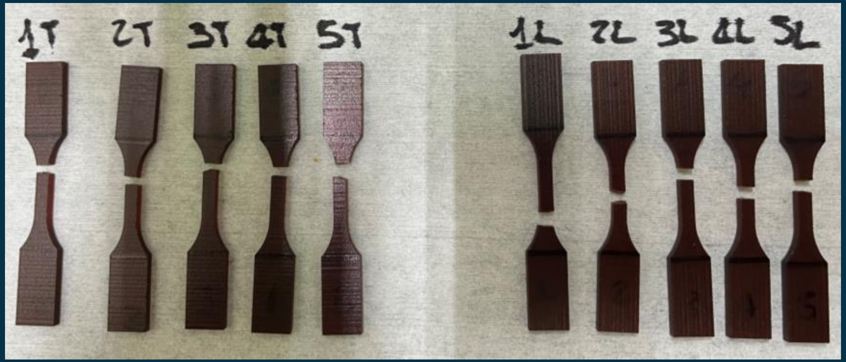
3 Point Bending, ASTM-D-790-2017

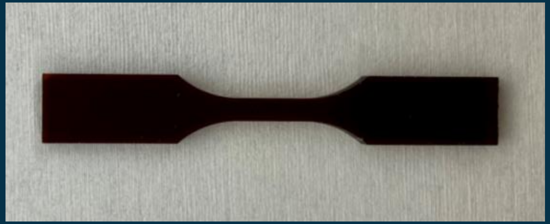


		Bending Strength @ Break (MPa)	Bending Modulus (GPa)	Def. @ Break (mm)	Force @ Break (N)
LONGITUDINAL	**Mean**	**45.348**	**1.588**	**4.252**	**72.632**
	S.D.	7.661	0.068	0.953	12.27
	CV	16.9%	4.28%	22.4%	16,9%
TRANSVERSAL	**Mean**	**42.5**	**1.446**	**4.449**	**68.08**
	S.D.	5.839	0.0988	0.5316	9.356
	CV	13.7%	6.8%	11.9%	13.7%

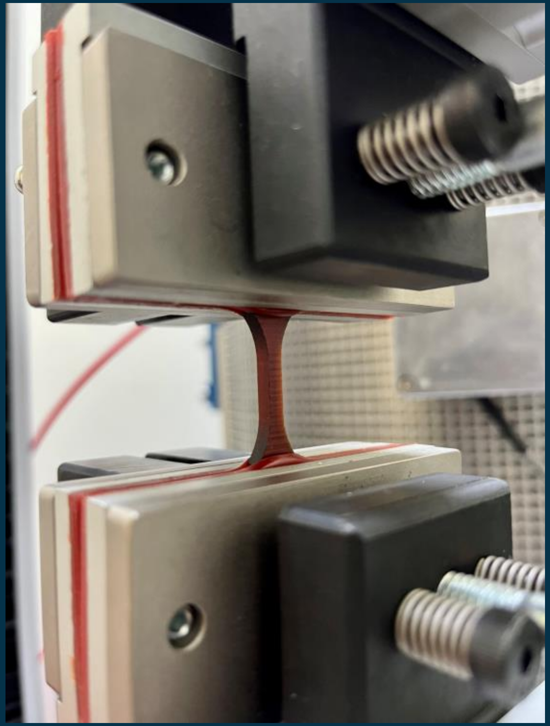
Mechanical Characterization

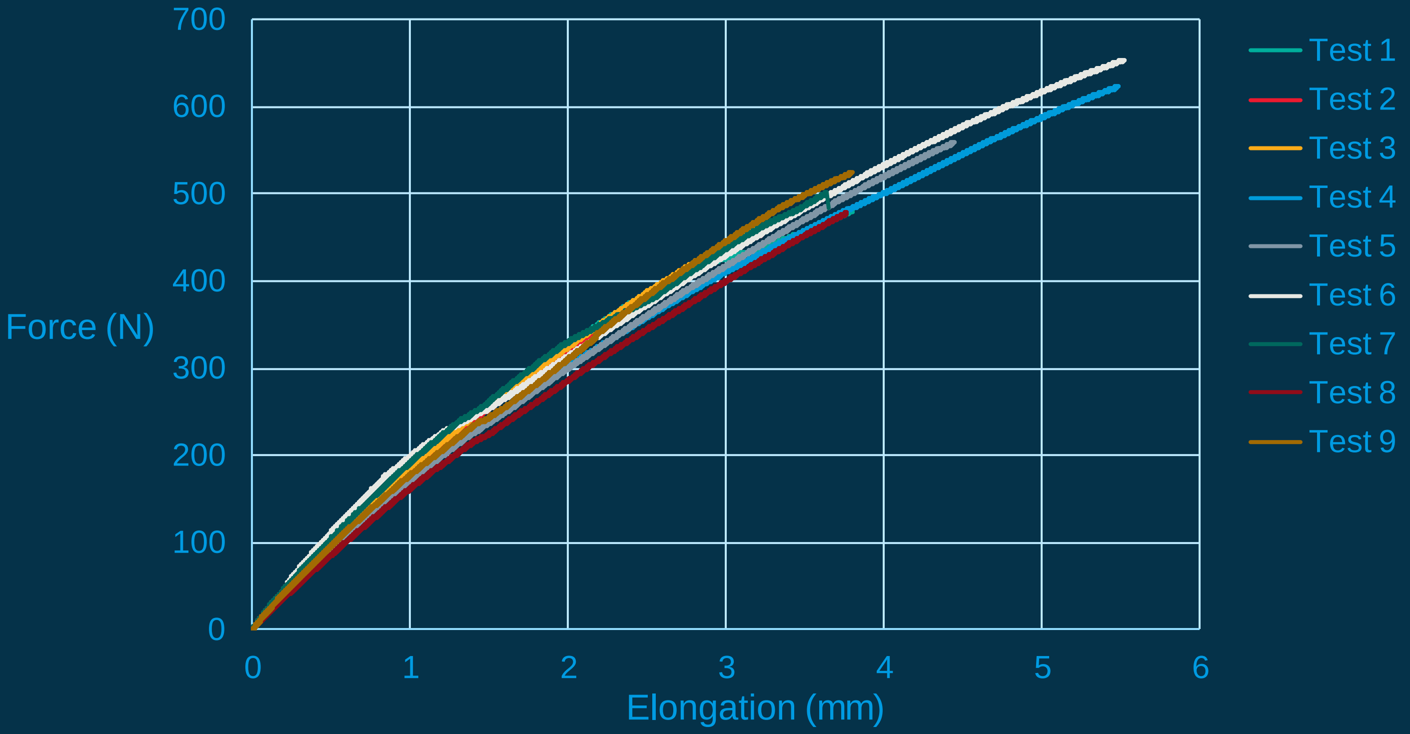
Tensile Tests, ASTM-D-638-14





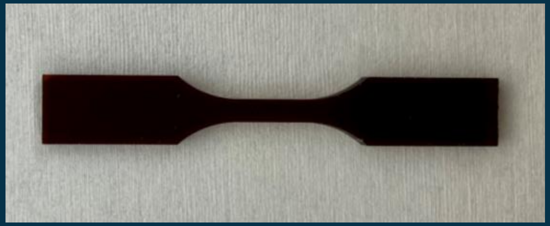
Test coupon Type 5

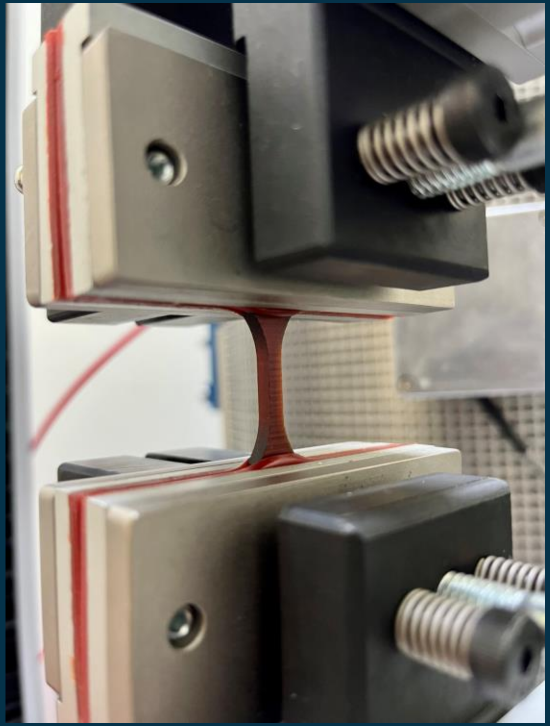




Mechanical Characterization

Tensile Tests, ASTM-D-638-14





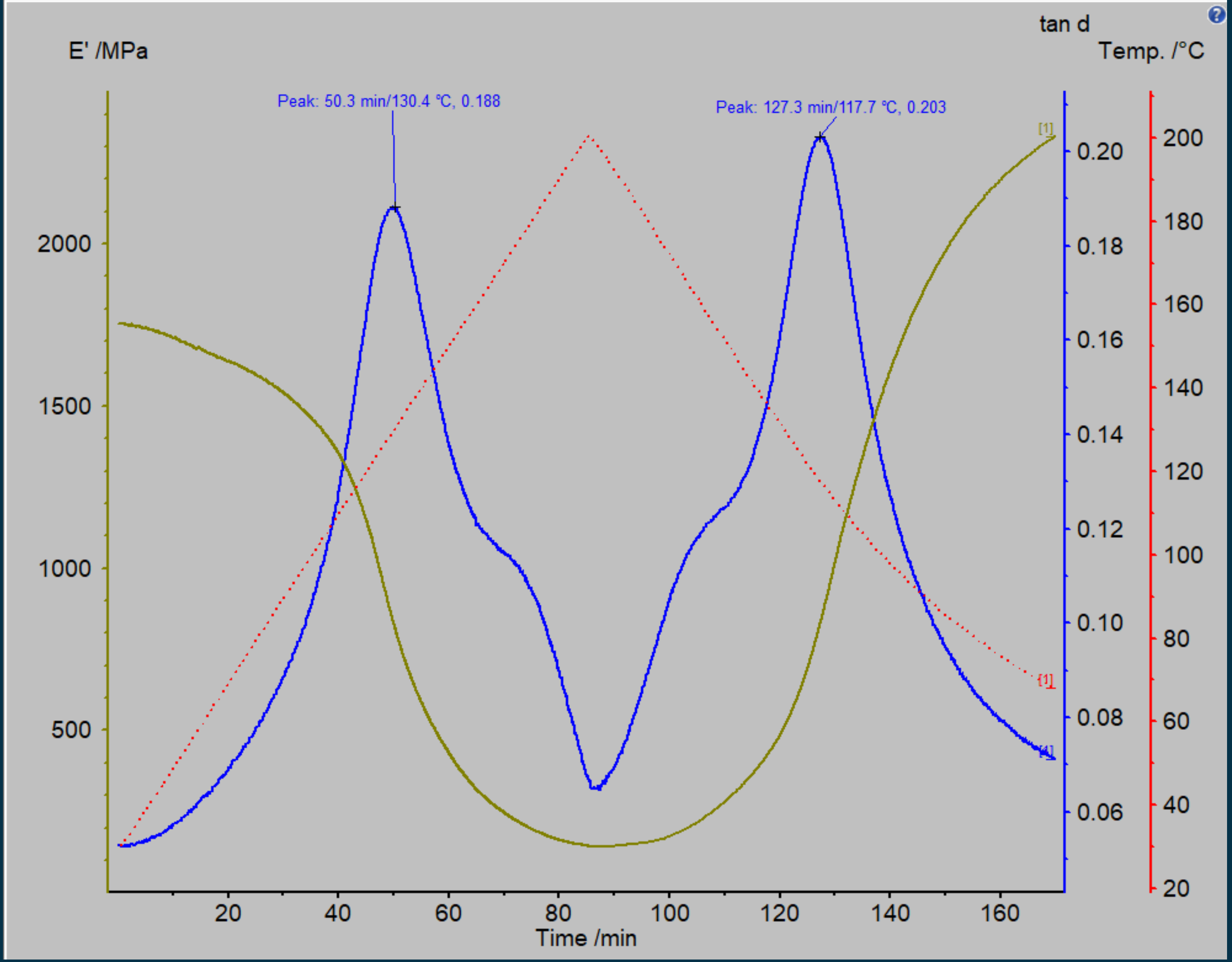
	Tensile Strength (MPa)	Elong. @ Break (%)	Elastic Modulus (GPa)
Mean	**49.9**	**53.7**	**0.161**
S.D.	6.78	11.5	0.0140
CV	13.6	21.5	8.71

Note: Elongation values estimated from cross-bar displacement might yield unreliable measures of elongation and break and Elastic Modulus.

Thermal characterisation – DMA
IPC-TM-650 2.4.24.4 Standard

Sample Details	Measured Parameter	Value
3D printed material supplied in 3 sheets of differing thicknesses	Glass Transition Temperature, Tg	124.05°C
Remarks: Average temperature from the 2 peaks of heating and cooling		

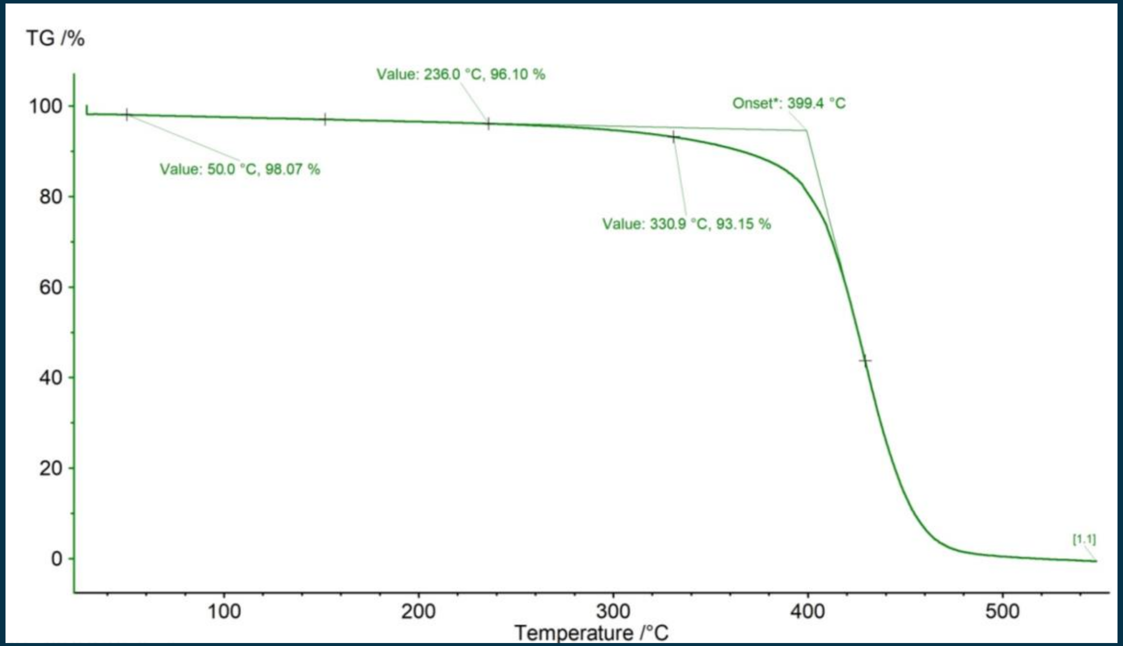
E’ ~ 1.75 GPa



Thermal characterisation – TGA
IPC-TM-650 2.4.24.6 Standard

Sample Details	Measured Parameter	Value
3D printed material supplied in 3 sheets of differing thicknesses	2% and 5% Decomposition Temperature	**2%: 236.0°C** **5%: 330.9°C**

Room temperature, 28°C and 35% humidity



Other Measurements

	DI 1092 measured	Unit	Condition	Test Method
Moisture absorption	0.467	%		IPC-TM-650, 2.6.2.1
Thermal conductivity	0.27	W/mK	25 °C	ASTM E1530-19
Roughness (Ra)	<6.6 Top	µm		IPC-TM-650, Method 2.2.22
	<0.64 Bottom	µm		

Observations

- Test coupons are printed in a few hours to make high volumes. They are designed to demonstrate the printer's capabilities; therefore, imperfections are to be expected.
- The "hairy" shapes at the edges of sections is to be expected due to the nature of 3D printing where pixels are stacked on top of each other.
- Cracks observed in the x-ray scans depend on the sintering, which can be optimized so that these do not form.
- Mechanical properties highly depend on the specific recipe utilized for curing. The curing itself can be optimized to achieve specific mechanical or electrical properties.
- Thermal properties measurement are close to data sheet values.
- Data sheet properties are measured in lab control environments, on specimens developed and cured specifically to optimize those properties.

OUTLINE

Project introduction 01

AM activities at ESA 02

ESA AM Strategy 03

04 Nano test coupon studies

05 Conclusions

Conclusions

- Innovative AM techniques hold the potential to support game-changing space applications.
- Initial investigations on AM components show their great potential, and capability for optimizing the curing process to different scopes.
- AM Electronics will provide fundamental changes in the way electronics for high variety-low volume are designed and manufactured, allowing digital, sustainable, agile production.
- In TEC-ED, we are planning to grow expertise in AM electronics to embrace the business model change for EEE procurement.

Thank you for your attention!

Dr Rita Palumbo
Rita.Palumbo@esa.int

ESA ECSAT

13/11/2023

Nano Dimension User Forum

Document Number: ESA-TECED-HO-2023-003197

AME in customized NDT probes and sensor systems at Fraunhofer IZFP

M. Sc. Philipp Stopp, 13.11.2023

Fraunhofer
IZFP

Fraunhofer-Institut für Zerstörungs-
freie Prüfverfahren IZFP

Sensor and Data Systems for Safety, Sustainability and Efficiency

Center of Expertise

Sensor-Intelligence and Microelectronics

CoE Sensor-Intelligence and Microelectronics

State of the art NDT sensor systems

Manual inspection

- Manual sensor manipulation
- Hardly data pre-processing -> raw data storage and visualization
- Evaluation and documentation by user

Semi-automatic inspection

- Automatic inspection, manual probe handling
- Most commonly raw data storage and online data processing
- Supported data analysis and documentation. Final evaluation by user

Automatic inspection

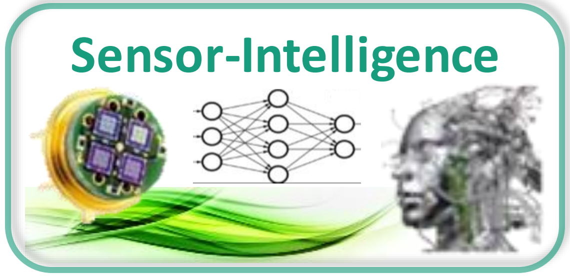
- Full automatic inspection; (in terms of executing)
- If possible data pre-processing to reduce the data traffic/storage
- High data volume -> tools support the user in the evaluation process

CoE Sensor-Intelligence and Microelectronics

Motivation

Vision: Use of multimodal NDT systems in the IoT world

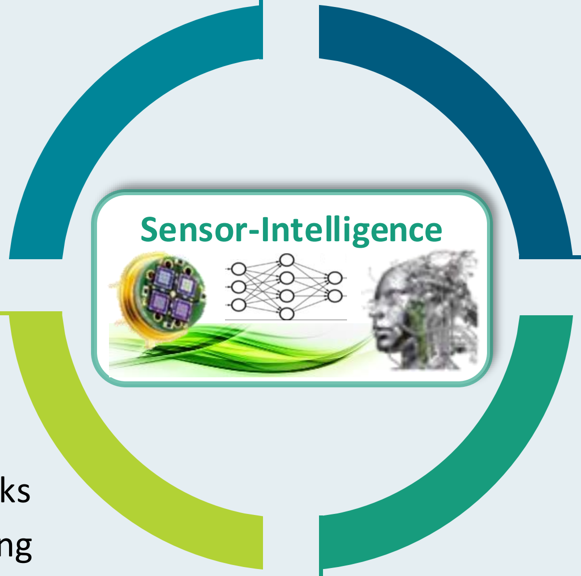
- **Challenge:**
  - Power consumption
  - Autonomous evaluation of test results
  - Miniaturization
  - Easy adaptation to the IoT world



CoE Sensor-Intelligence and Microelectronics
Fraunhofer Center for Sensor Intelligence ZSI

CoE Sensor-Intelligence and Microelectronics

Definition



Edge Computing

- Analog and digital circuit design
- Application-oriented use of microelectronic e.g. µC, DSP, FPGA
- Biologic inspired ASIC e.g. Neuromorphic Hardware, In-Memory Computing

Online Data Processing

- Fusion of (NDT) sensor data to improve the information base
- Implementation of standard and **AI** algorithm in hardware accelerators

Intelligent Sensor Networks

- Auto- adaptive und self-learning
- Links and combine (NDT) Sensors with meta- and process data from machine- and environment data
- Data source for IoT & Industry 4.0

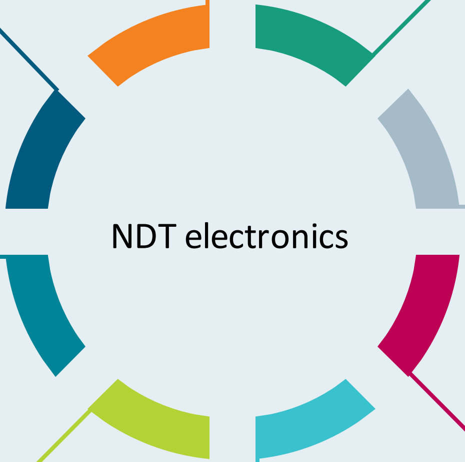
Complex, self-sufficient IoT-Devices

- Multimodal & cognitive
- Miniaturized
- Energy and decision self-sufficient
- „plug ‘n‘ play“ connectivity

CoE Sensor-Intelligence and Microelectronics

Edge Computing

Edge Computing



NDT electronics

HVUT

4-channel High Voltage Ultrasound

(SHD)

IUSE

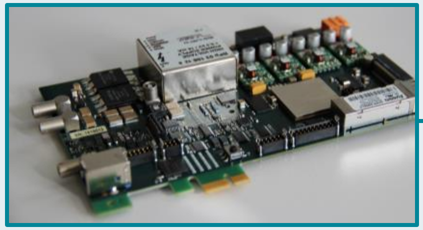
16-channel

Piezo-Ultrasound (UT)

EMUS 4K

4-channel

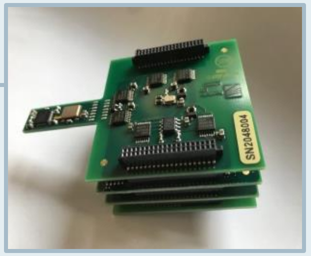
Electromagnetic Ultrasound (EMAT)



UNIUS

1-channel

Piezo-Ultrasound (UT)



MAUS

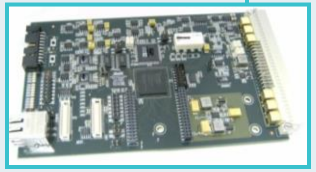
Modular sensor platform for

rapid prototyping

inspECT-PRO

2-channel High Frequency

Eddy-Current Testing (ET)



inspECT

1-Channel

Eddy Current Testing (ET)

Different other platforms

…

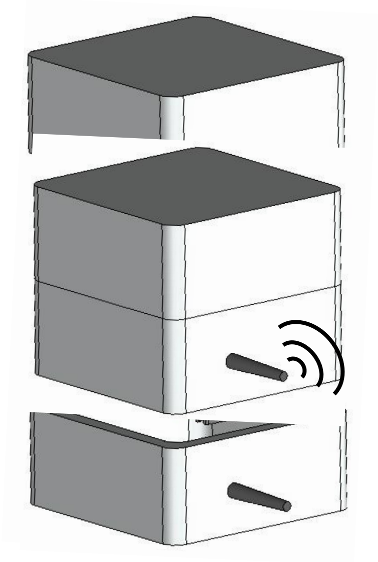
CoE Sensor-Intelligence and Microelectronics

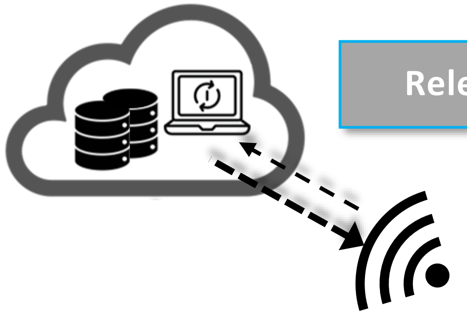
Multimodal autonomous sensor platform - MAUS

Complex, self-sufficient
IoT-Devices

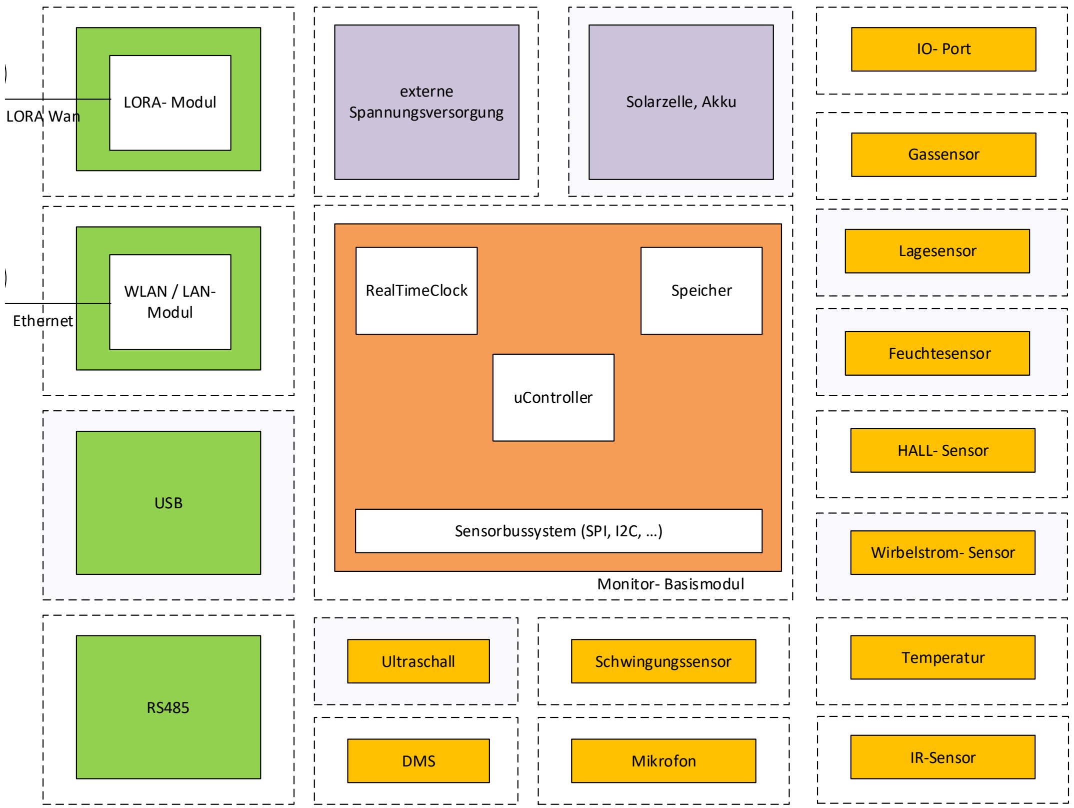
<u>Mission:</u> Fast market access with customized multimodal NDT monitoring systems for the IoT world

Solution → Modular platform concept





Relevant Informations -> Cloud



LORA Wan
LORA- Modul
externe Spannungsversorgung
Solarzelle, Akku
IO- Port
Gassensor
Ethernet
WLAN / LAN-Modul
RealTimeClock
Speicher
uController
Sensorbussystem (SPI, I2C, ...)
Monitor- Basismodul
Lagesensor
Feuchtesensor
HALL- Sensor
Wirbelstrom- Sensor
USB
RS485
Ultraschall
Schwingungssensor
Temperatur
DMS
Mikrofon
IR-Sensor

CoE Sensor-Intelligence and Microelectronics

Rapid Prototyping

Complex, self-sufficient
IoT-Devices

Specification

- Application analysis
- Implementation concept

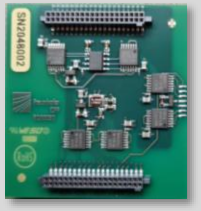
Problem-specific development / customization

- Hardware specification
- Development and assembly

Prototype / small batch

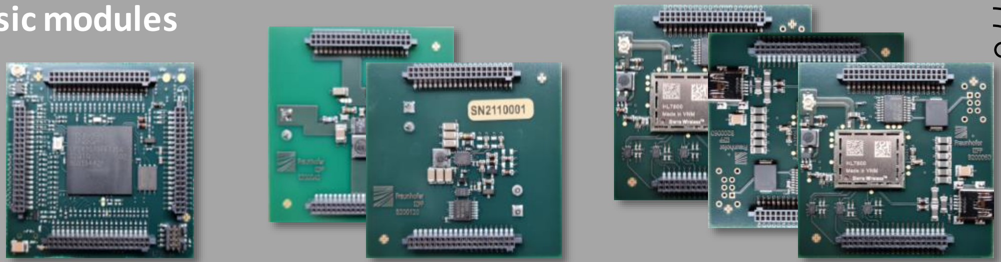
- Assembly
- System test
- Validation

Environmental
Vibration
Acoustics
Ultrasound
Eddy current
…



Sensor modul

Basic modules



Processing-Unit

Power-Modul

Communication-Modul

CoE Sensor-Intelligence and Microelectronics

Electronics manufacturing technologies

SMD assembly Line

Solder paste printer & SMD assembly

Soldering temp.: 210°C

Soldering temp.: 155°C

Vapor phase soldering systems

AME
Dragonfly IV

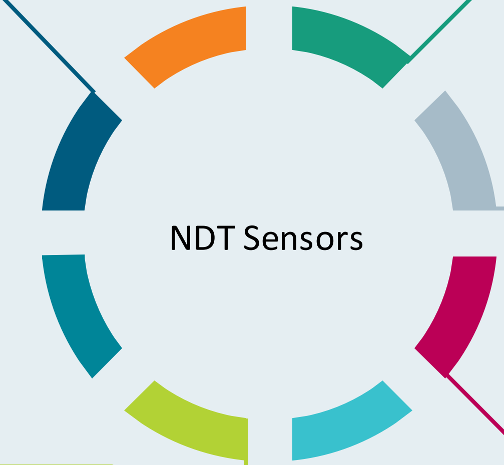
CoE Sensor-Intelligence and Microelectronics

IZFP sensor development

Edge Computing

Piezo electric ultrasound transducer

(Air-, water-coupled; singel-channel or phased array; defect detection, surface hardness depth)

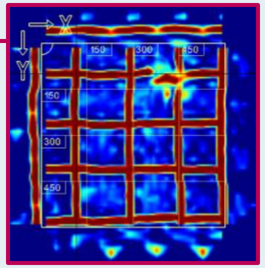


NDT Sensors

(Micro-) Magnetic sensors

Micro- and macroscopic sensors

Electro magnetic ultrasound (EMAT) Ultrasonic testing without coupling agent

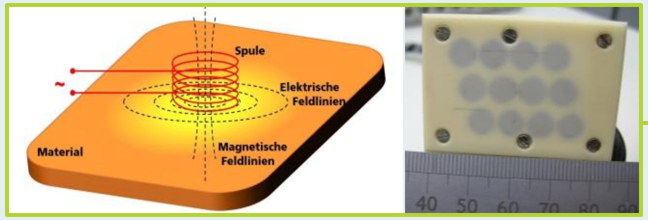


Radar- & Terahertz-Sensors

for infrastructure monitoring

Eddy current

High freq. eddy-current, Sensor-arrays customized sensors,…)

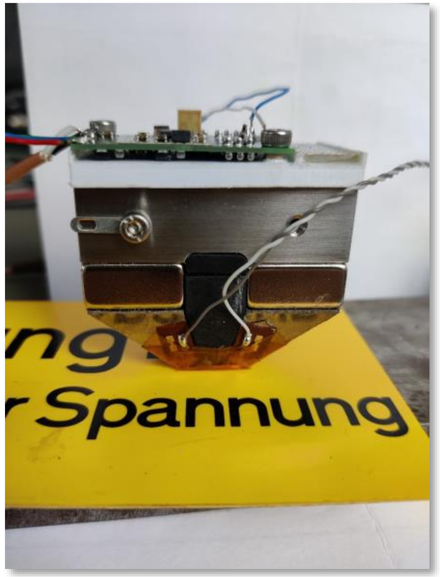


CoE Sensor-Intelligence and Microelectronics

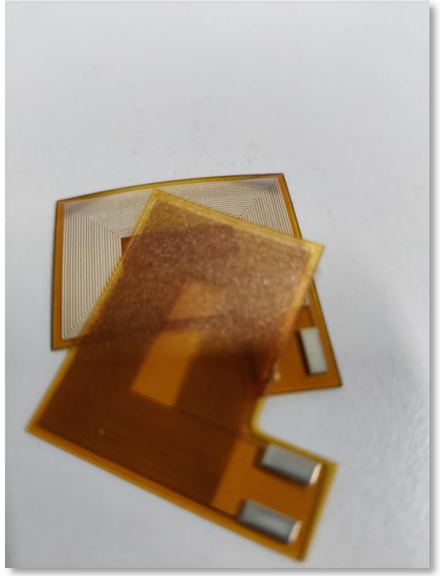
NDT Sensor Design

Electromagnetic ultrasound transmitter (EMAT)

Current EMAT sensor housing



Current EMAT sensor inner circuits



First EMAT Coils manufactured with DaragonFly IV

Benefits using AME:

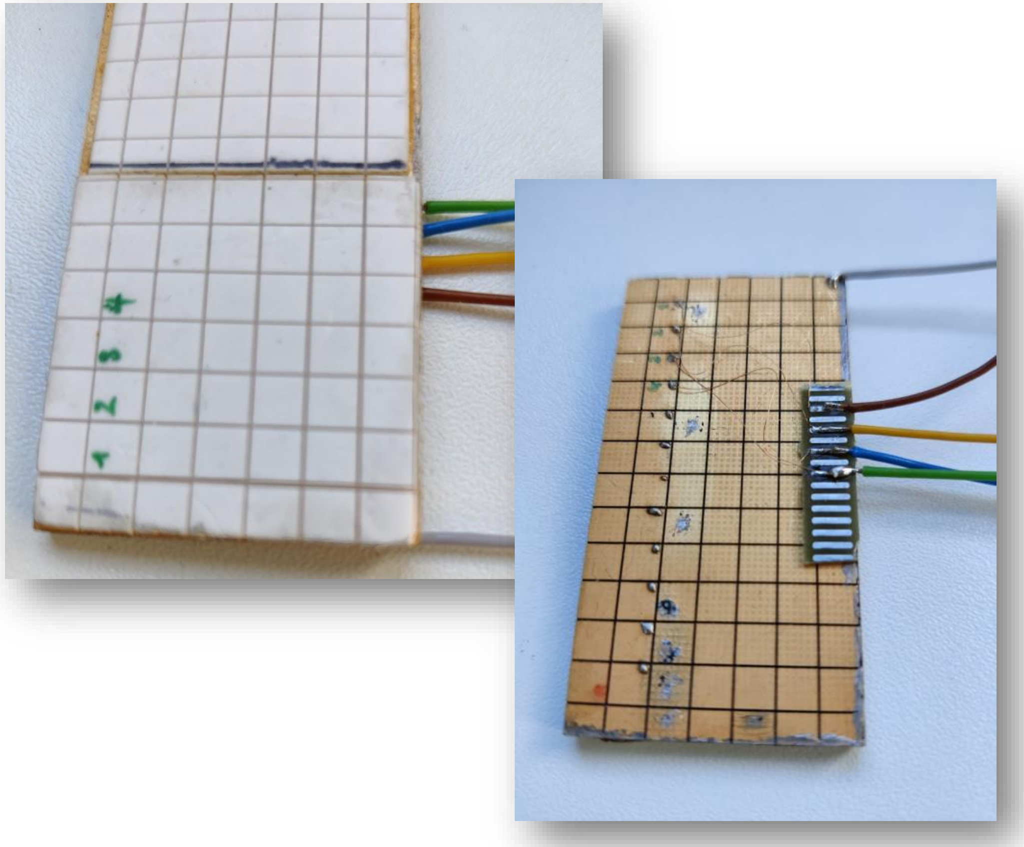
- Increase reproducibility of coil structures
- Higher levels of integration
  → pre-amp attached to coil
  → Better signal to noise ratio
- New 3D coil structures

CoE Sensor-Intelligence and Microelectronics

NDT Sensor Design

Edge Computing

Piezo electric ultrasound



Benefits using AME with Piezo electric transducers:

- AME directly attached to the transducer
  - Bonding technology
    - Higher signal quality (routes, impedance control)
    - Smaller pitch

  - Higher levels of integration
    - Transmitter circuits directly on ceramic
    - Receiver pre-amplifiers directly on ceramic

      → Better signal to noise ratio

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NDT Sensor Design

Edge Computing

Micromagnetic sensors (e.g. material characterization)

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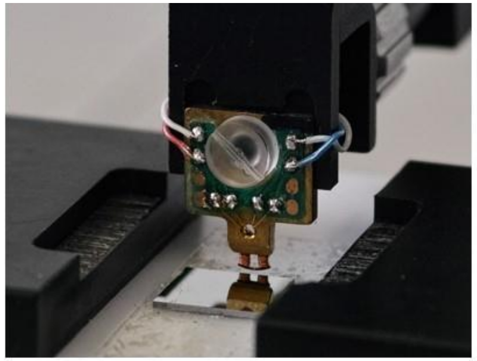
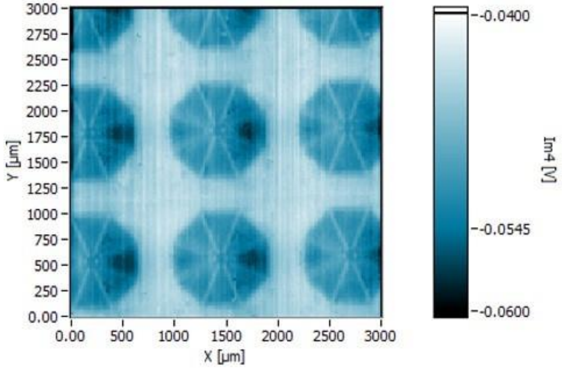


Wafer with GMR sensors



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Benefits using AME:

- Miniaturization
- New coil structures
- Availability and no supply chain

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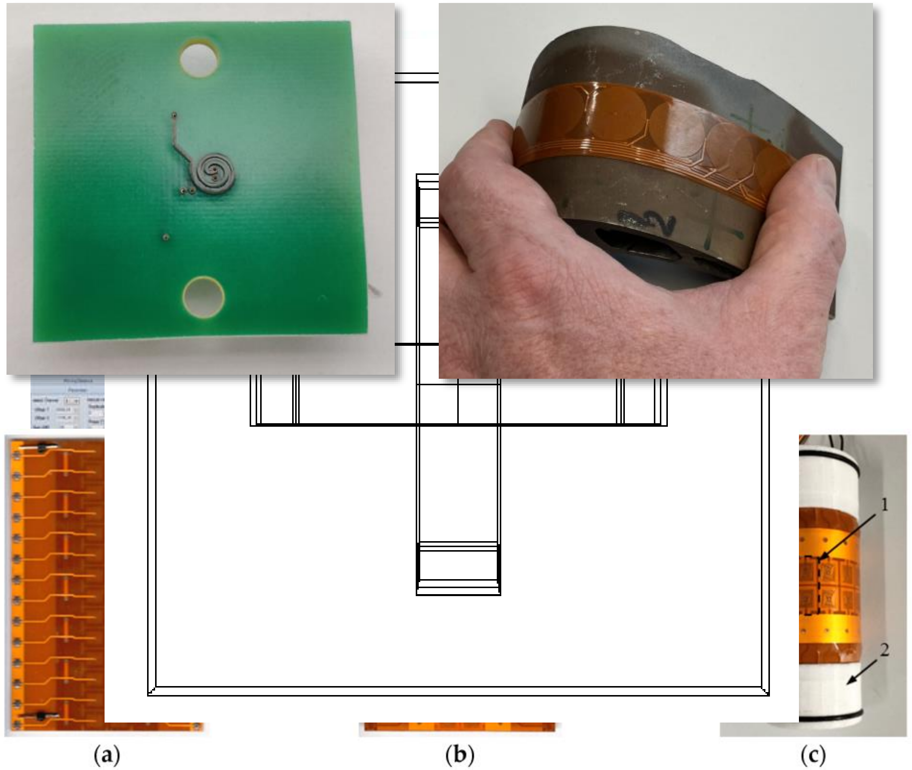
CoE Sensor-Intelligence and Microelectronics

NDT Sensor Design

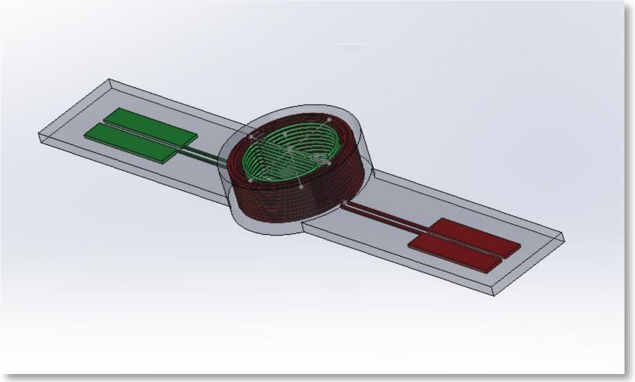
Edge Computing

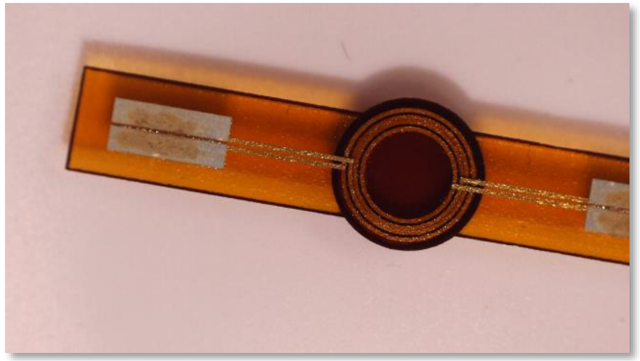
Eddy current sensor coils



A Flexible Arrayed Eddy Current Sensor for Inspection of Hollow Axle Inner Surfaces by Zhenguo Sun, Dong Cai, Cheng Zou, Wenzeng Zhang and Qiang Chen

Evaluation software





Benefits using AME:

- Increase reproducibility of coil structures.
- Better correlation between simulation and physical coil

- New 3D coil structures
    - Field-forming
    - Curved surfaces
      (e.g. turbine blade)

- Higher levels of integration
  → pre-amps, multiplexers as close as possible to the receiver

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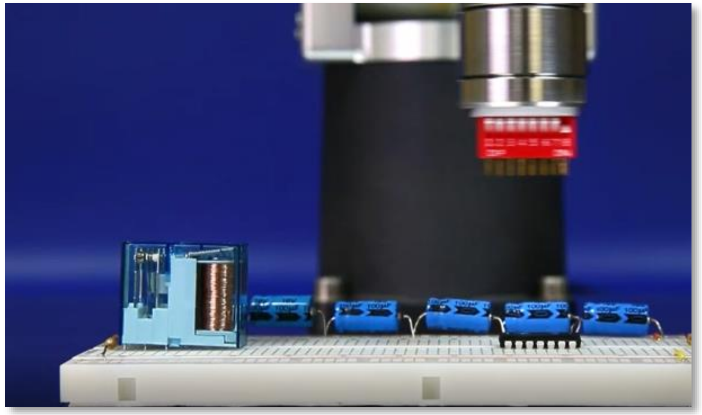
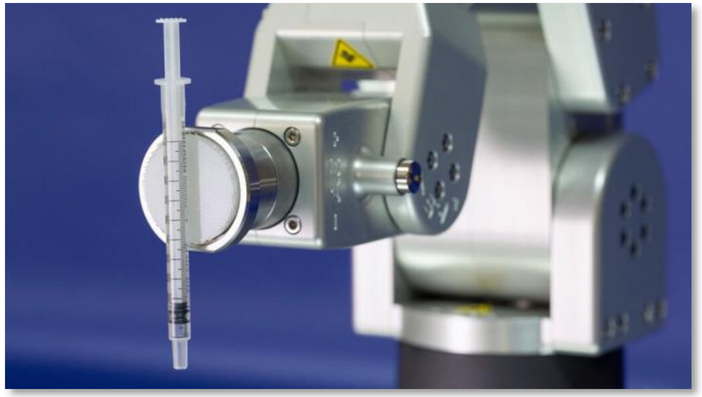
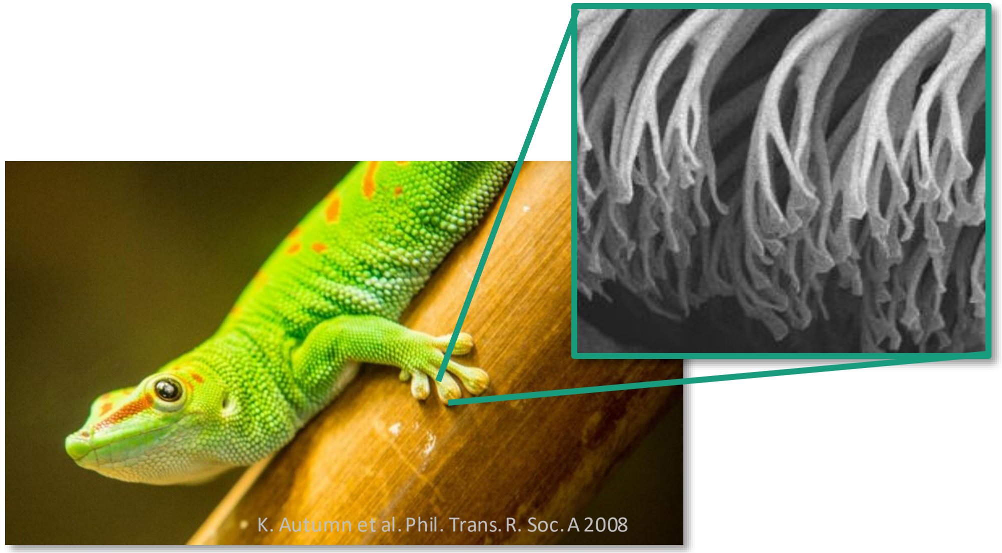
Project with AME potential - GecKi

Edge Computing







K. Autumn et al. Phil. Trans. R. Soc. A 2008

© Pictures: Innocise

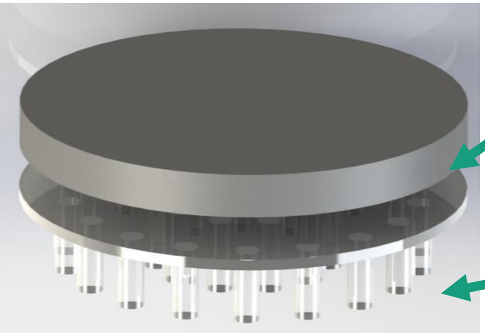
CoE Sensor-Intelligence and Microelectronics

NDT Sensor Design

Edge Computing

GecKi - Eddy current alignment and force measuring system

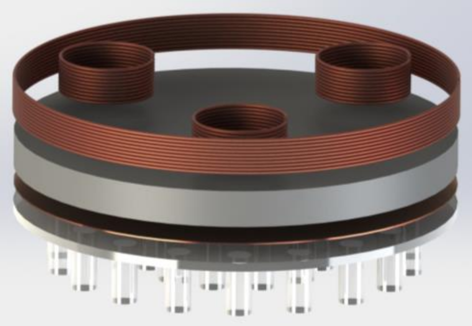
Setup without sensors



foam

adhesive structure

Setup with IZFP-sensors



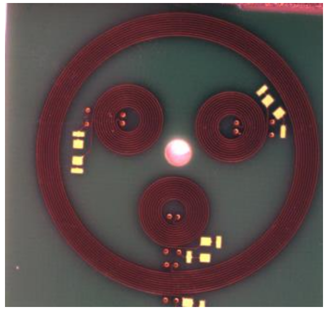
coil-system

foam

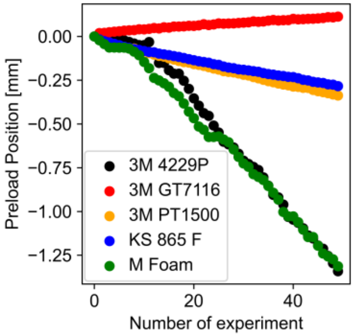
Target material

adhesive structure

v.1.0 Coil System:



foam:



Target material:

adhesive structure:

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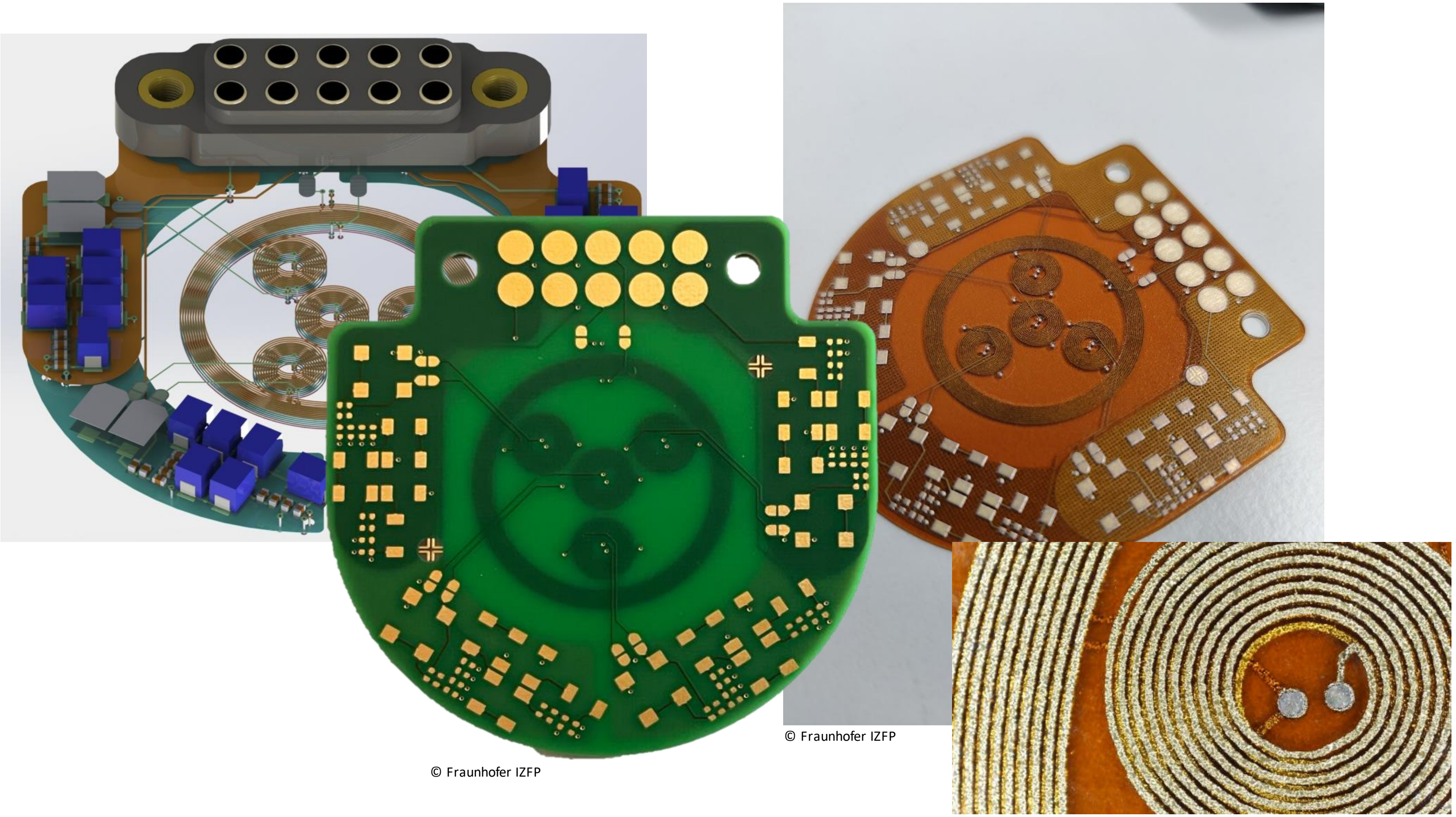
NDT Sensor Design

Edge Computing

GecKi - Eddy current distance and force measuring system



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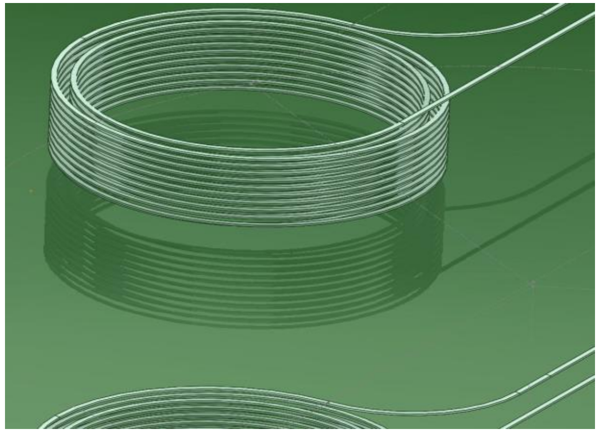
Potential steps using AME:

- Use of 3D- Coils
  (no vias, different geometries)
- Use of Meta Material (in future)



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Thank you for your attention

Let's stay in touch!

philipp.stopp@izfp.fraunhofer.de
www.izfp.fraunhofer.de

AME User Forum

EMEA - 2023

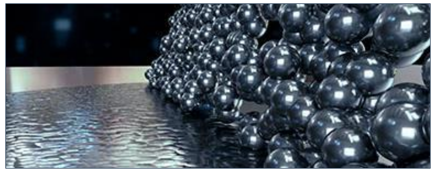
Additive Manufacturing, Driving Industry 4.0

Additive Manufacturing

DragonFly IV
Additively Manufactured
Electronics

Fabrica 2.0
Micro AM

Admatec
Ceramic and Metal AM



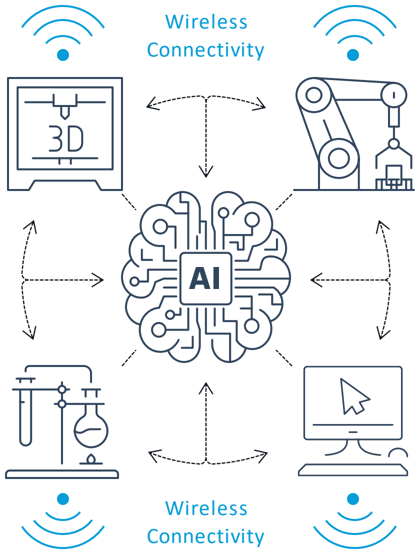
Conductive and Dielectric Inks

Ceramic

Polymer

Metal

Advanced Materials & Processes



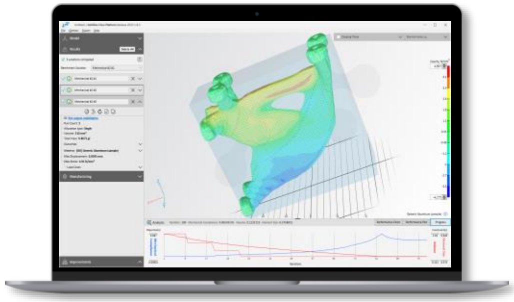
DeepCube
Deep Learning
Based AI Platform

Robotics

SMT Suite of Products
Surface Mount Technology
for Electronics

Digital Printing Platform
Printer control systems and software

FLIGHT Hub & Control
Design-to-Manufacturing
Testing, simulation, and management



Additive Flow
Multi-Material Topology Optimization
for AM, AME and Volumetric Manufacturing

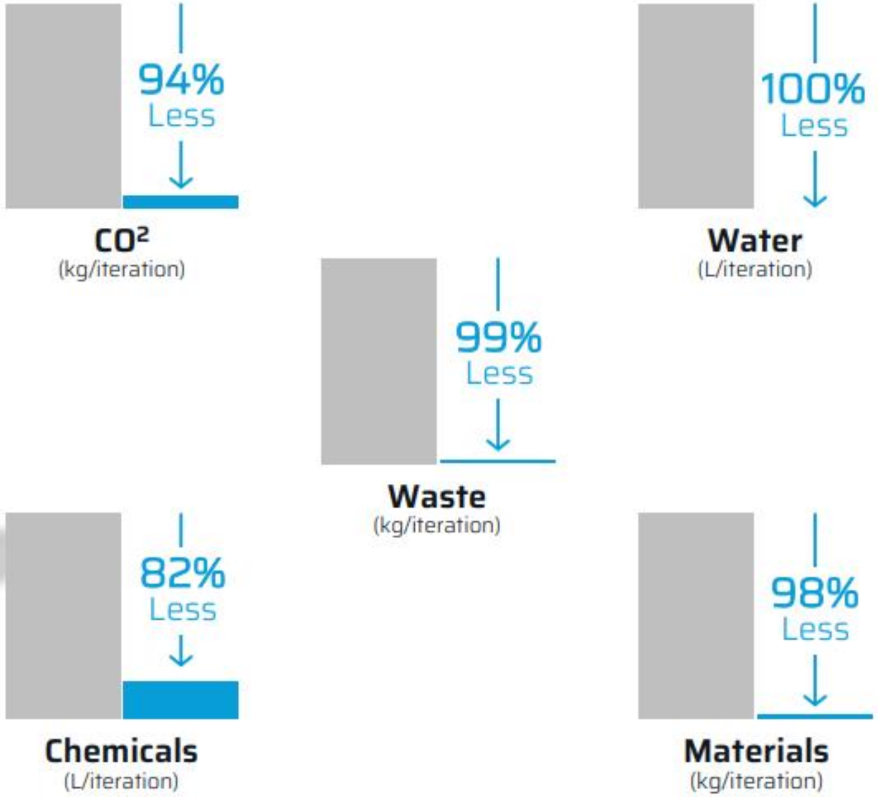
Software

Building a Sustainable Future

Traditional manufacturing vs sustainable additive solutions

Before

After

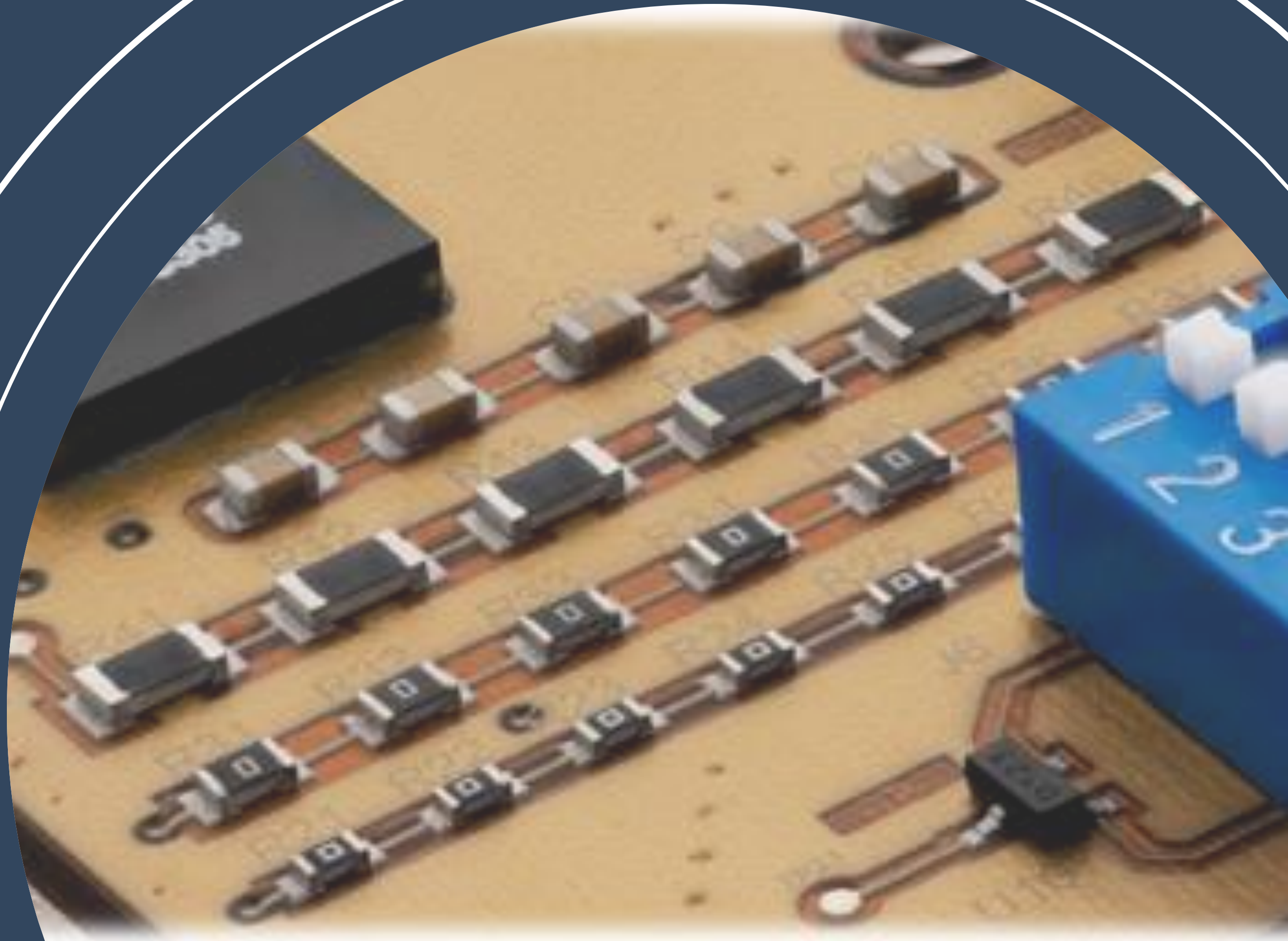


1 Based on a 2021 study by HSSMI, a UK based sustainability consultant

NANODIMENSION

AME Materials

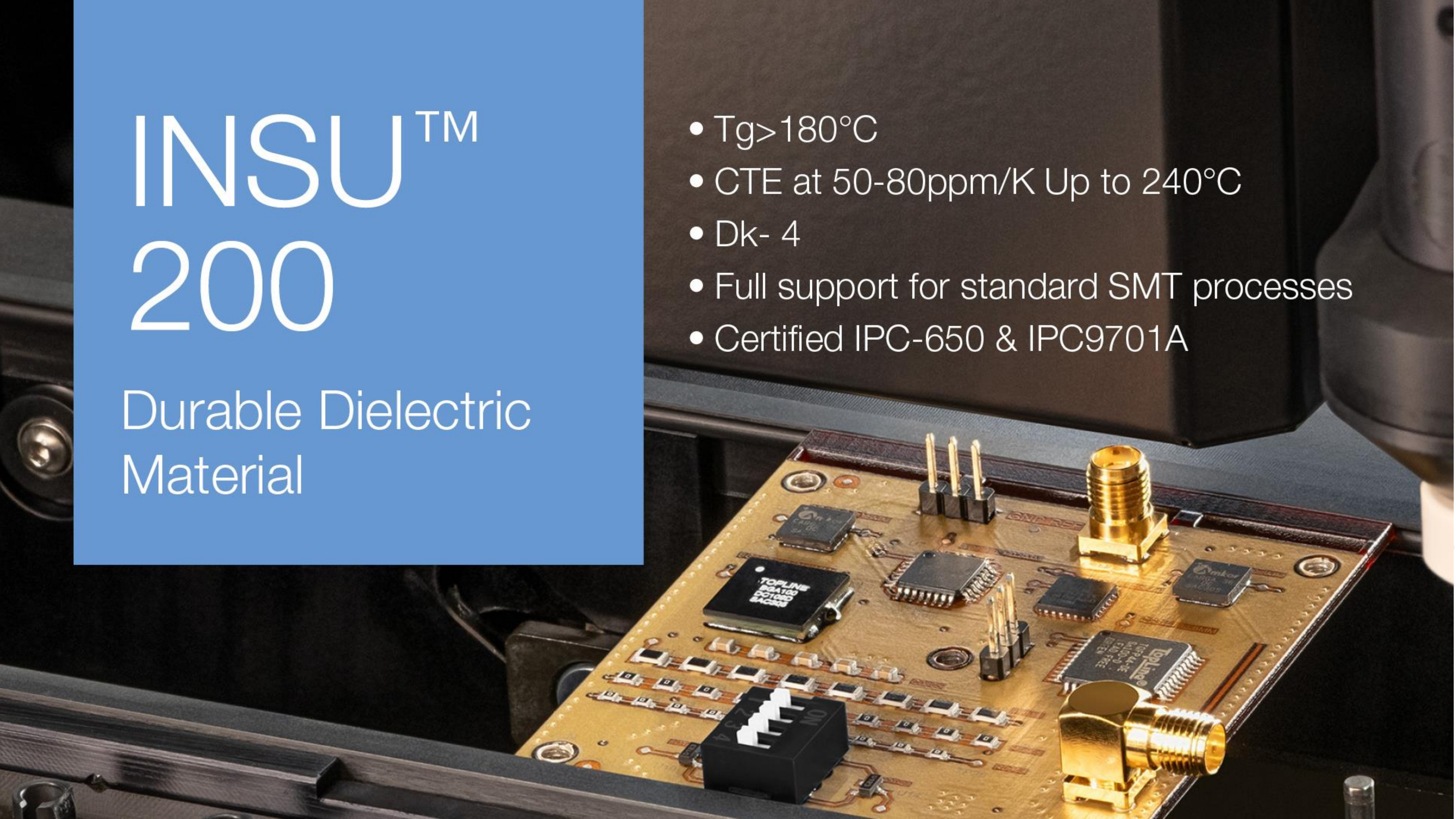
New Product Introduction



INSU™ 200

Durable Dielectric Material

- Tg>180°C
- CTE at 50-80ppm/K Up to 240°C
- Dk- 4
- Full support for standard SMT processes
- Certified IPC-650 & IPC9701A



INSU200 - Material Properties

High temperature

Tg>180°C

CTE at 50-80ppm/K up to 240°C

Full support for standard SMT processes

Durability

Impact strength >200 J/m

Flexural strength ~160 Mpa

Resistance to mechanical shock & vibrations

Reliability Standards

Certified IPC-650 & IPC-9701

Complies thermal reliability standards of bare (IST & HATS) and assembly boards from 0°C to 70 °C

Complies vibration tests after assembly

Tg (Glass Transition Temperature) - temperature at which material changes from hard/glassy state to soft state

CTE (Coefficient of Thermal Expansion) - the rate at which a material expands with increase *(at a given)* in temperature

IPC 650 – Test method to determine the Tg of dielectric materials used in printed boards by differential scanning calorimetry (DSC)

IPC 9701 – Thermal Cycling Test Method for Fatigue Life Characterization of Surface Mount Attachments

INSU™200

Durable Dielectric Material

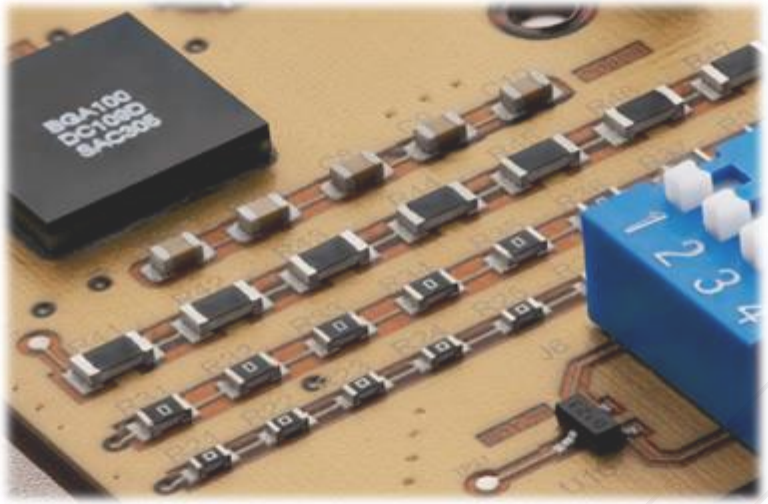
	FR4	**INSU200**
tg (°C)	150-170	180-220
CTE(ppm/K)	*20-60 <Tg 230-250>Tg	50-80 up to 240°C
DK (1Hz-66GHz)	4	4
Df (1Hz-66GHz)	0.01	0.01-0.03

*Measured on z axis

Standard SMT

Support of ROHS compliant reflow soldering processes enhances AME solution for PCB prototyping

- ❖ Sensitivity with reflow temperatures has been a significant challenge for AME users
- ❖ With INSU200, our customers can now use standard SMT processes for soldering of active and passive components (including BGAs)



INSU200 Dielectric Properties

Mapping of D_k/D_f values for frequencies up to 65GHz

Frequency	1GHz	2.5GHz	5GHz	7.5GHz	10GHz	30GHz	40GHz	50GHz	65GHz
Dielectric Constant (D_k)	4.07	4.02	3.98	3.86	3.78	3.70	3.69	3.65	3.60
Tangential Loss (D_f)	0.018	0.019	0.018	0.016	0.014	0.013	0.016	0.015	0.014

FLIGHT Software

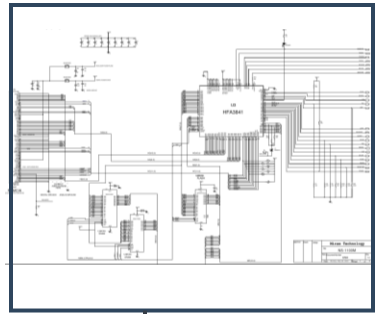
New Product Introduction

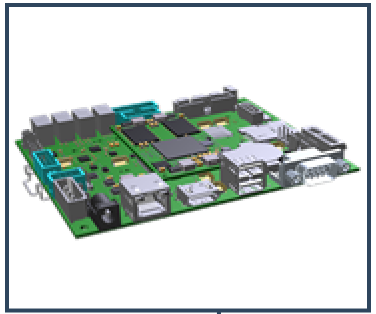
FLIGHT Software Suite

NANODIMENSION
Electrifying Additive Manufacturing

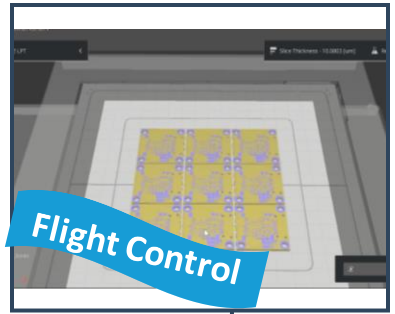
Software-fueled agile hardware development

Schematics Design → **Layout Design** → **Digital Manufacturing** → **Manufacturing**





ECAD



FLIGHT SUITE

Printer UI & OS

DF OS

1 Design ››› **3-4 weeks**

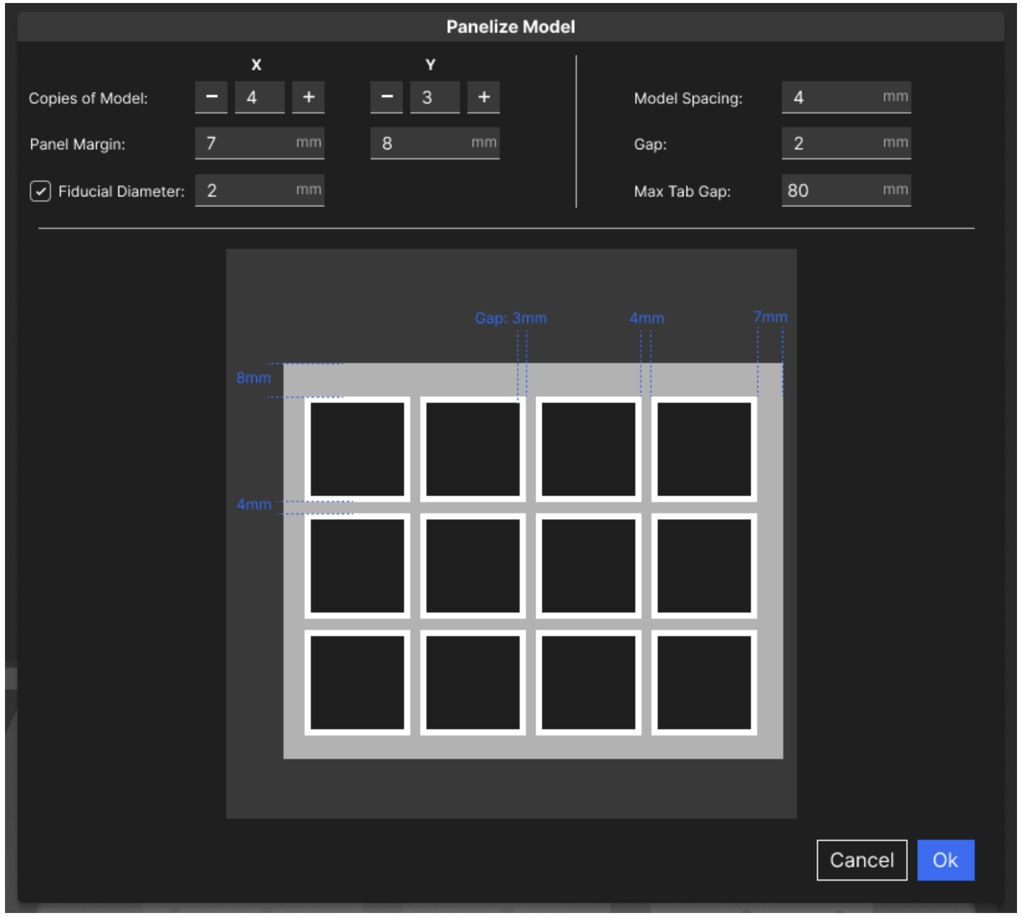
Traditional Manufacturing Process

10 Variations ››› **1-2 Days**

AME Process

Introducing - Automatic Panelization

Parametric panel creation dialogue in FLIGHT Control software



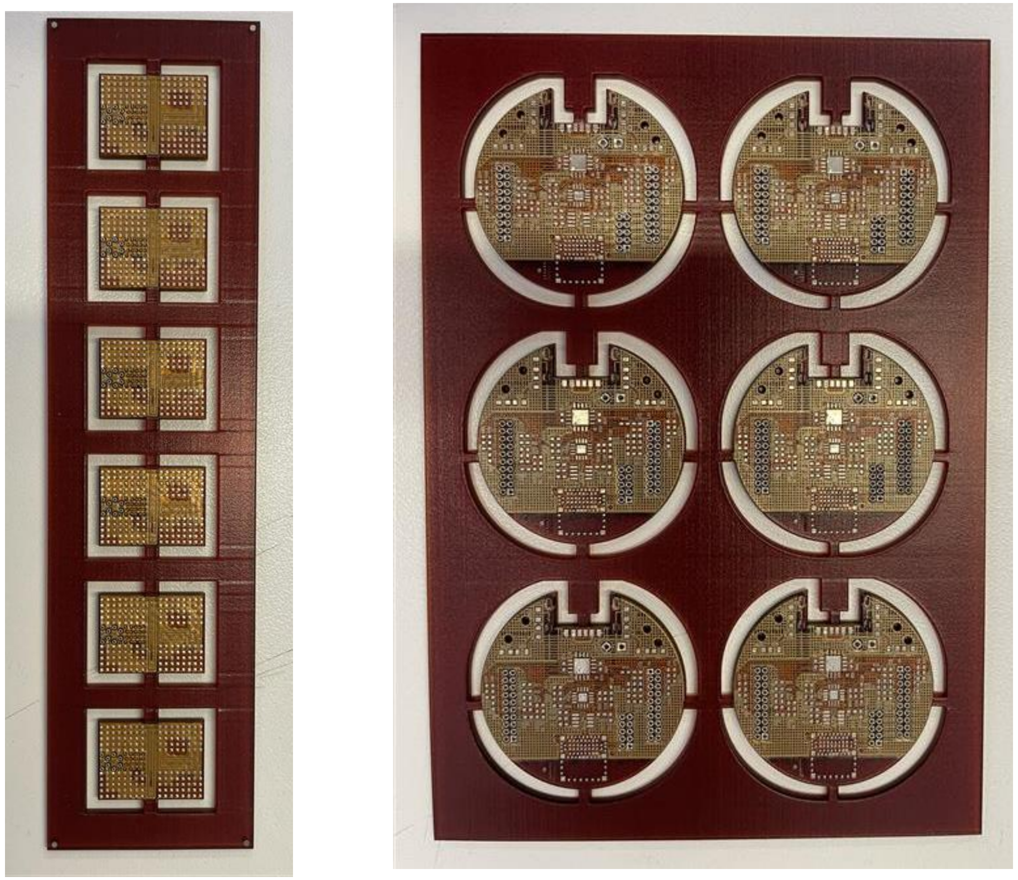
Panelize Model

	X	Y
Copies of Model:	4	3
Panel Margin:	7 mm	8 mm
☑ Fiducial Diameter:	2 mm	

Model Spacing: 4 mm

Gap: 2 mm

Max Tab Gap: 80 mm

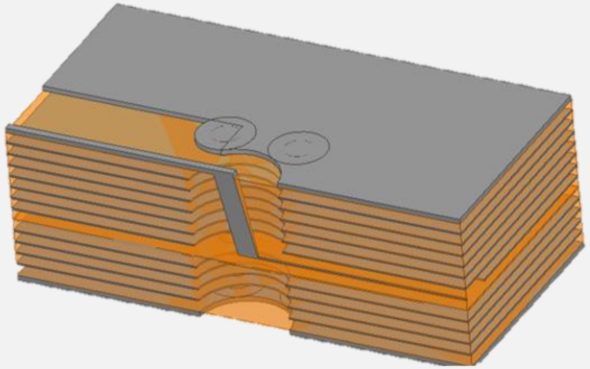


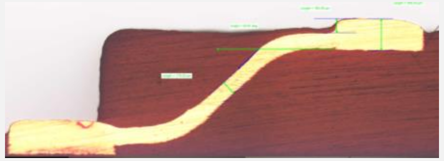
AME: Design in 3 Dimensions

1

3D Traces (3DT)

- Vias eliminated
- Any angle routing
- Low loss
- Improved impedance match

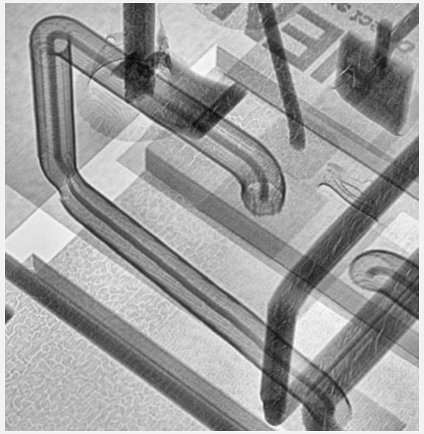




2

Printed Coaxial Line

- Embedded custom shaped (circular, square, rectangular, etc.)
- Reduced EMI
- Better SI (signal integrity)
- Impedance control
- Wider bandwidth



3

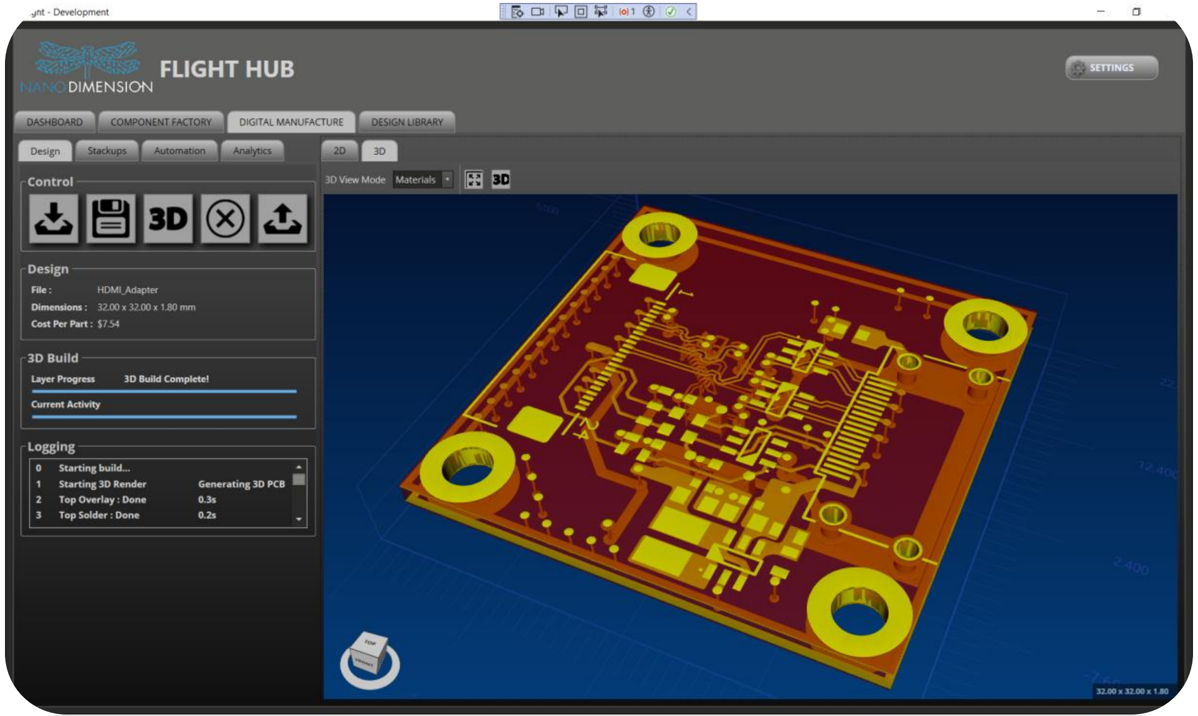
Embedded Twisted Pair

- Reduced EMI
- Improved SI
- Impedance control

Introducing – Flight Hub

Integrated mCAD and eCAD design

- Explore the potential of AME
- Digitally create AME Components
- Integrate AME Components into eCAD workflows
- Export eCAD designs (IPC-2581) to Flight Hub
- Digitally Build, Optimise and Evaluate Designs
- Export to Flight Control for manufacture



Design

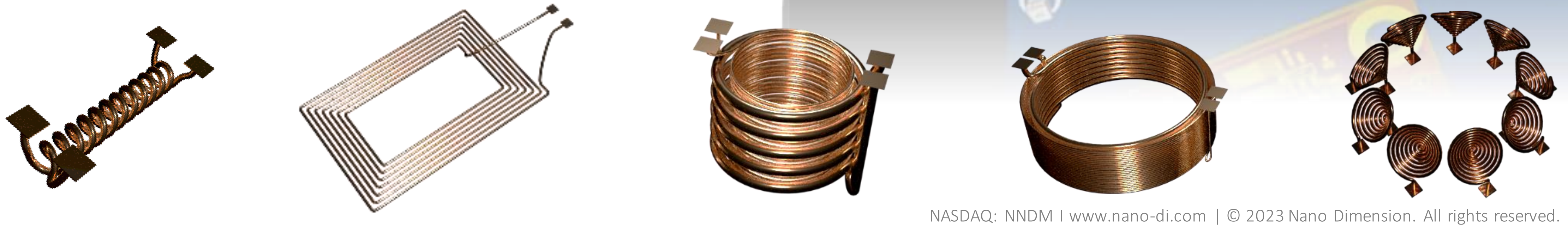
File : HDMI_Adapter
Dimensions : 32.00 x 32.00 x 1.80 mm
Cost Per Part : $7.54

3D Build

Layer Progress **3D Build Complete!**
Current Activity

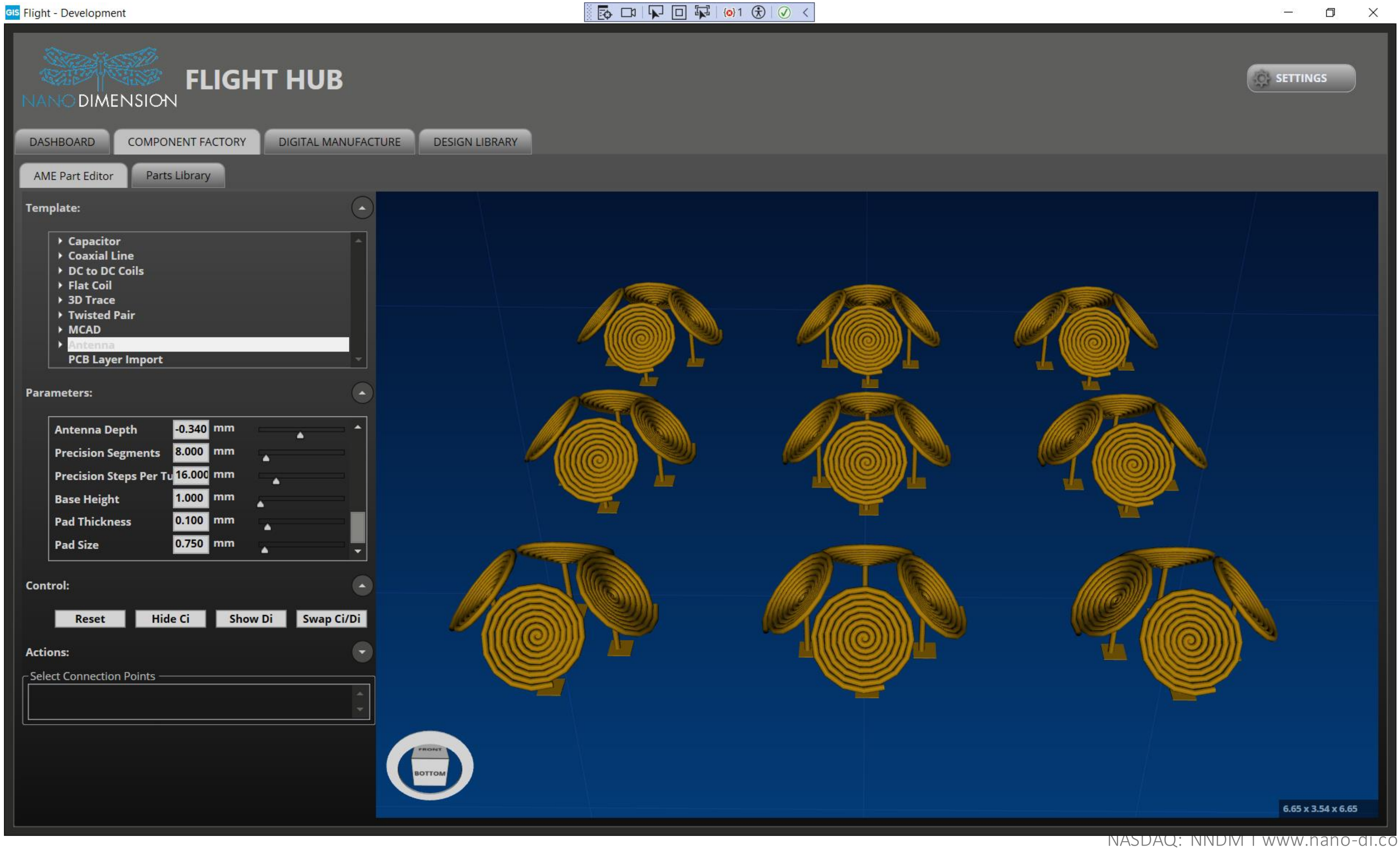
Logging

```
0   Starting build...
1   Starting 3D Render          Generating 3D PCB
2   Top Overlay : Done          0.3s
3   Top Solder : Done           0.2s
```

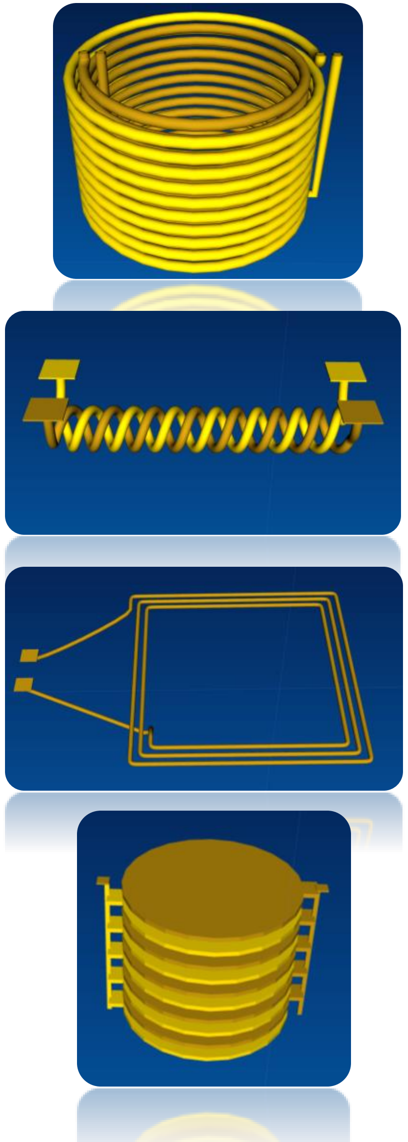


Flight Hub: Component Factory

Parametric 3D Component Generation



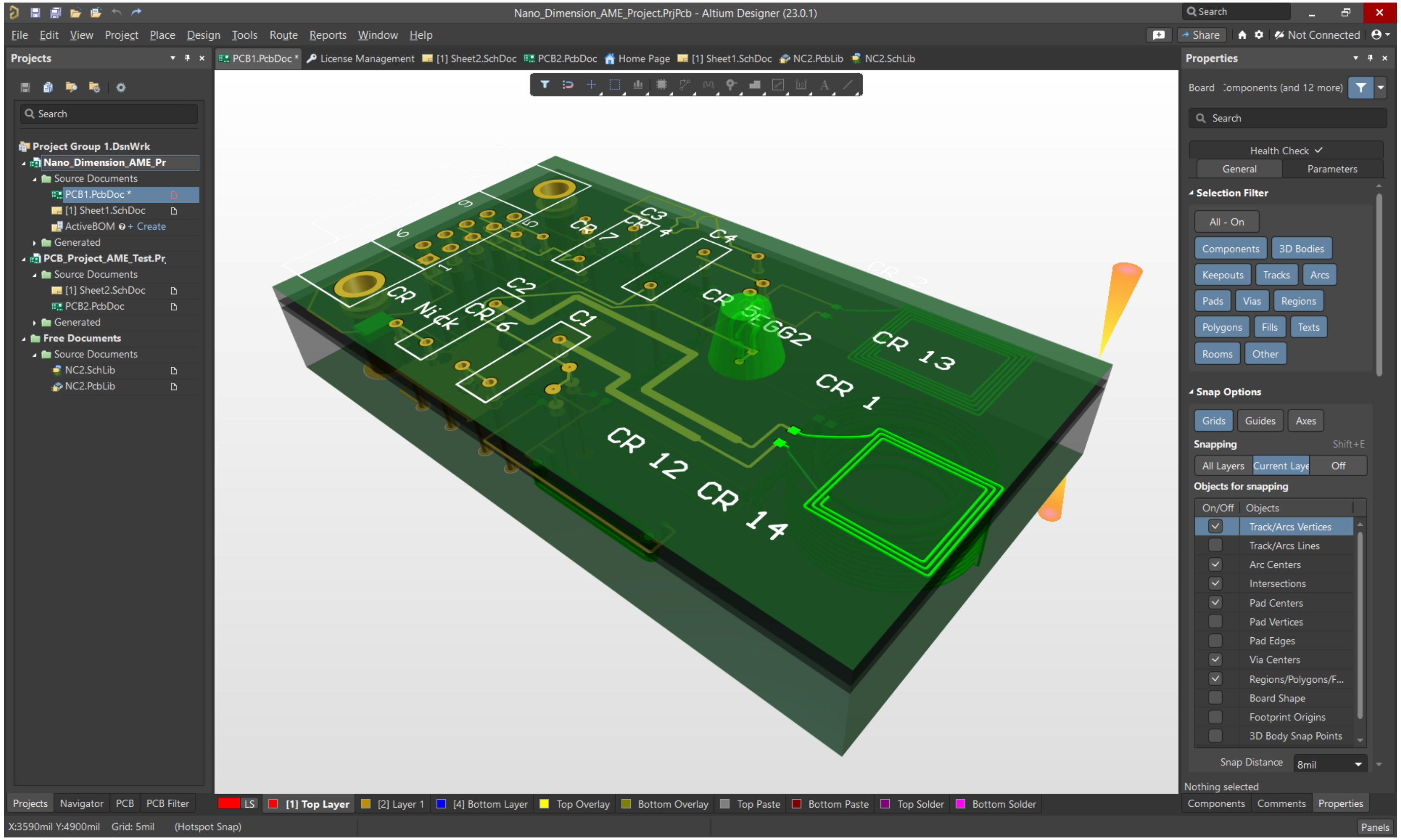
Antenna Depth -0.340 mm
Precision Segments 8.000 mm
Precision Steps Per Tu 16.000 mm
Base Height 1.000 mm
Pad Thickness 0.100 mm
Pad Size 0.750 mm



Flight Hub: eCAD Integration

NANO DIMENSION
Electrifying Additive Manufacturing®

eCAD Workflows with AME Components

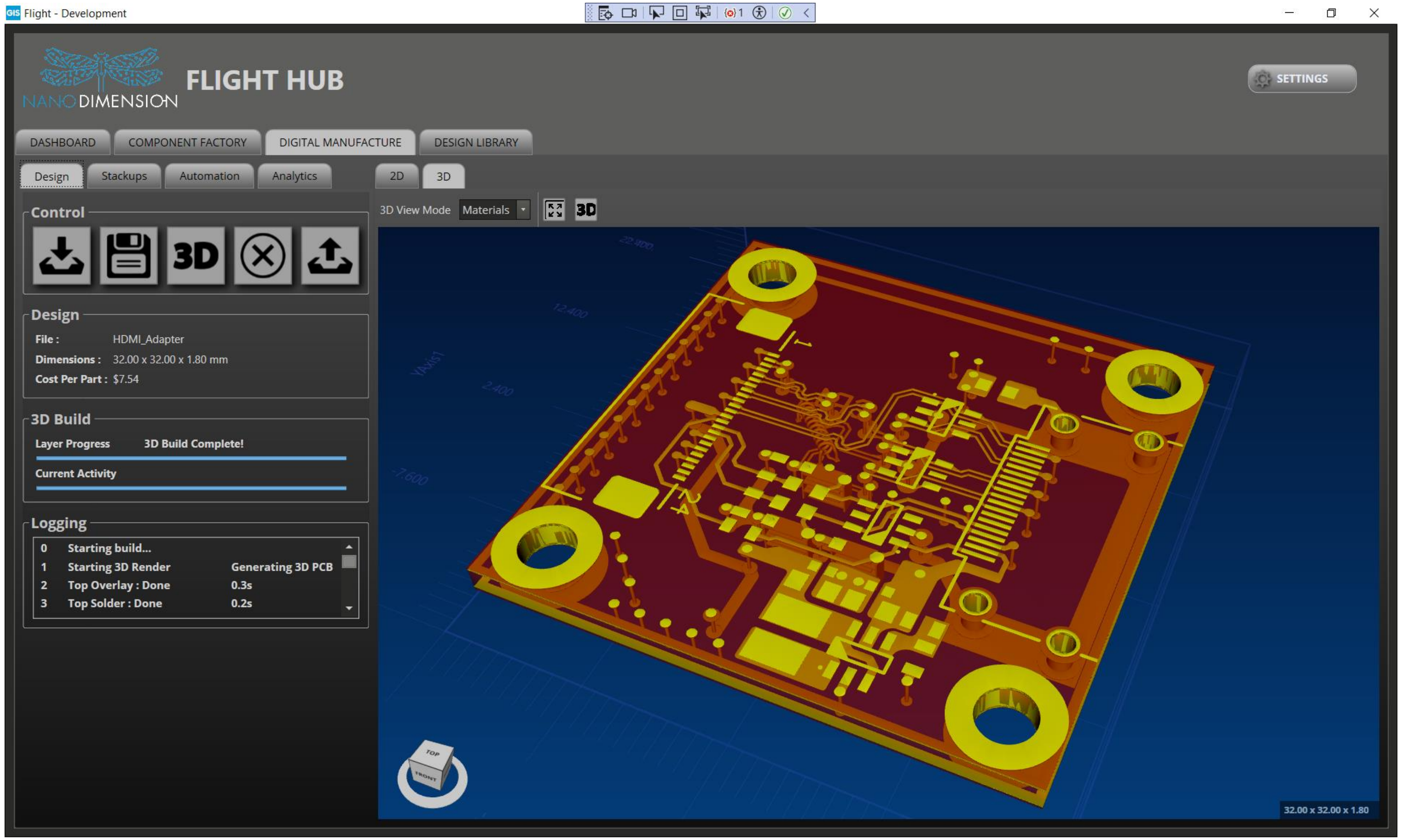


cadence®
Allegro®

ALTIUM
DESIGNER

Flight Hub: Digital Manufacture

Combine eCAD and mCAD into a single design for optimization and analysis



Design

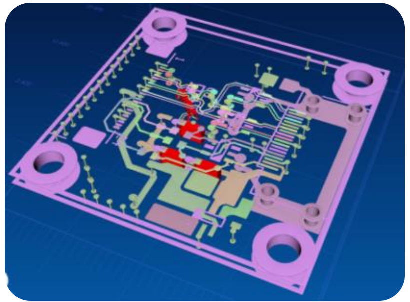
File : HDMI_Adapter
Dimensions : 32.00 x 32.00 x 1.80 mm
Cost Per Part : $7.54

3D Build

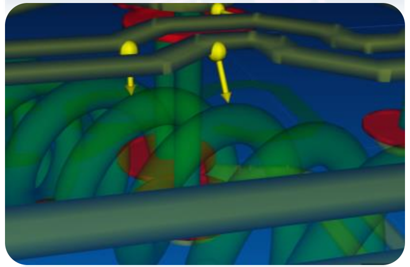
Layer Progress **3D Build Complete!**
Current Activity

Logging

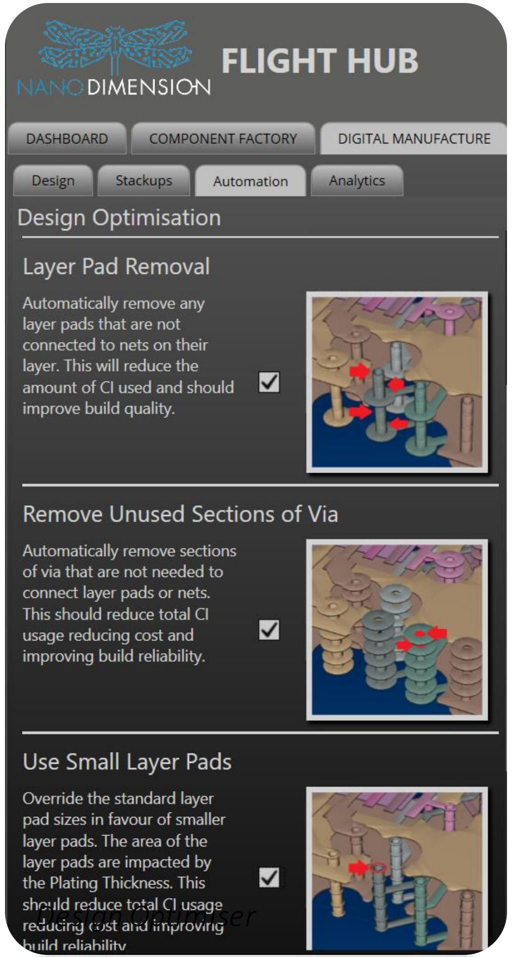
```
0   Starting build...
1   Starting 3D Render        Generating 3D PCB
2   Top Overlay : Done        0.3s
3   Top Solder : Done         0.2s
```



Net List View



Proximity Checker



Design Optimisation

Layer Pad Removal

Automatically remove any layer pads that are not connected to nets on their layer. This will reduce the amount of CI used and should improve build quality. ☑

Remove Unused Sections of Via

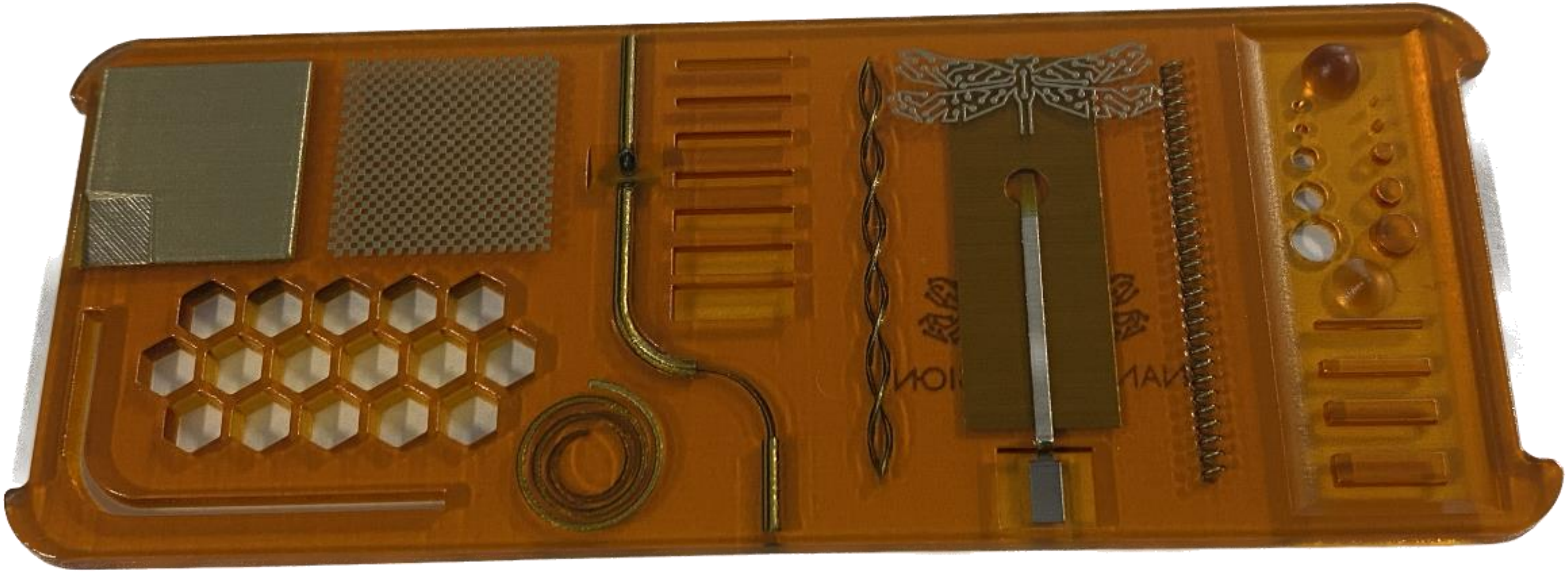
Automatically remove sections of via that are not needed to connect layer pads or nets. This should reduce total CI usage reducing cost and improving build reliability. ☑

Use Small Layer Pads

Override the standard layer pad sizes in favour of smaller layer pads. The area of the layer pads are impacted by the Plating Thickness. This should reduce total CI usage reducing cost and improving build reliability. ☑

Design Optimiser

Flight Hub: Integrated 3D Design



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THANK YOU

Gilad Berenblut | Product Champion

@nanodimensiontech

@3Dpcb

www.nano-di.com

J.A.M.E.S

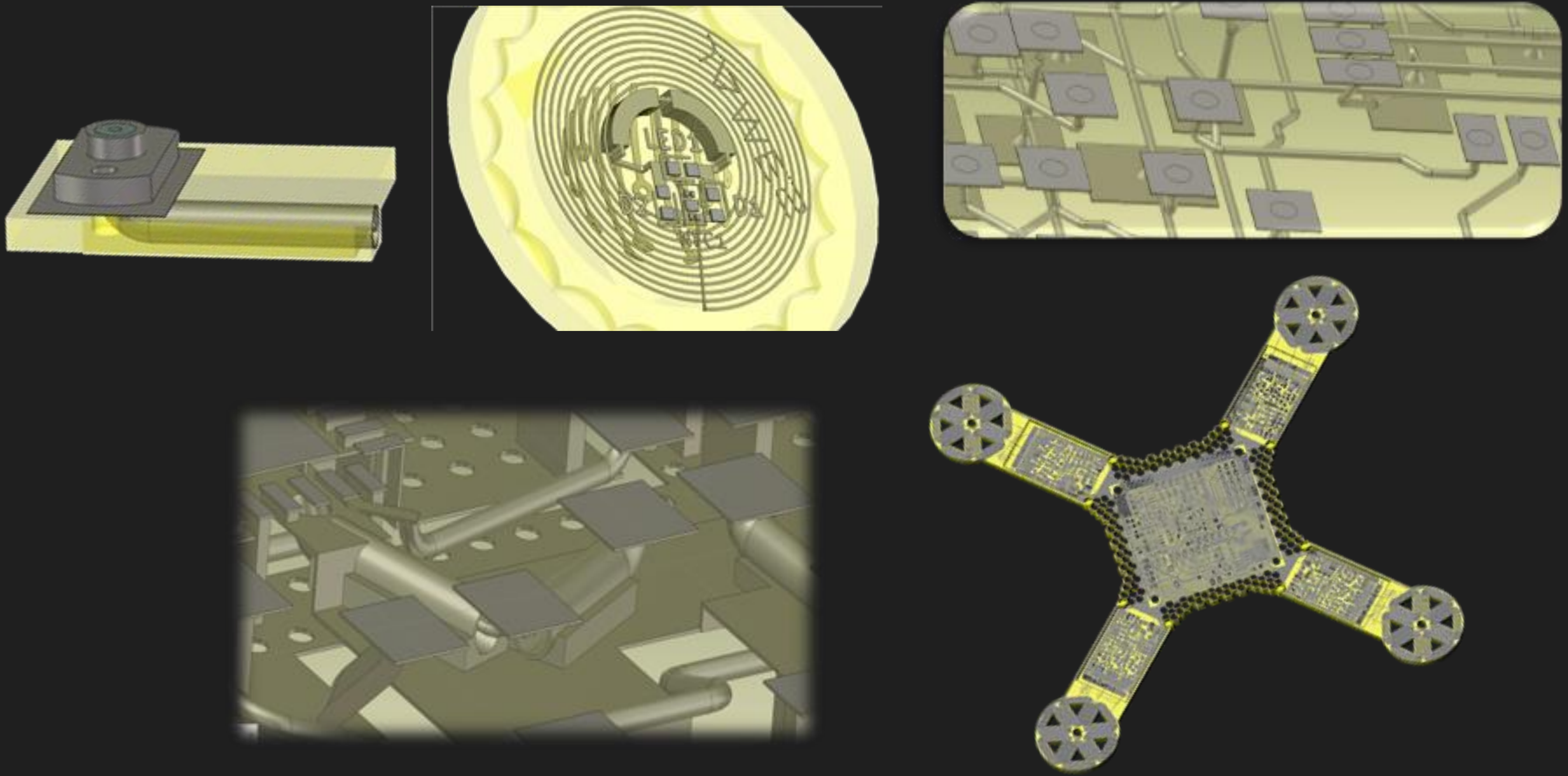
Additively Manufactured Electronics

The Next Level of Electronics Manufacturing

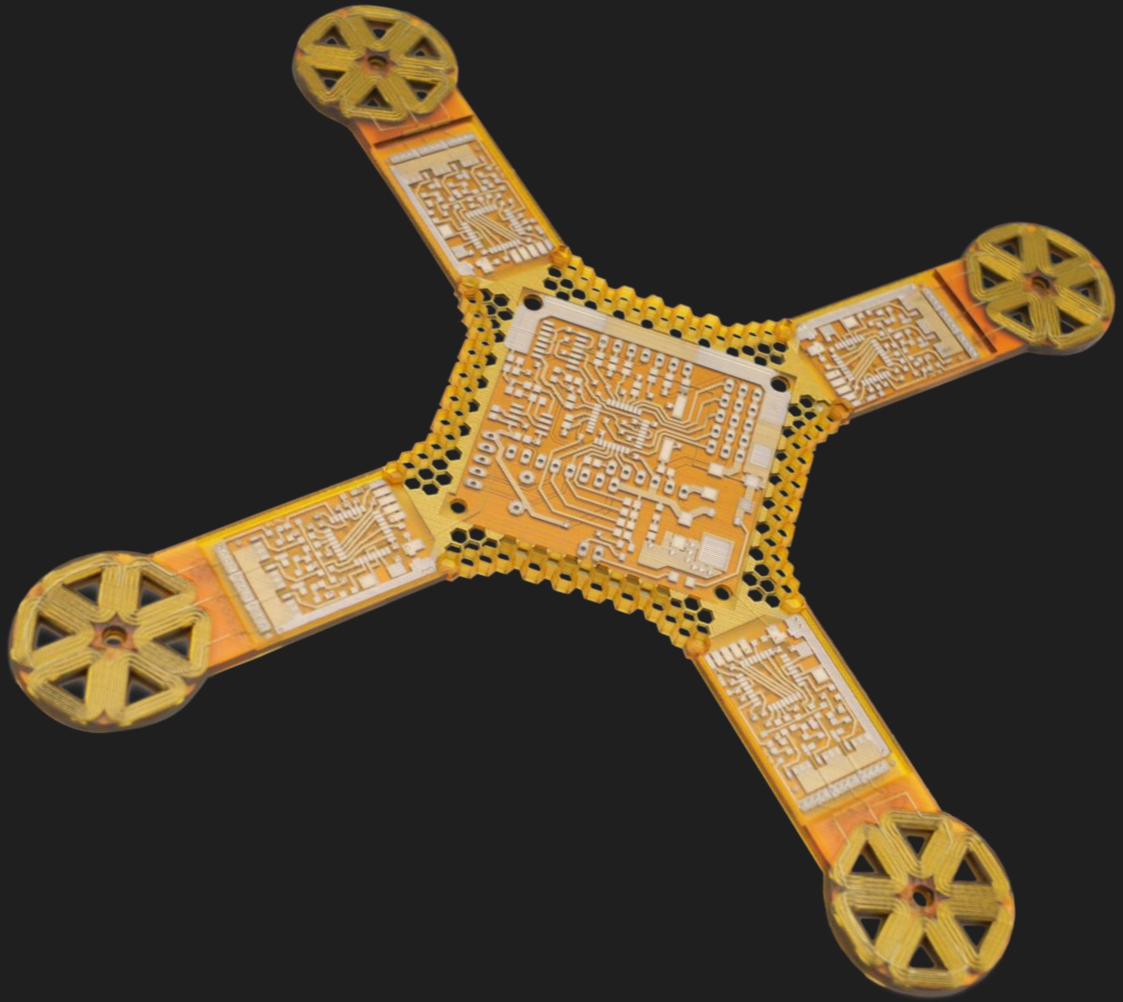
Pascal Fischer
Technical Designer

Benefits of AME

- **Electrical:**
  - Avoid vias
  - Better RF-Performance
  - Higher signal integrity
  - Lower latency
  - No unwanted crosstalk
  - No connectors
- **System:**
  - Lower weight
  - No cable assembly
  - Variable form-factors
  - Individualization
- **Ecological**
- **Logistics**



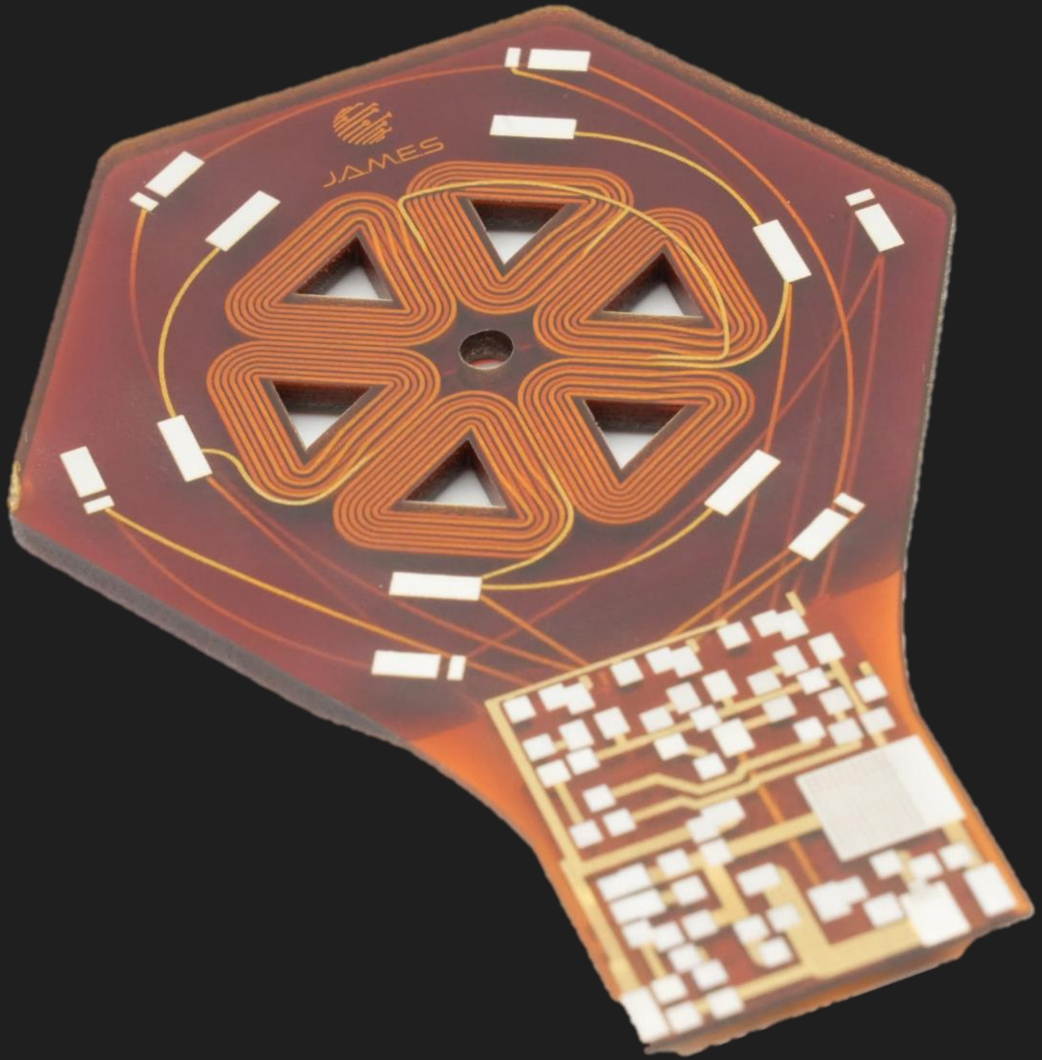
Showcase AME Drone



New way of electronics design

- Reduce assembly effort
- Avoid connectors and cables
- Optimize overall shape
- Reduce weight

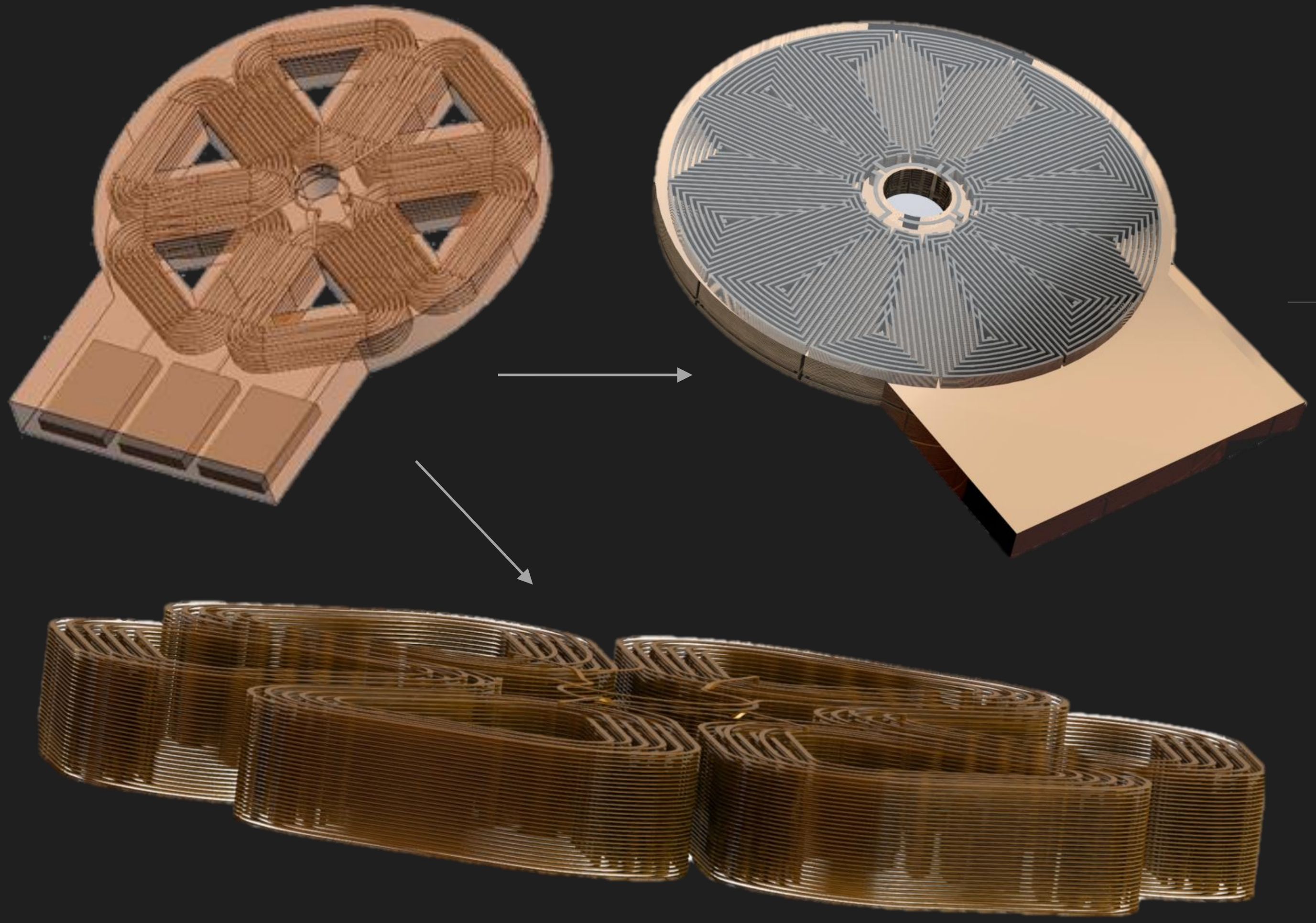
First Step



Improvements

- Direct cooling of high-power components
- Reduced weight avoid connectors and cables
- Increased mechanical stability

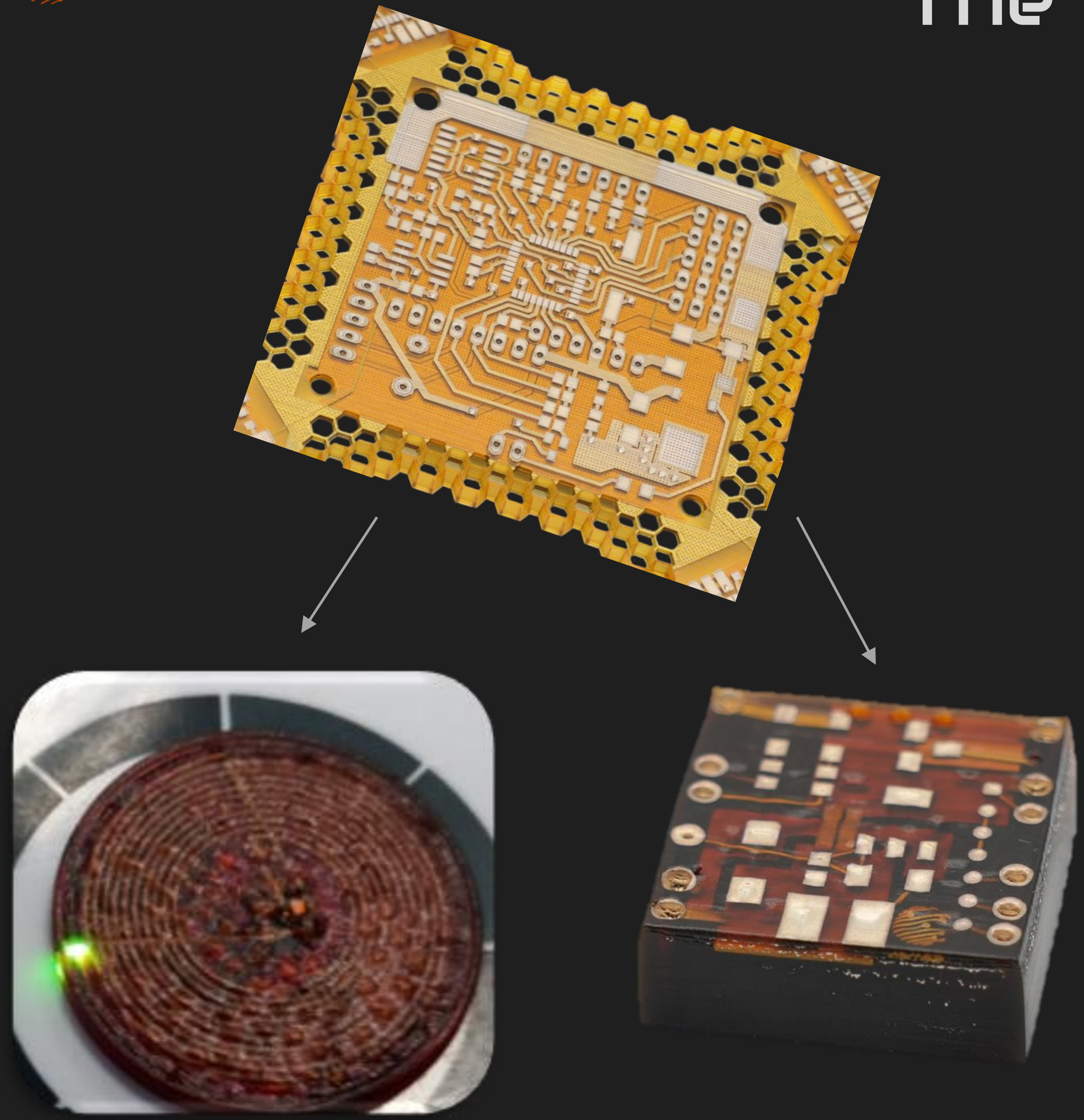
The way ahead



Improve the motor design

- Increase magnetic field
- Arbitrary shaped coils

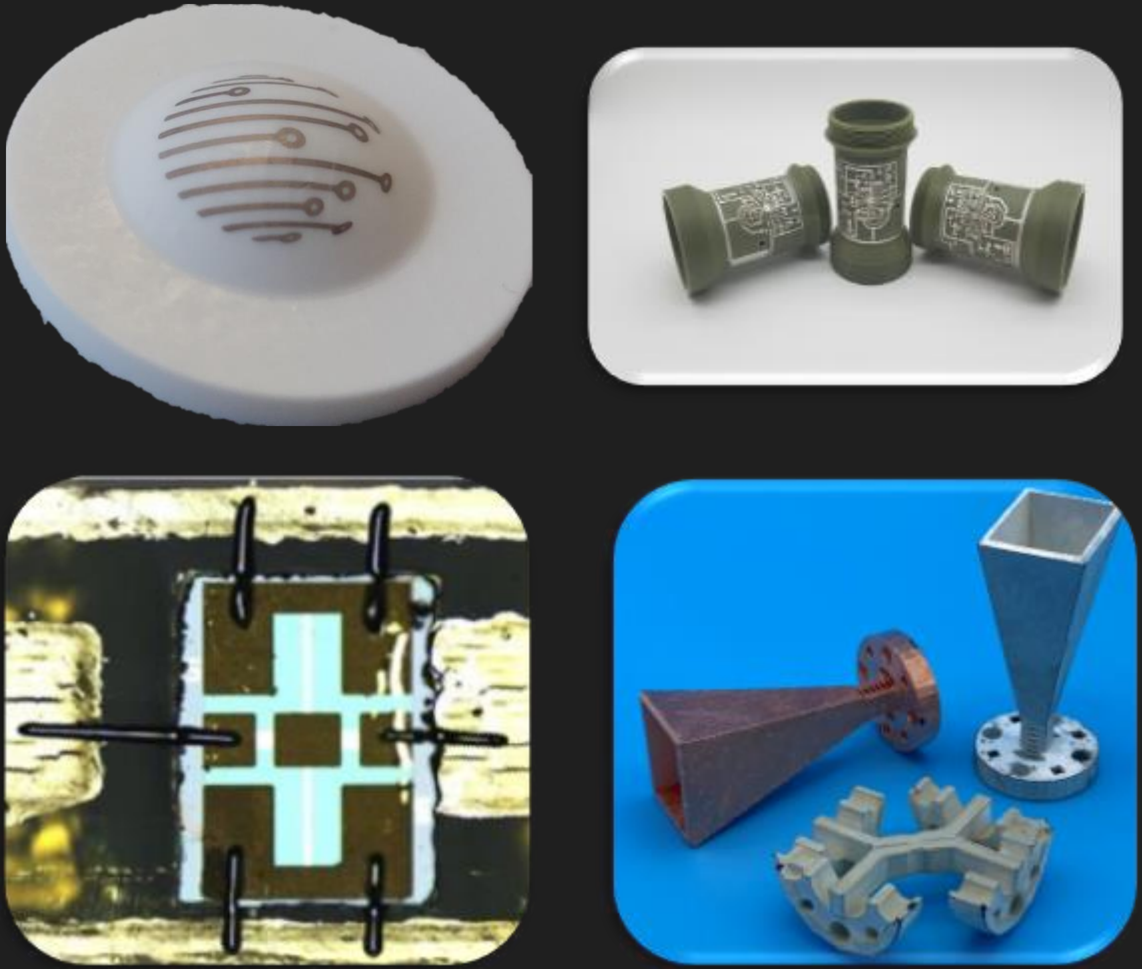
The way ahead



Improvements of system design

- Higher mechanical stability
- Reduce weight
- Embedding components

The way ahead



Merge of different processes

- Use a variety of different Inks
- Variety of assembly processes
- Several 3D printing processes

J.A.M.E.S

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AME Revolution

www.j-ames.com

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J.A.M.E.S GmbH
Willy-Messerschmitt-Straße 3
82024 Taufkirchen
Germany

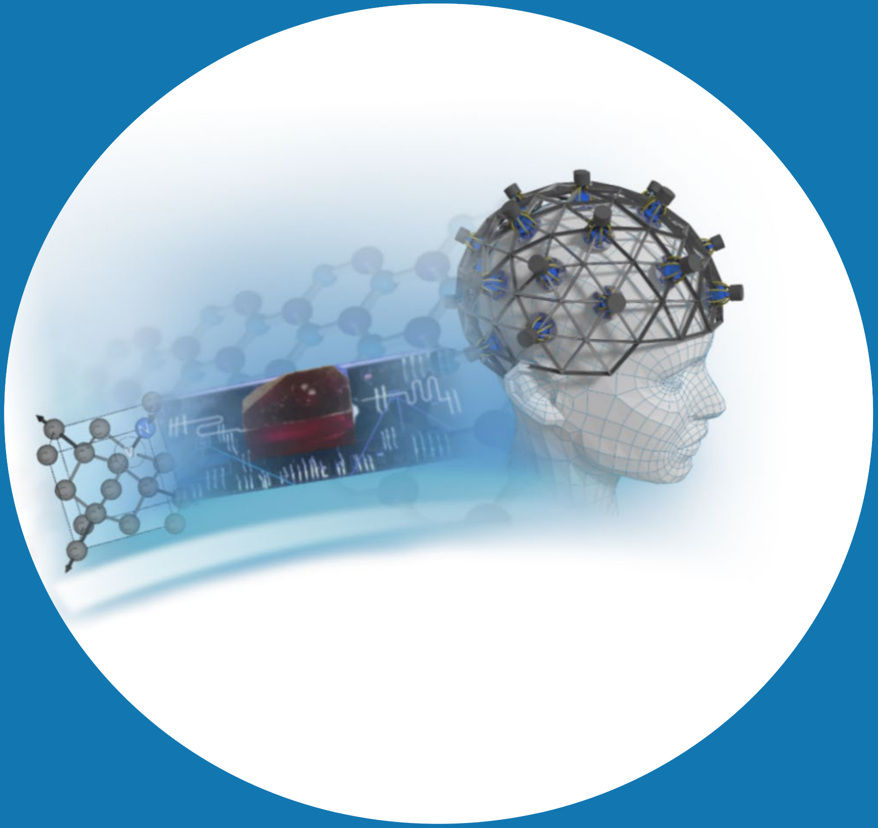
IQ ST Integrated Quantum Science and Technology

Universität Stuttgart

universität ulm

QSens

Quantum Sensing - Opportunities for Novel Additive and Subtractive Manufacturing Methods



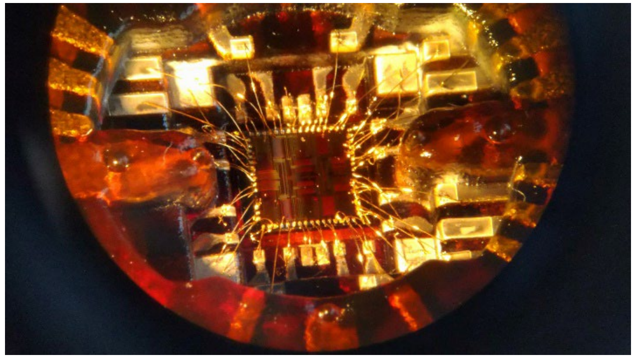
M. Kern

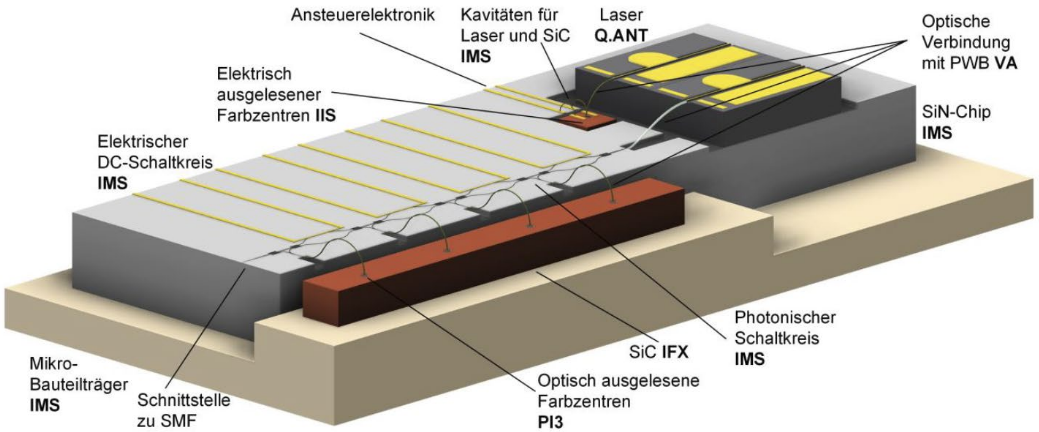
AME User Forum, Munich

13. November 2023

Outline

- Institute of Smart Sensors
- 1st generation Quantum Sensors (QS)
- Example: Novel MRI Sensing using e-skin and AME
- BMBF “Cluster4Future” Qsens and 2nd generation QS
- Hybrid integration and novel manufacturing methods in the context of QS
- Example: Novel high-frequency AME electrodes for high-end quantum sensing and computing applications
- Example: AME PCB for driving of solid-state quantum sensors



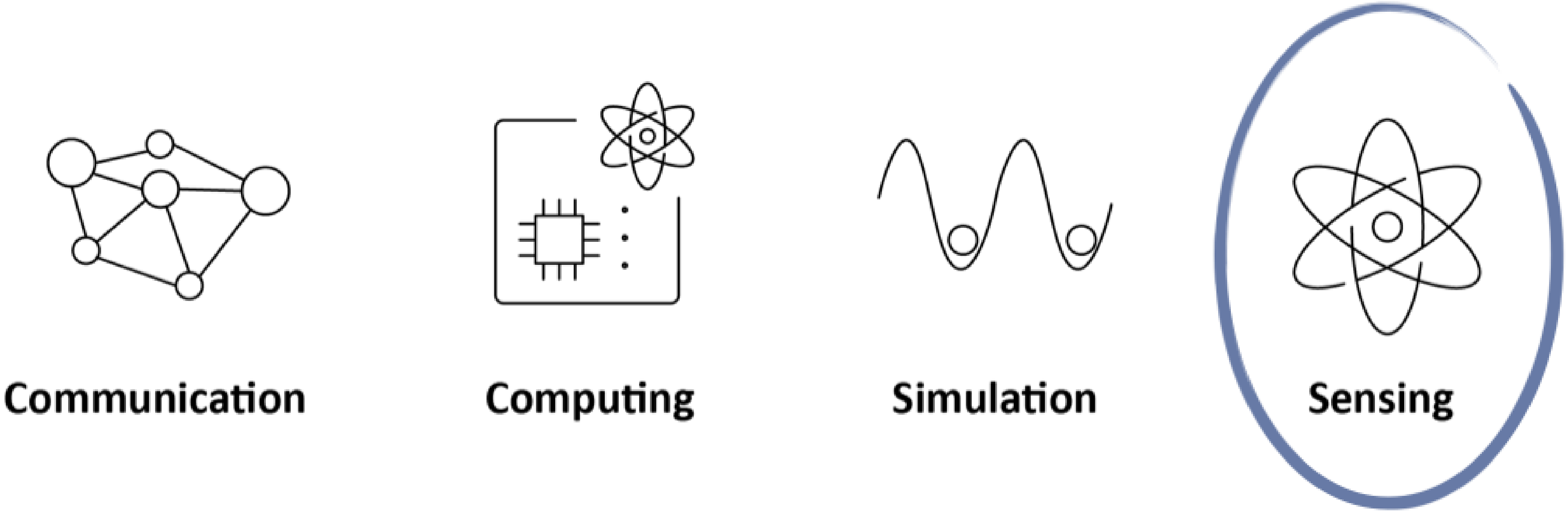


Institute of Smart Sensors

- Your experts for smart sensors and integrated interface electronics at the University of Stuttgart
- Almost 50 people, led by Prof. Dr. Jens Anders and three group leaders with over 30 PhD students
- Design and development of custom ASICs and systems for various sensing applications, with focus on magnetic resonance and quantum sensing
- Holistic development of the whole signal chain:
  - Signal generation
  - Detection
  - A/D conversion
  - DSP
  - Custom FPGA-based backend development

Quantum sensing

- Quantum technologies exploit often fragile quantum states for various applications
- Quantum sensing uses engineered quantum states to measure various external quantities with unprecedented sensitivity



- 1st generation quantum sensing: e.g. standard magnetic resonance spectroscopy and MRI
- 2nd generation quantum sensing: using engineered materials and states down to single-atom level
- Both can benefit from further development (and need novel manufacturing methods for that)

Improving 1st gen. quantum sensing

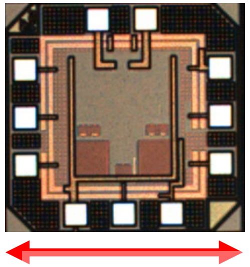
- Today’s commercial magnetic resonance devices are still mostly based on “ancient” discrete electronics paradigm
- Integrating the devices into ICs can drastically reduce cost, complexity and improve accesibility

Source: Bruker

1 - 2 m

10 x 10 cm, 400$

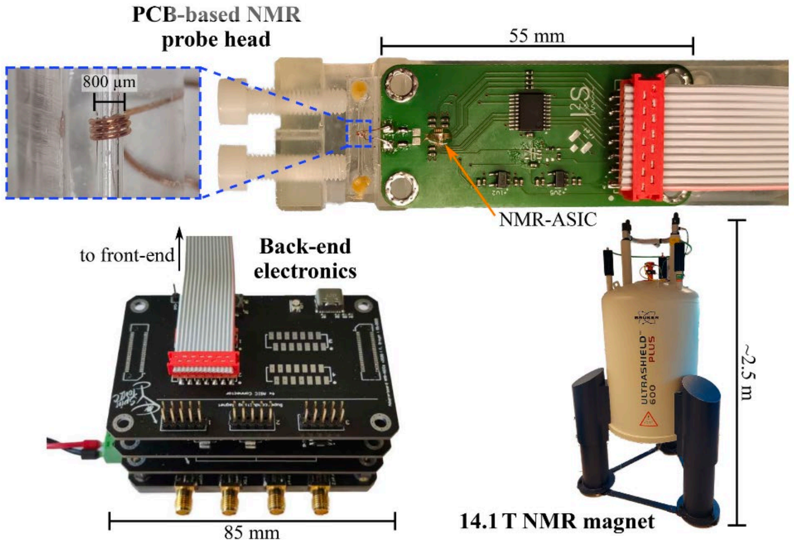
Source: Digilent

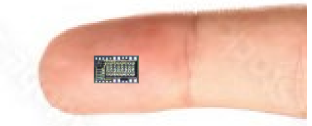


1 mm

Novel manufacturing needed to further improve integration and scalablity

Works great, but at what cost in $, space and infrastructure?



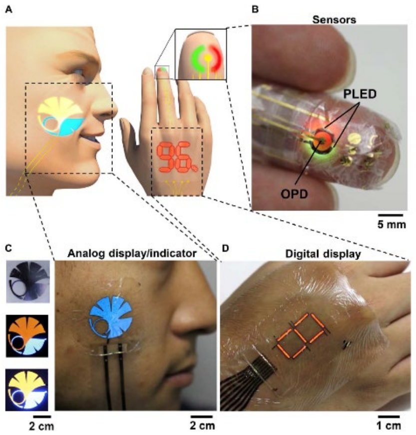


263 GHz source

Example 1: AME for 1st gen quantum improvements

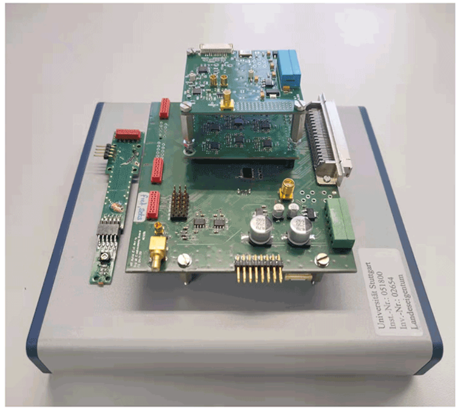
- Project: Probing the brain using long-term implantable e-skin magnetic resonance imaging sensors
- Passive resonators are known to significantly enhance the SNR and/or resolution of MRI measurements, they have, however a limited penetration depth, and opening of the cranium should be minimized

Prof. Someya, Uni. Tokyo



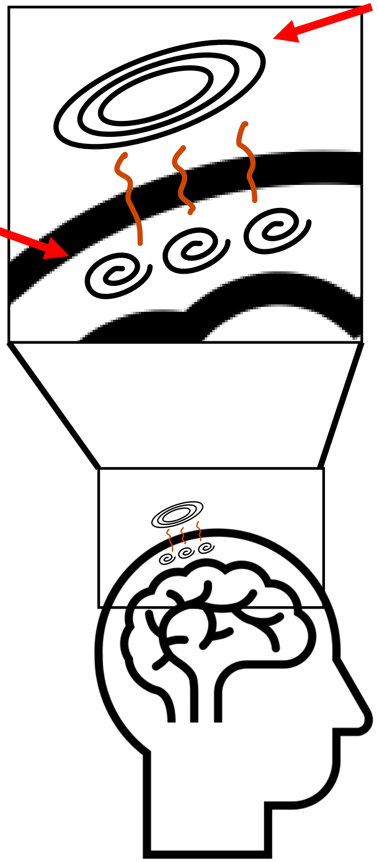
Biocompatible electronics

Prof. Anders, Uni. Stuttgart



(b)

Miniaturized magnetic resonance



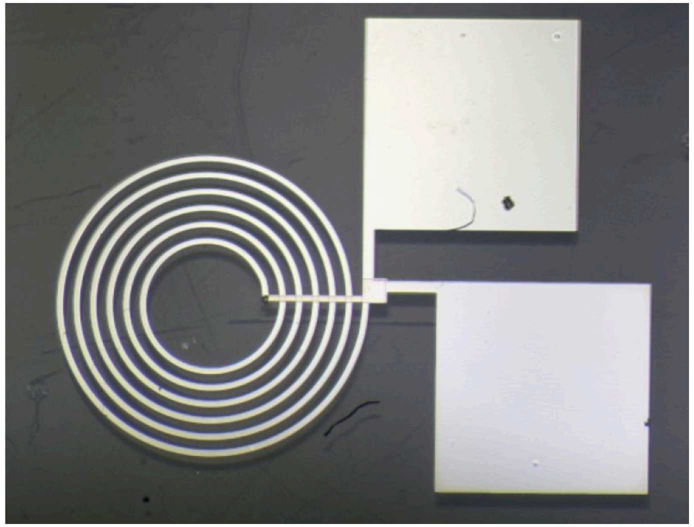
Implantable passive structures

Miniaturized MR readout system

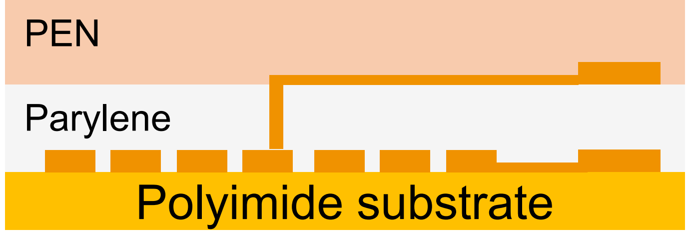
Example 1: AME for novel 1st gen quantum sensing

- Project: Probing the brain using long-term implantable e-skin magnetic resonance imaging sensors

Passive LC resonator

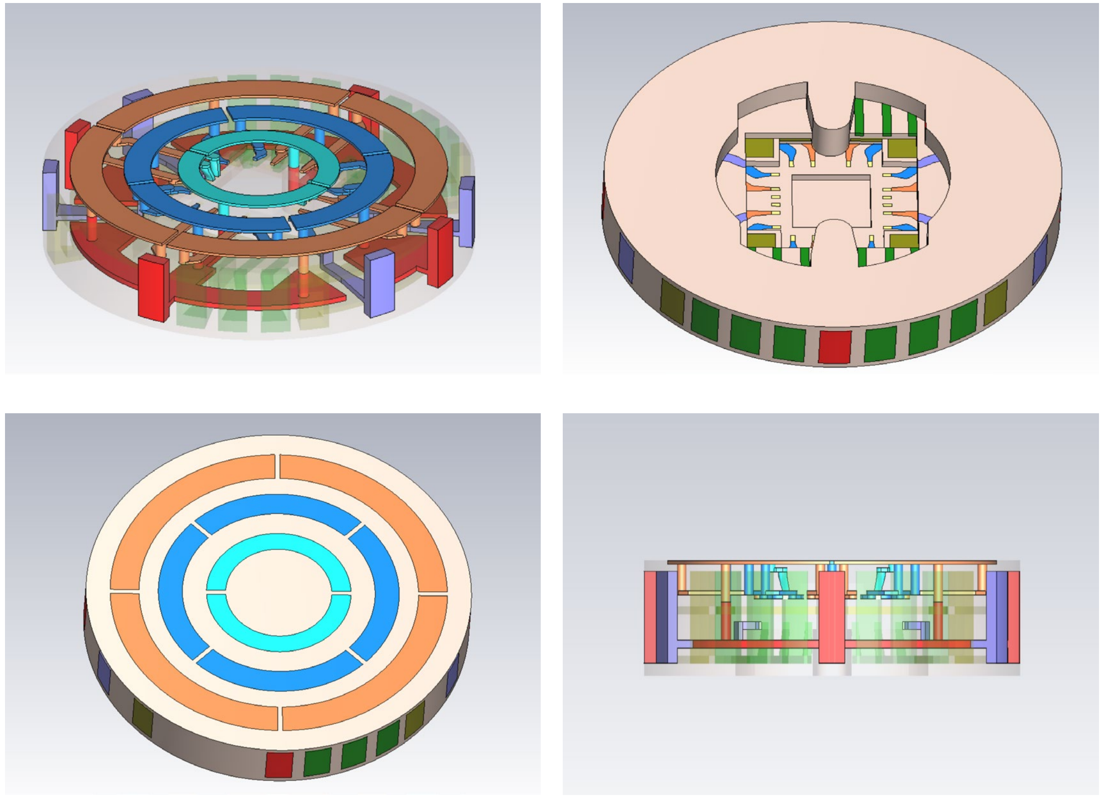


Non-implantable test structure to prototype geometry (Glass/Ag/Perylene/Ag)



Implantable material stack

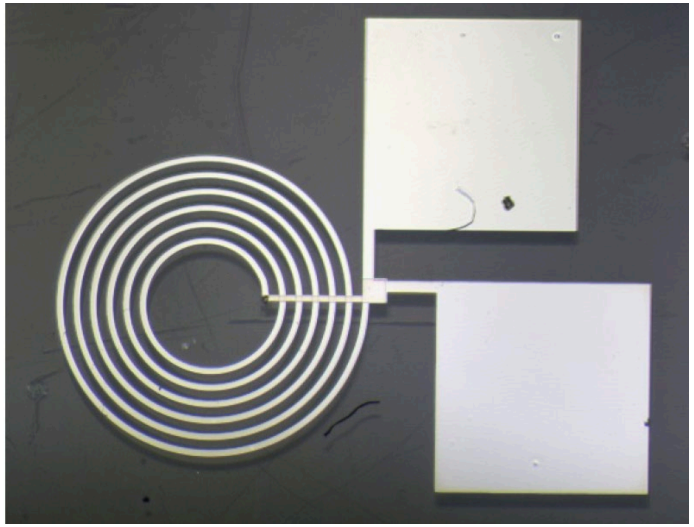
AME 3D coil with ASIC interface



Example 1: AME for novel 1st gen quantum sensing

- Project: Probing the brain using long-term implantable e-skin magnetic resonance imaging sensors

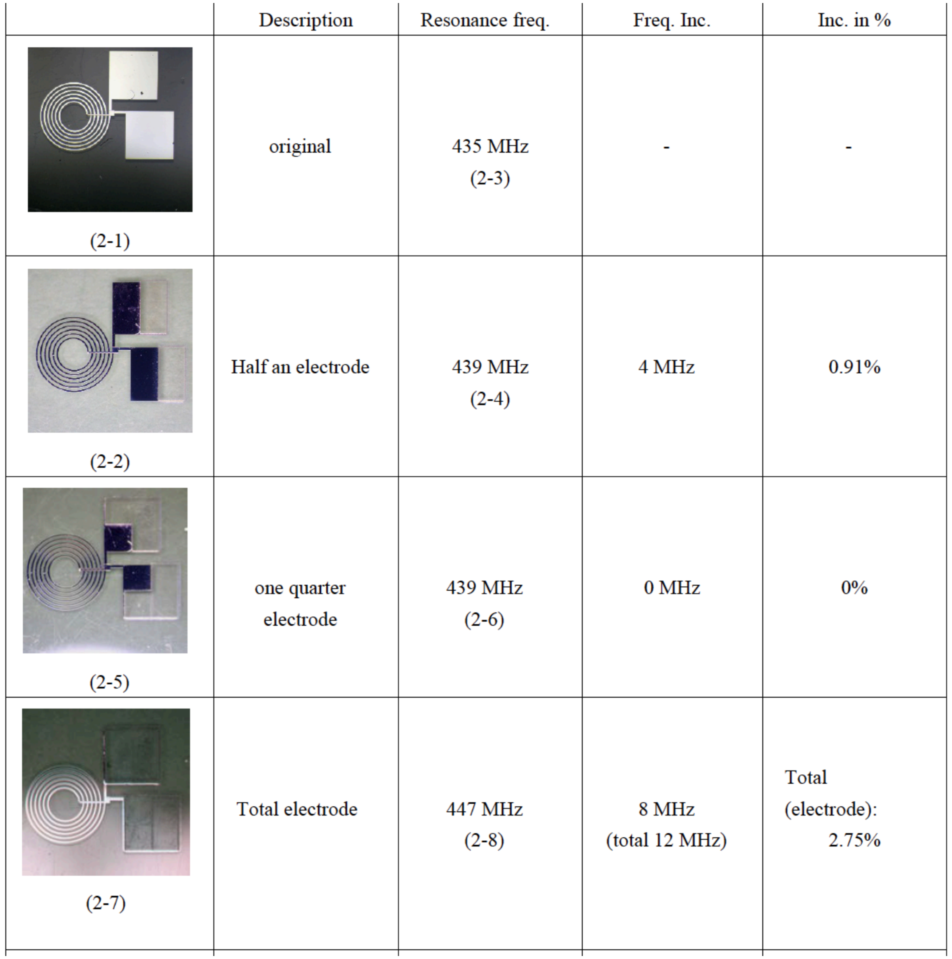
Passive LC resonator



First prototype manufactured using sputtering and chemical vapor deposition

Resonance frequency 435 MHz

Fine tuning using ps laser ablation

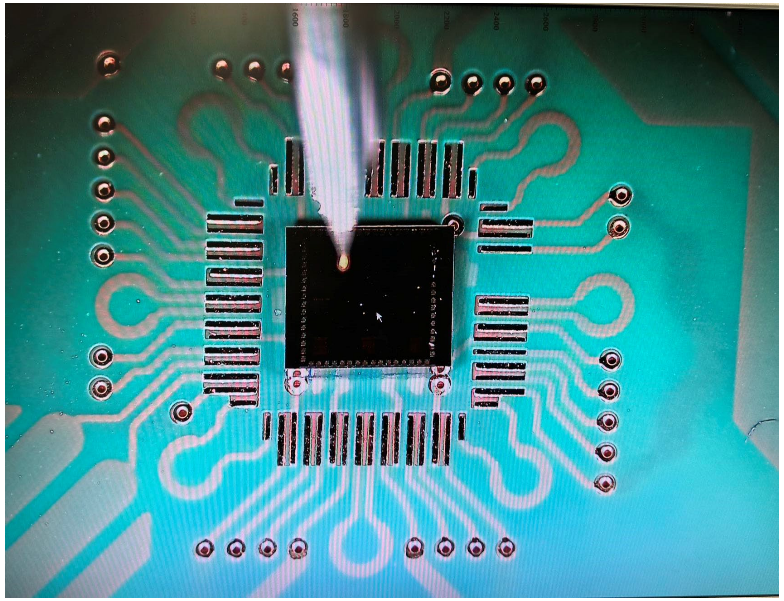


	Description	Resonance freq.	Freq. Inc.	Inc. in %
(2-1)	original	435 MHz (2-3)	-	-
(2-2)	Half an electrode	439 MHz (2-4)	4 MHz	0.91%
(2-5)	one quarter electrode	439 MHz (2-6)	0 MHz	0%
(2-7)	Total electrode	447 MHz (2-8)	8 MHz (total 12 MHz)	Total (electrode): 2.75%

Example 1: AME for novel 1st gen quantum sensing

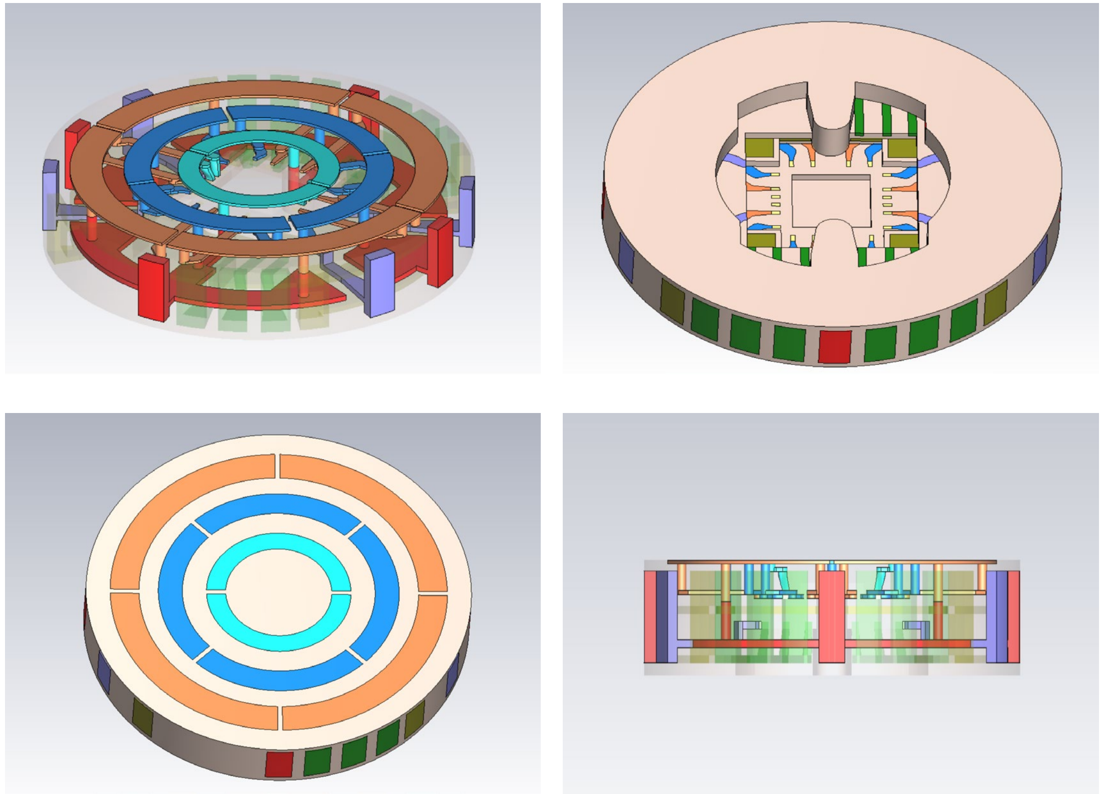
- Project: Probing the brain using long-term implantable e-skin magnetic resonance imaging sensors

ASIC driving conventional PCB coils



- Limited to small coil sizes on the periphery
  - limited readout depth

AME manufactured 3D PCB



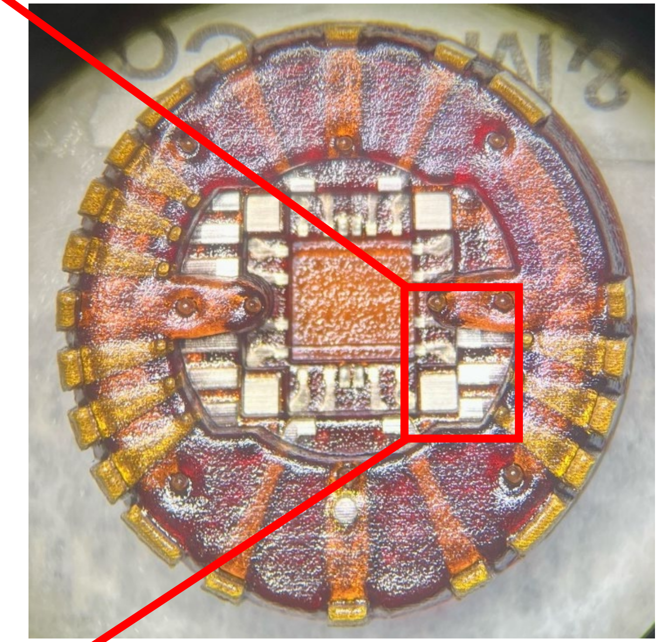
- Much larger segmented coils possible thanks to 3D integration

Example 1: AME for novel 1st gen quantum sensing

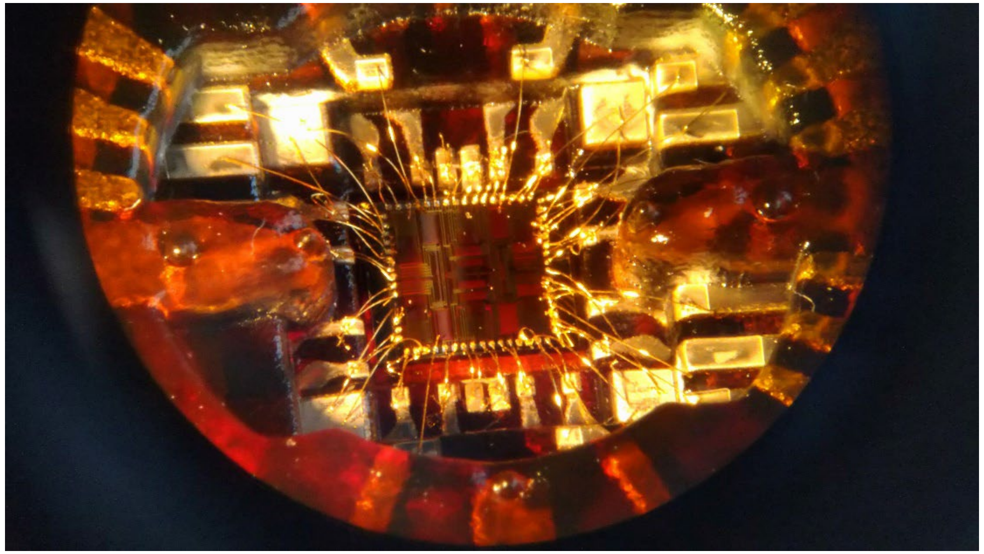
- Project: Probing the brain using long-term implantable e-skin magnetic resonance imaging sensors
- First prototypes printed using Dragonfly IV - trying to improve bondability of AME bonding pads with postprocessing

Using ps laser ablation

More optimized parameters



Bonded chip



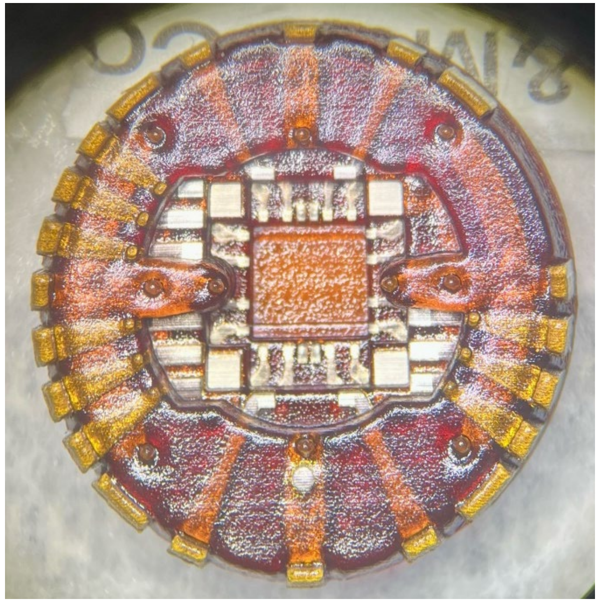
- Removes oxide, improves surface quality, improves bondability
- Didn’t manage to improve roughness/larger topological errors
  - May be possible with more optimization

Example 1: AME for novel 1st gen quantum sensing

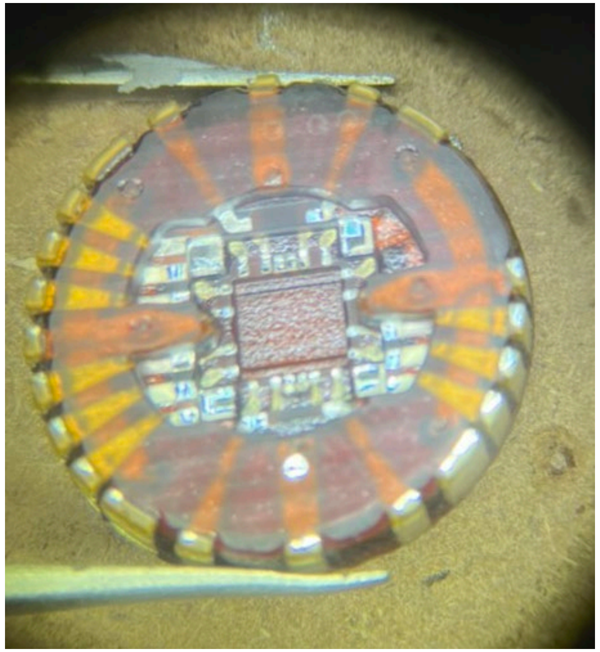
- Project: Probing the brain using long-term implantable e-skin magnetic resonance imaging sensors
- First prototypes - trying to improve bondability of AME bonding pads with postprocessing

Bonding pad planarization using a micro-CNC mill

Before



After



- Makes the bonding pads almost perfectly flat
- Signficantly better bondability even compared to laser ablation

QSens – BMBF “Cluster4Future”

- 2nd generation quantum sensors push the boundaries of what is technologically/physically possible

IOT & Lifestyle

Smart Health Sensors

Turning consumer wearables into reliable everyday medical devices

Mobility

Navigational Sensors

The next level of autonomous driving requires levels of precision demonstrated by quantum sensors

Healthcare & Biomedical

Highly specific sensors

Enabling rapid and specific screening of active pharmaceutical ingredients and metabolites

Sustainability

Environmental sensors

Specific detection of free radicals for contaminant detection, food shelf-life determination and improvement of catalysts

QSens – BMBF “Cluster4Future”

- QSens pursues the goal of bringing quantum sensors to mass markets within the next 9 years
- The QSens team

19 industrial partners - Global players, SMEs and startups

University partners

Research institutes

QSens – BMBF “Cluster4Future”

- Qsens research

Quantum platforms

- solid state defects
- photons
- atoms

Technology areas

- material and process development
- photon sources
- (micro) optical integration
- microelectronic integration
- signal processing

Application areas

- healthcare
- mobility
- IoT
- sustainability

2nd generation quantum sensing

- For room-temperature sensing, two platforms are investigated today: gases and defects in solids
- Gas-based sensors can provide a better performance but are unlikely to scale to mass markets, defects in solid can cater mass markets, still outperforming conventional sensors

Gases

Pros: Longer-lived quantum states
Cons: Low density, complex/hard to integrate

Large-bandgap semiconductors

Pros: Compact, relatively easy to integrate
Cons: Shorter-lived quantum states

2nd generation quantum sensing

- Quantum sensors can be more sensitive and more specific than conventional sensors
- But they are tricky to use, often requiring both high-end RF and MW electronics as well as sensitive optics

Conventional setups

- ☹ High-cost optics and electronics
- ☹ Large volume
- ☹ Very low level of integration
- ☹ Not scalable

kann nicht angezeigt werden.

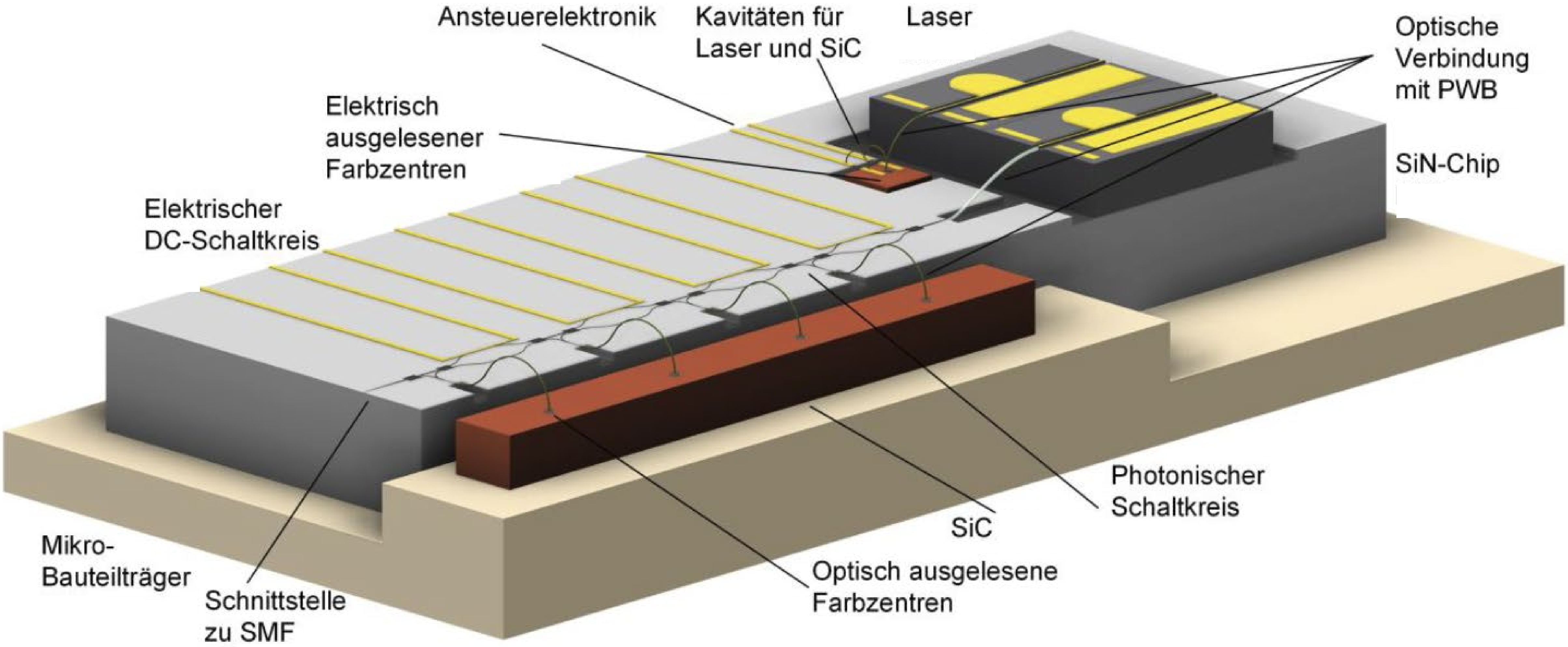
ELECTRONIC INTEGRATION

PHOTONIC INTEGRATION

Integrated systems

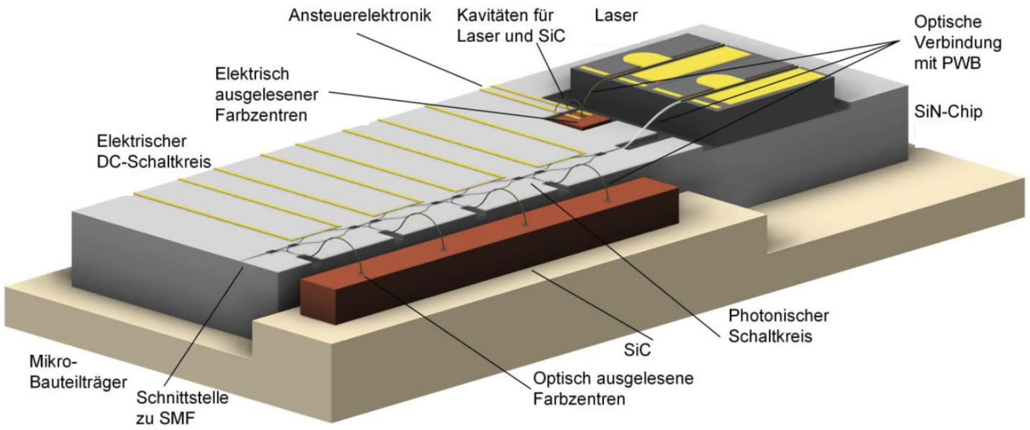
- ☺ Highly scalable
- ☺ Energy-efficient
- ☺ Low-cost

How will 2nd gen quantum sensors look like?



How to manufacture a QS chip?

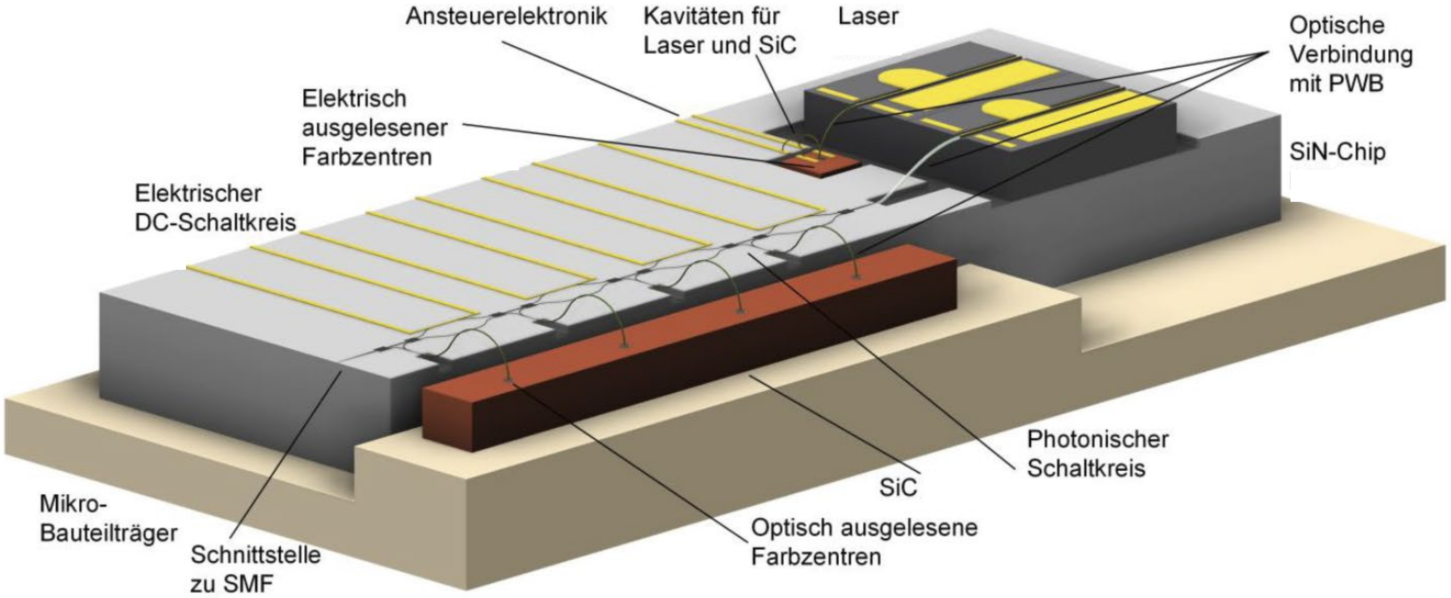
- Photonic ICs
  - SiN cleanroom techniques
- Photonic interconnects
  - Photonic bondwires using two-photon photolithography (commercial systems available)



PWB images: Vanguard Automation

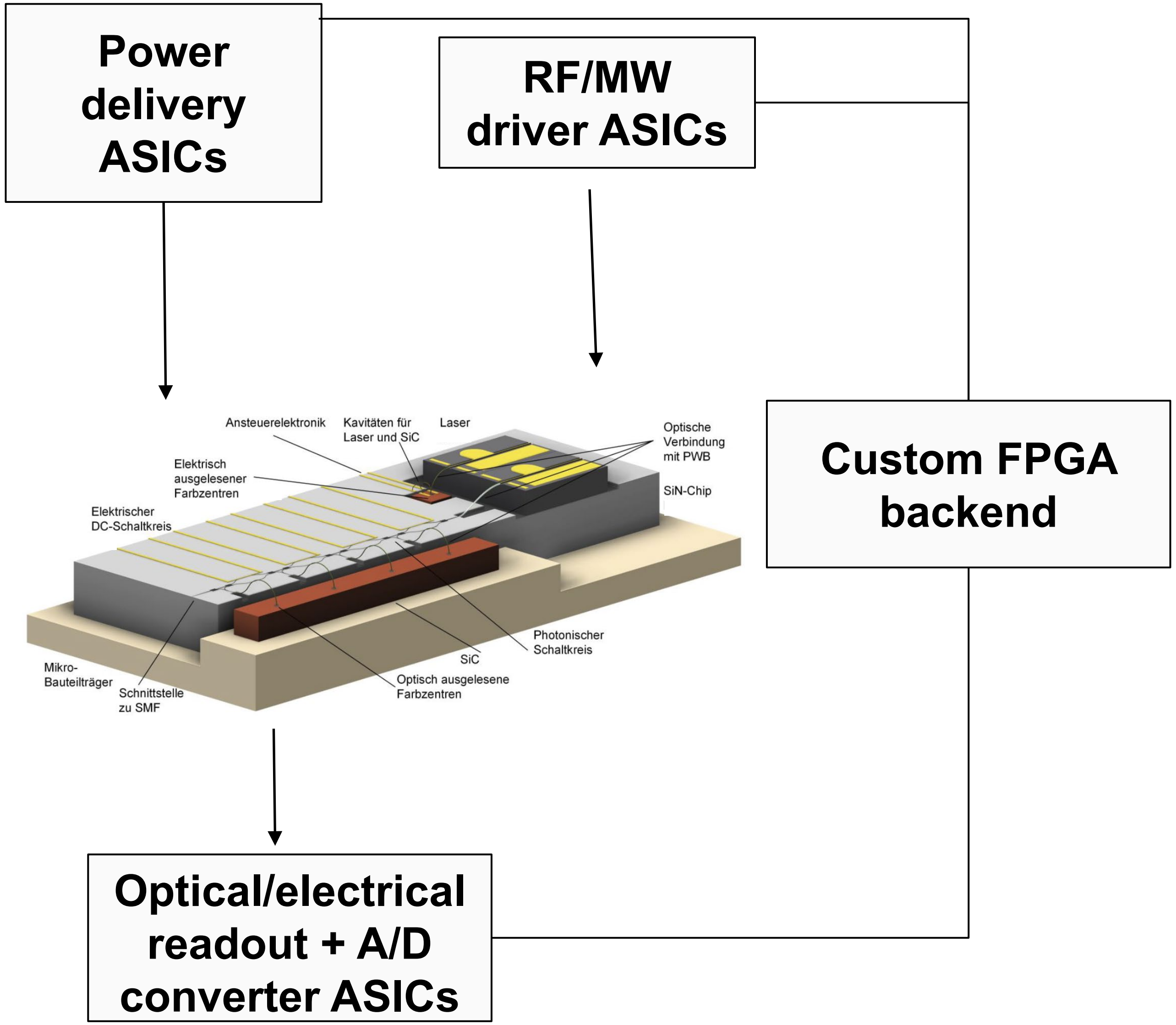
How to manufacture a QS chip?

- SiN structuring and metallization
  - Cleanroom techniques
- Carrier
  - Cleanroom?
  - Traditionally machined ceramics?
  - AM ceramics? Or even AME?



How to drive and read out a QS chip?

- While the QS chip itself will need cleanroom techniques, the requirements for system integration are lower
- Additive manufacturing and AME specifically could play a huge role in system integration
  - Higher integration density thanks to 3D integration
  - Bondwire-less and 3D chip interconnects allow shorter connection paths and non-50 Ohm matching, improving efficiency
- Other QS chip designs could benefit from AME even more



Power delivery ASICs

RF/MW driver ASICs

Custom FPGA backend

Optical/electrical readout + A/D converter ASICs

Roadmap in QSens

TODAY	+ 3 Years	+ 6 Years	+ 9 Years
• Discrete hybrid integration • Sensor volume: 10 cm^3 • Sensor cost: 100 EUR • Potential: 1 000 pcs/year	• Multi-chip electronics • Sensor volume: 1 cm^3 • Sensor cost: 10 EUR • Potential: 10 000 pcs/year	• Microhybrid integration • Sensor volume: 0,1 cm^3 • Sensor cost: 1 EUR • Potential: 10^6 pcs/year	• Volume production at industrial partners • Potential: 10^9 pcs/year

Small-series production of special sensors

Small/medium series production

Volume production

Example 2: AME for 2nd gen. quantum sensing

- Project: Controlling Rydberg atoms using circularly polarized MWs at 21 GHz for ultra-sensitive gas sensing

0.5mm

2.5mm

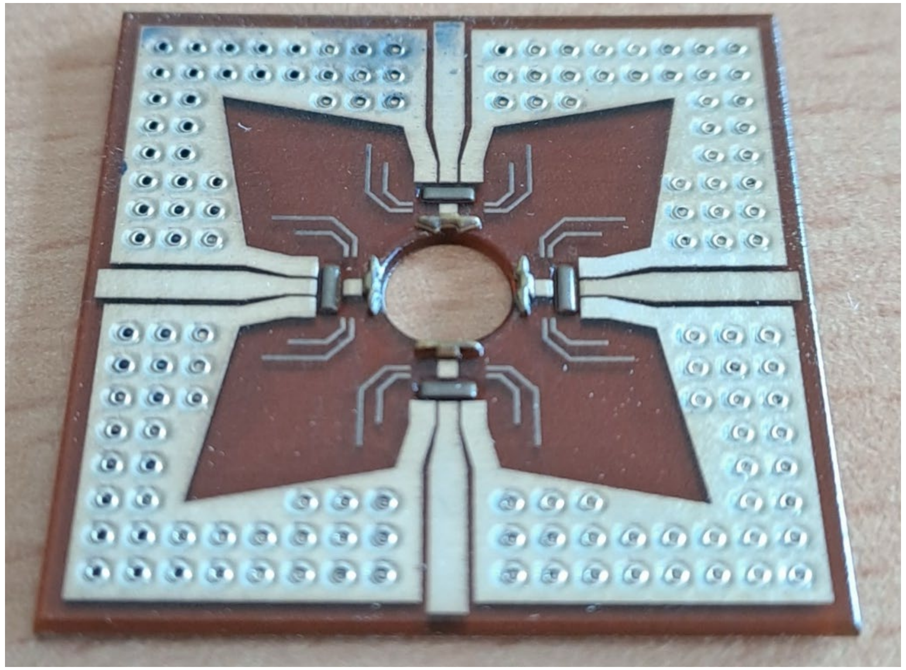
0.34mm

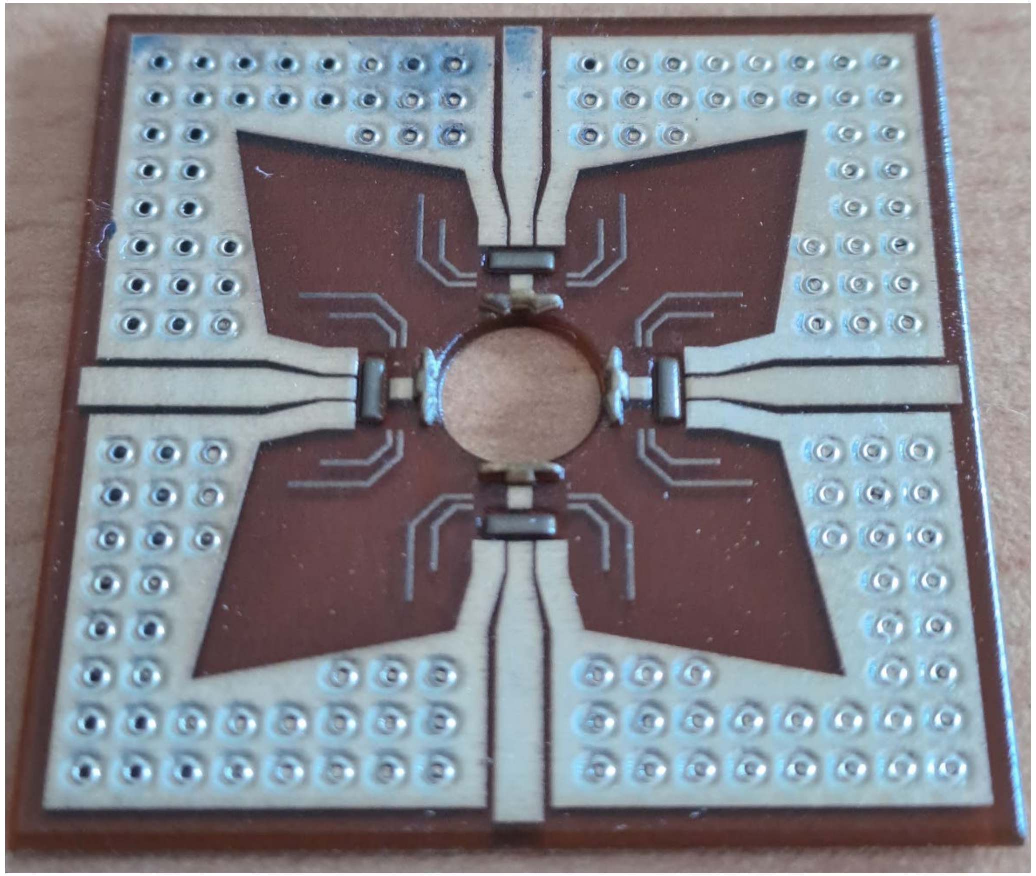
0.79mm

Example 2: AME for 2nd gen. quantum sensing

- Project: Controlling Rydberg atoms using circularly polarized MWs at 21 GHz for ultra-sensitive gas sensing

First printed prototypes

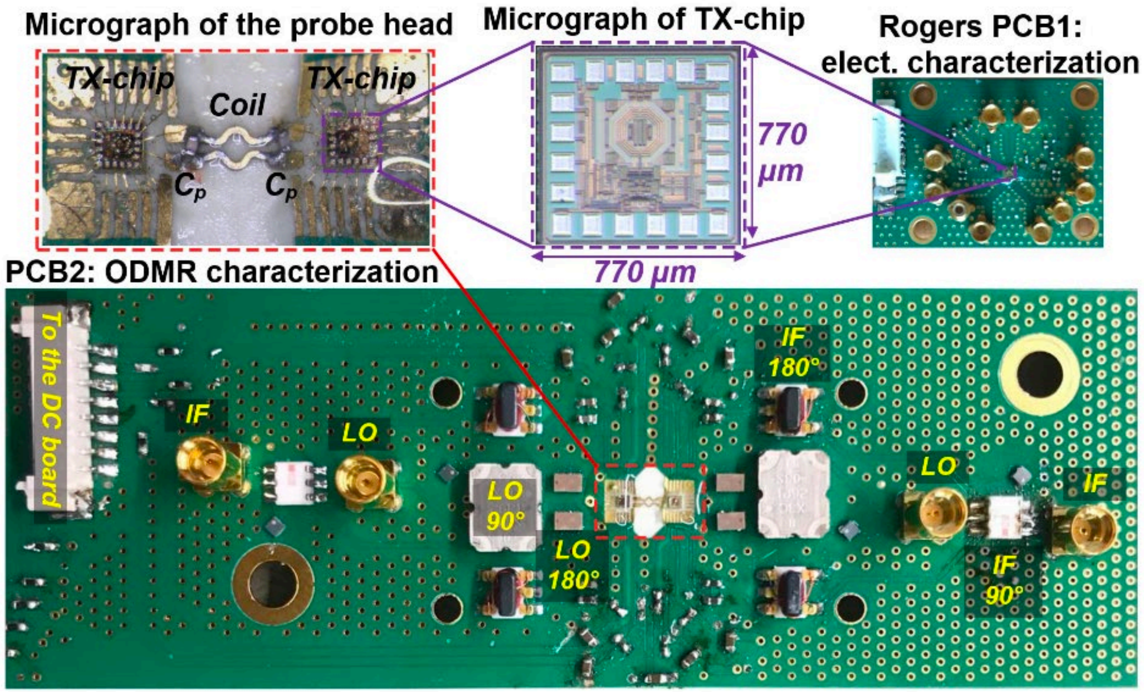




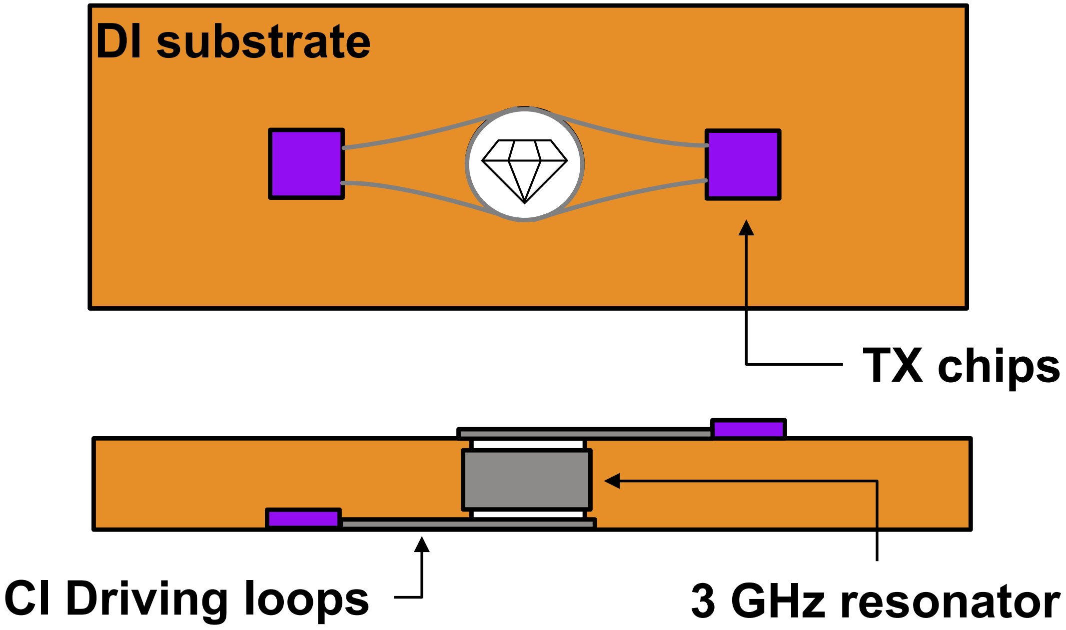
Example 3: AME PCB for 2nd gen. quantum sensing

- Project: Driving of solid-state defects in diamond for high-precision quantum sensing of magnetic fields

ASICs driving conventional PCB coils



ASICs integrated in an AME PCB



Conclusion

- Quantum technologies will require novel manufacturing and integration methods to become scalable
- Quantum sensing is well on it’s way to become a part of our everyday lives
- Novel additive and subtractive manufacturing methods are needed both for protyping and for volume production of quantum devices
- First experiences with AME show that it will become another tool in the toolkit, the same as FDM