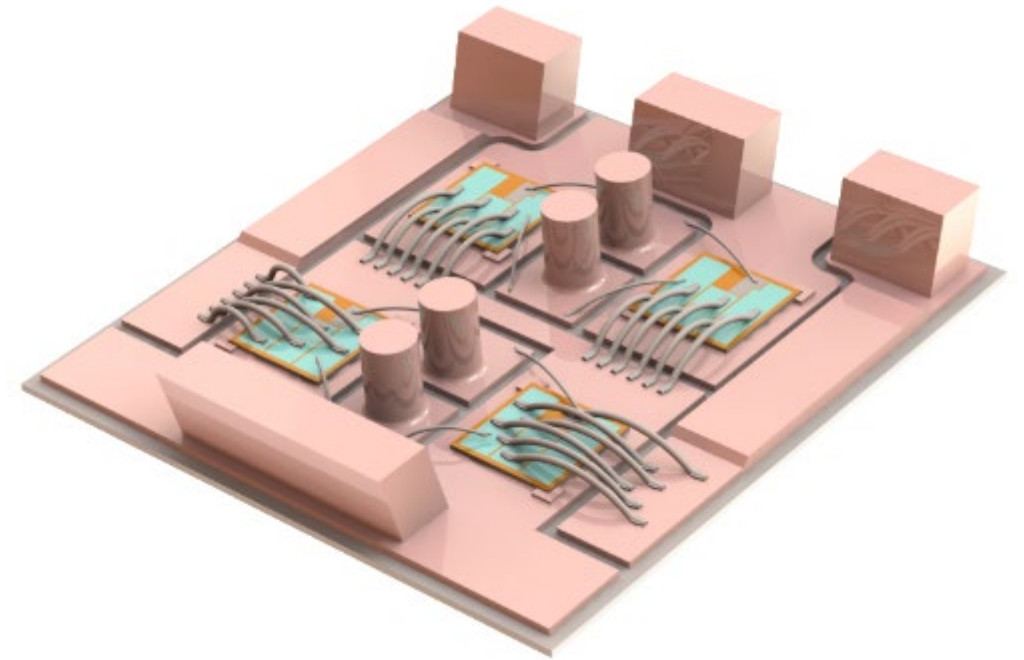


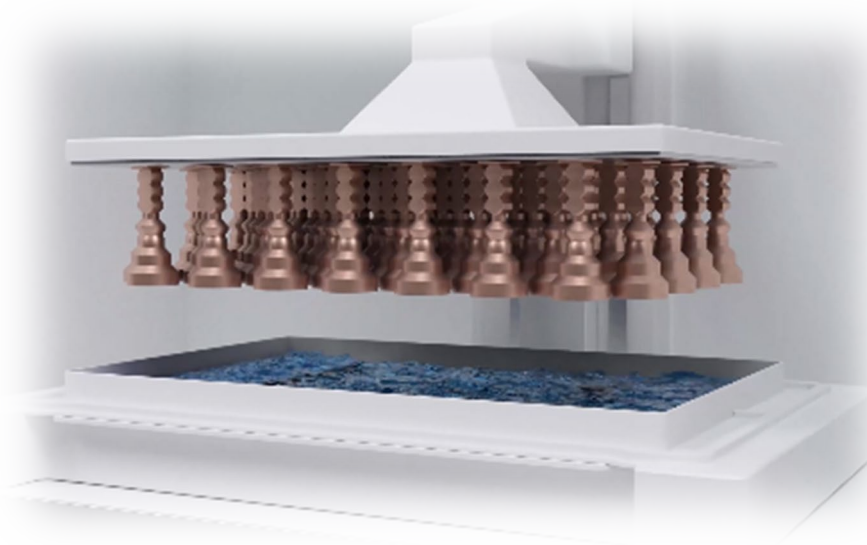


FABRIC8LABS

Electrochemical Additive Manufacturing

***ECAM Technology for Power
Electronic Modules***

Advanced 3D Metal Printing with Electrochemistry



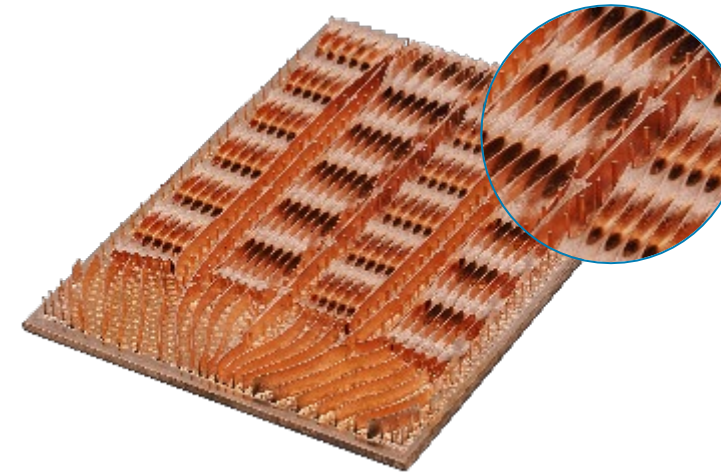
High-Resolution Pure Copper

Room Temperature Printing

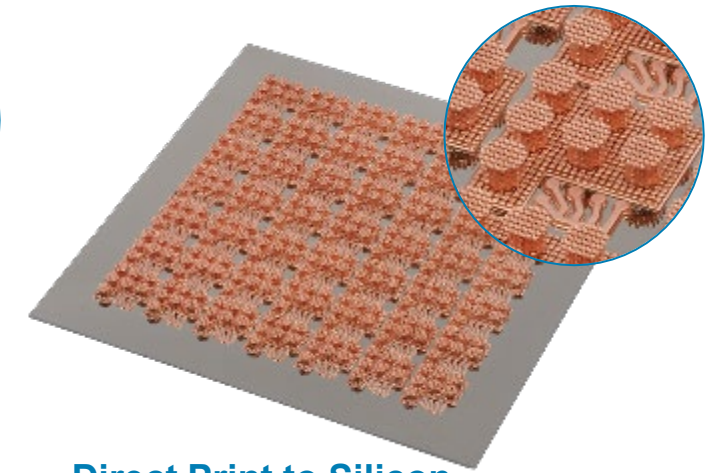
Powder-Free Process

No Post Processing

Thermal Management Solutions for High Power Density Applications

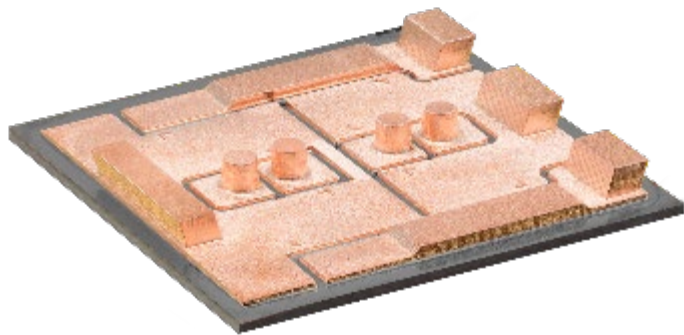


Customized Solutions for
Device Power Map

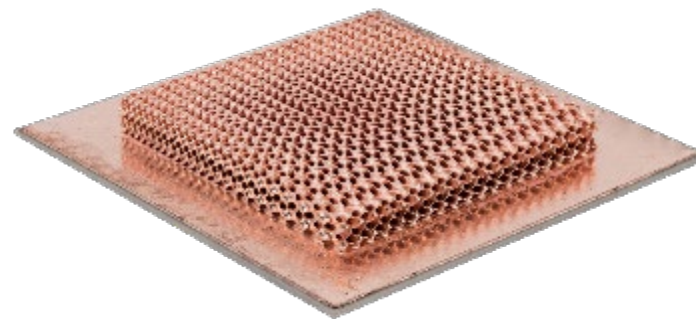


Direct Print to Silicon
Capability

Power Electronics Optimized for Performance, Cost, and Weight

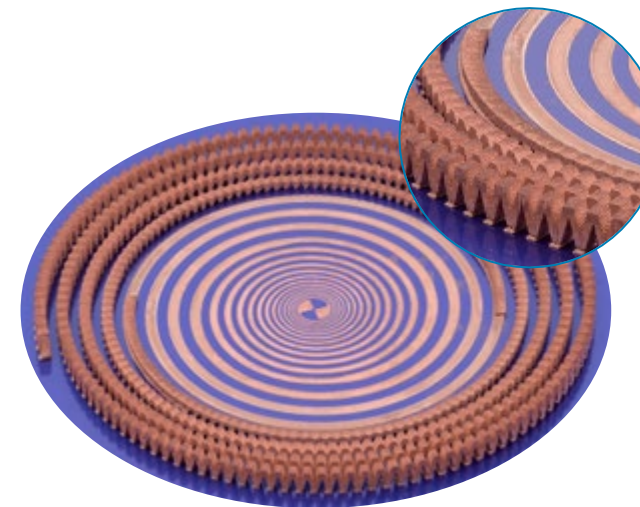


Custom Packaging Enhances Current
Capacity and Terminal Integration

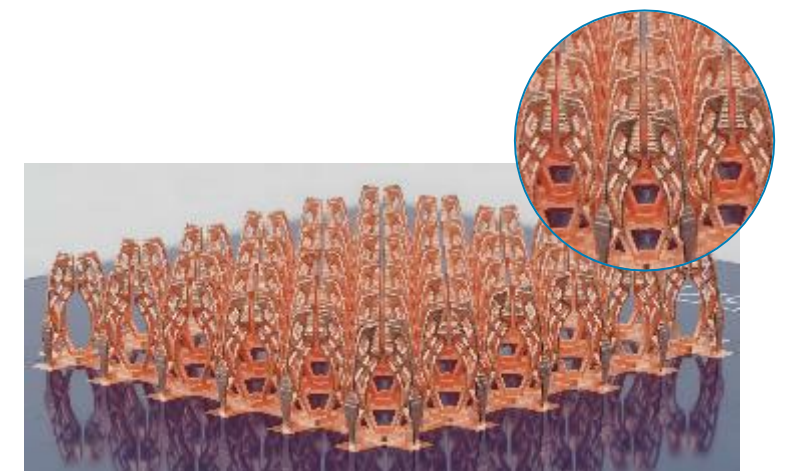


Cooling Structures Printed on Direct
Bond Copper Eliminates TIM

Wireless Components Directly Printed to PCB Optimizes SWaP-C



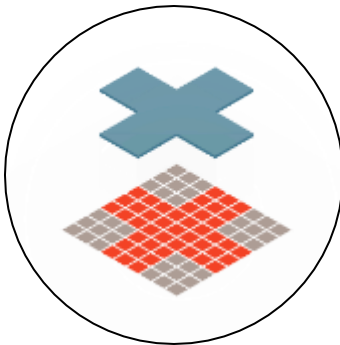
Wideband Antennas



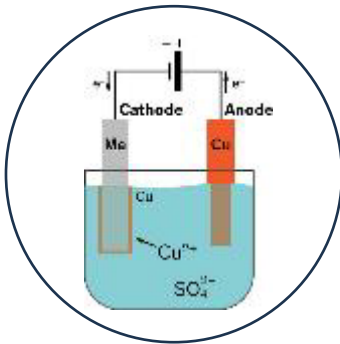
Phased Arrays

Electrochemical Additive Manufacturing (ECAM)

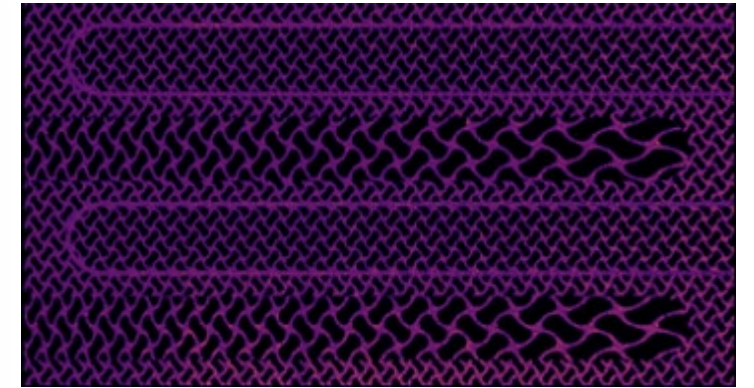
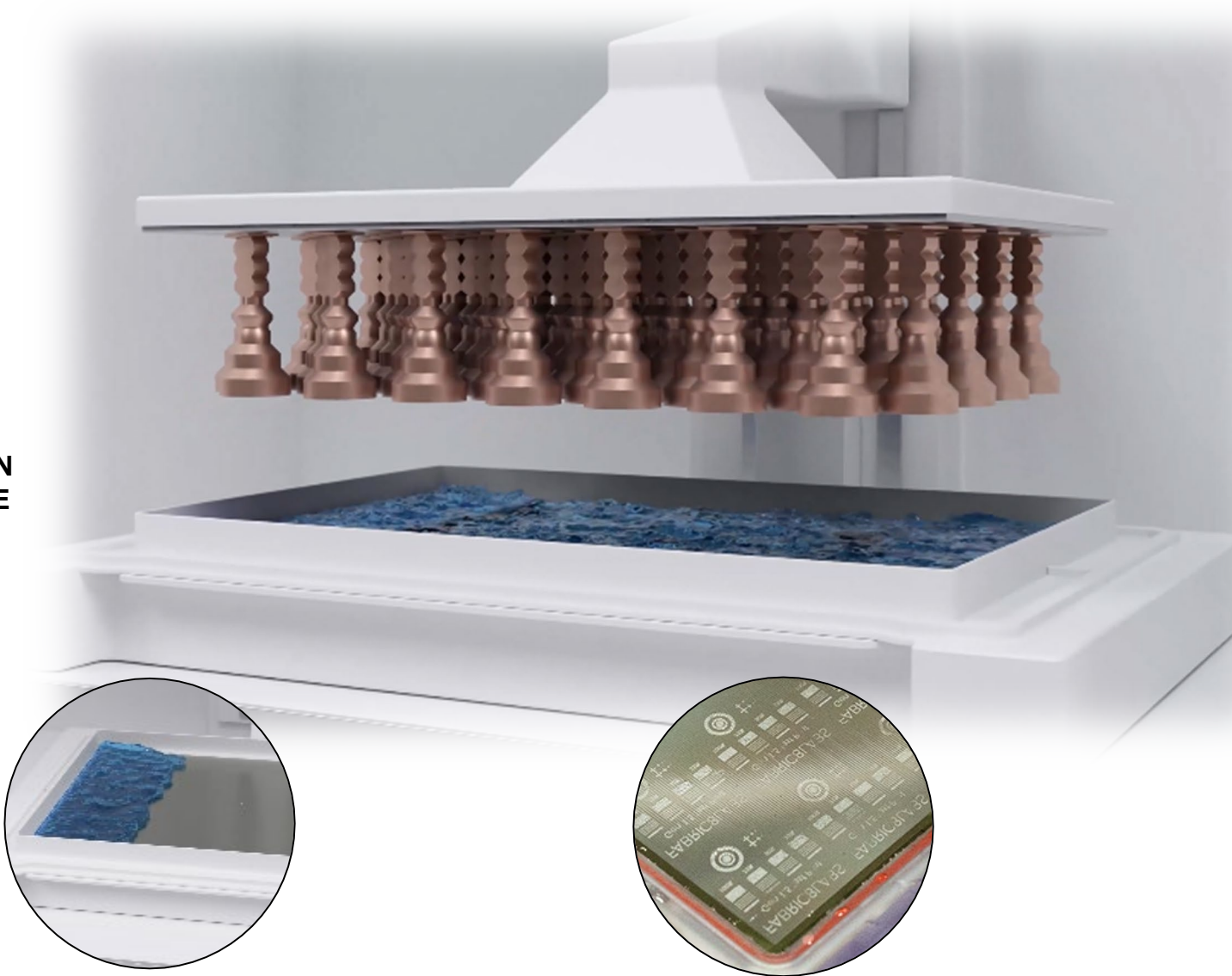
ECAM Converges High-resolution Display Technology With The Scalability Of Electroplating



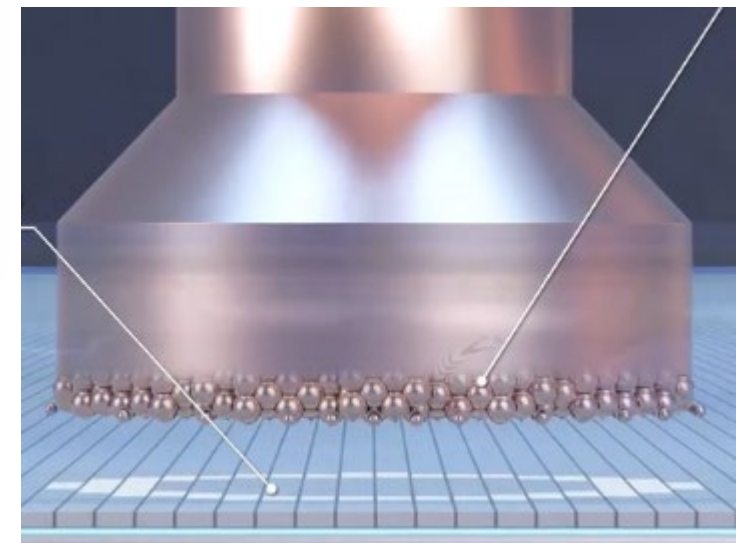
PROVEN
DISPLAY BASED
PRINthead
TECHNOLOGY



METAL DEPOSITION
BASED ON MATURE
ELECTROPLATING
PROCESS



DEPOSITION ALGORITHM ANALYZES
REAL TIME PRINT DATA TO DRIVE QUALITY



1

ELECTROPLATING
SOLUTION FLOWS
ACROSS PRINthead

2

MICRO-ELECTRODE PRINthead
PIXELS ACTIVATE FORMING
PRECISE ELECTRIC FIELDS

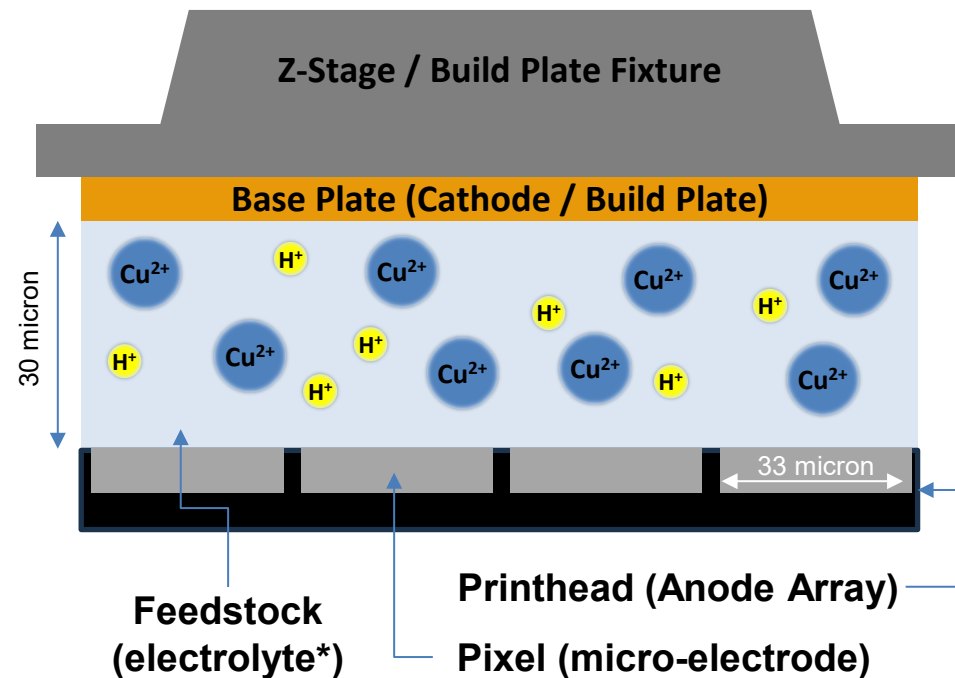
3

PIXEL ACTIVATION DRIVES FOCUSED
ELECTRIC FIELD TO PRECISELY DEPOSIT
METAL: $\text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu}$

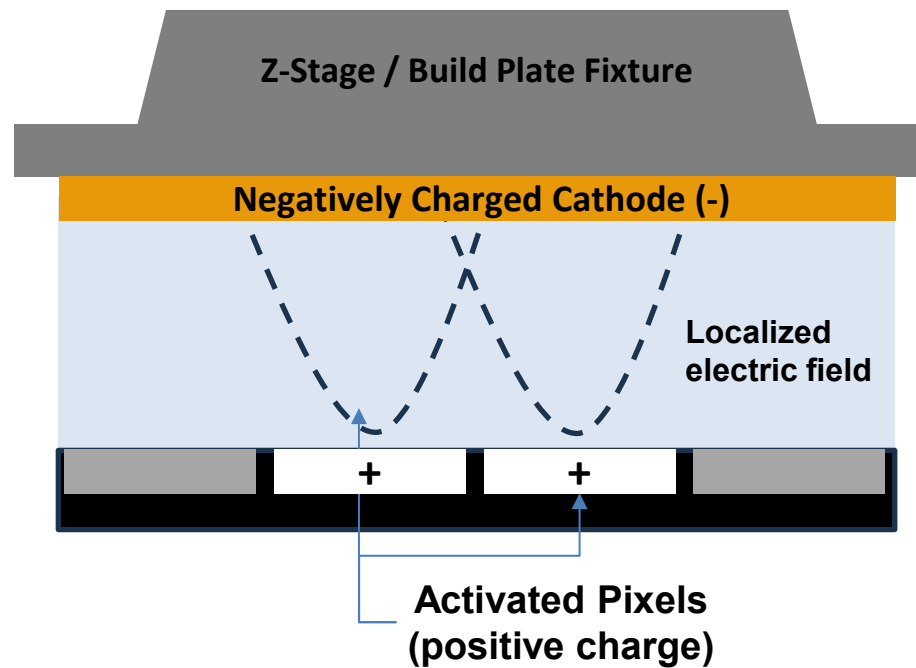
Electrochemical Additive Manufacturing (ECAM)

Detailed View of the ECAM Electrochemical Cell

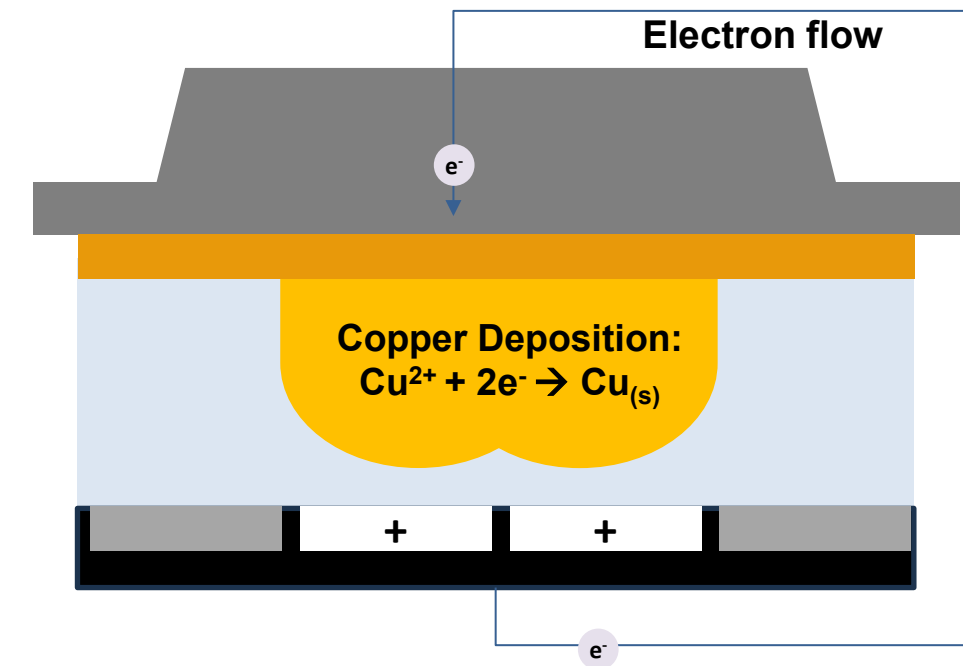
Plating Cell Elements



Activated Pixels Create Localized Electric Field



Copper Deposits Within Active Field



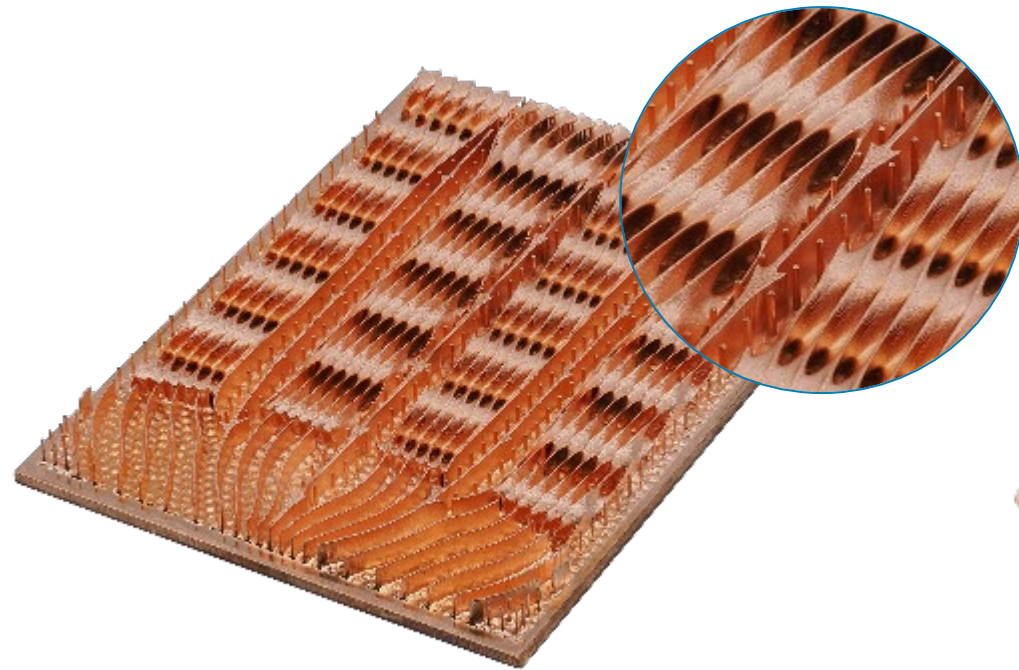
The ECAM printhead is a dynamic micro-anode array which acts as a digital mask, selectively activating "pixels" for precise, high-resolution metal deposition, building metal parts layer by layer.

**Only cations shown for simplicity*

Enhanced Electrical & Thermal Performance With ECAM

Enabling Higher Power Densities and Improved Device Efficiency

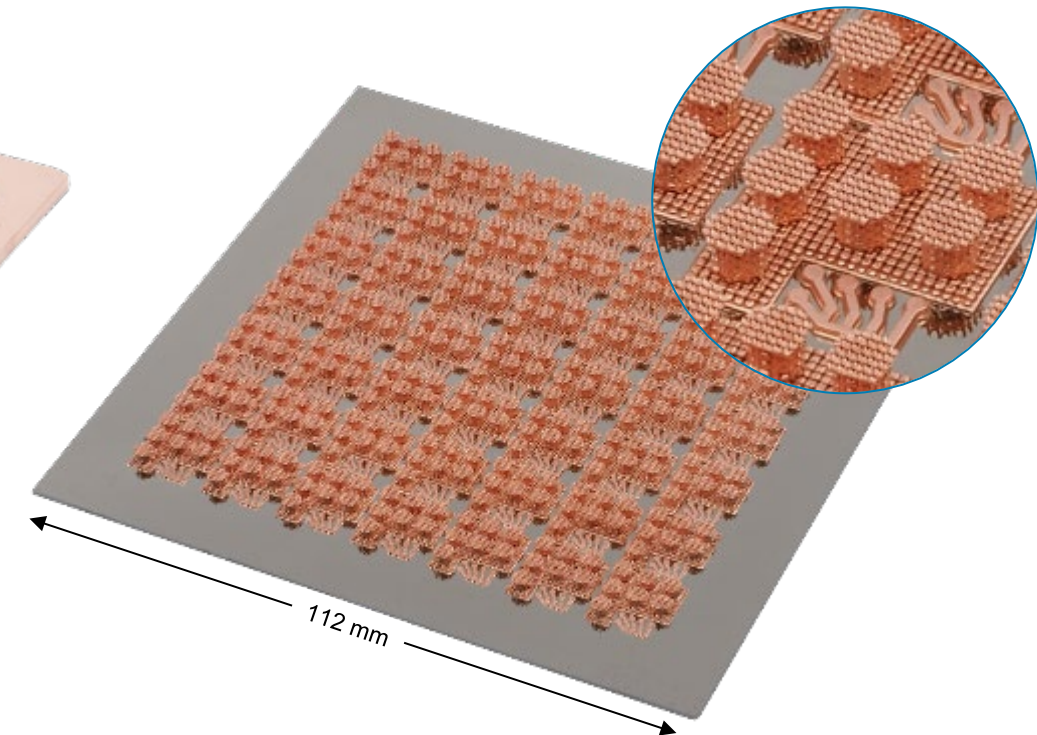
High-resolution, Pure Copper
Features Unique to ECAM



Application Optimized through
Generative AI Driven Design



Direct-print to SiC, DBC, and Foil to
simplify assembly workflow



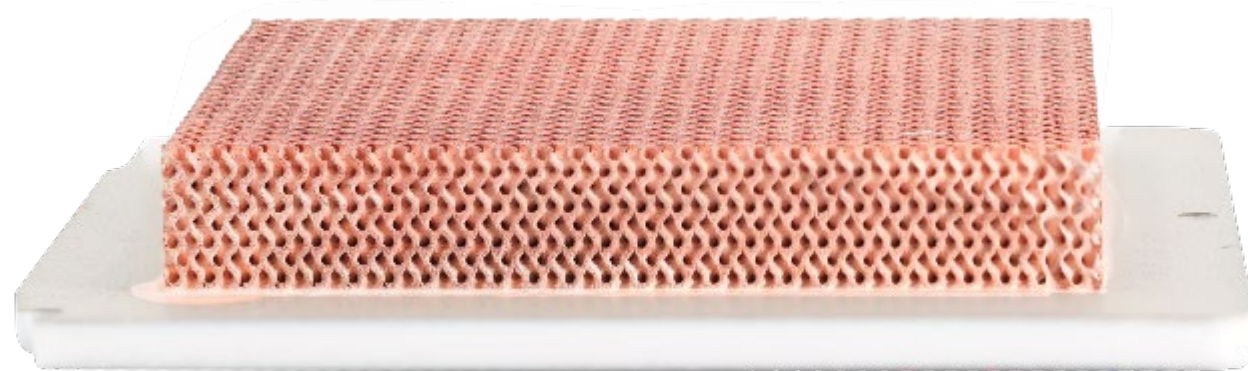
**Enables electrical & thermal performance to meet industry roadmap requirements.
ECAM product costs are comparable to traditional manufacturing.**

Direct Print To Silicon, Glass and Ceramic Substrates

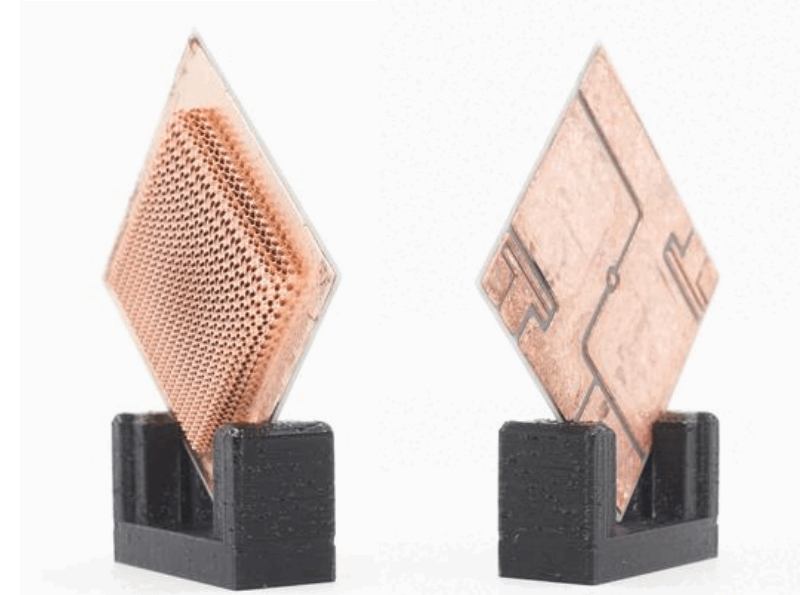
Eliminate CTE mismatch between IC and cold plate



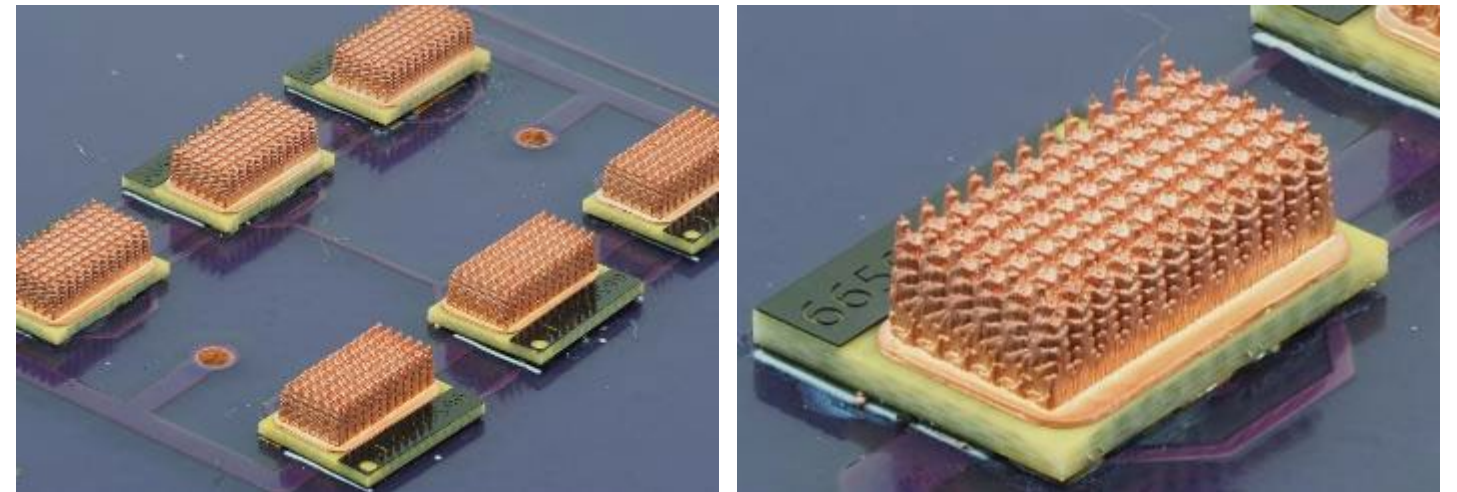
Silicon



Alumina



Direct Bond Copper (DBC) on Ceramic (AlN)

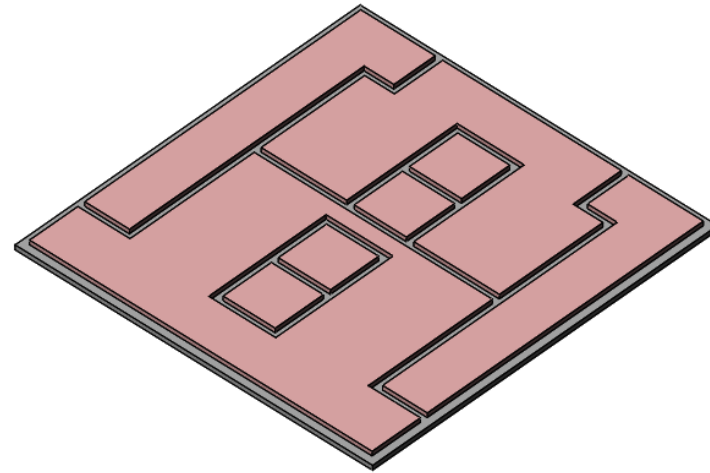


GaN Chip

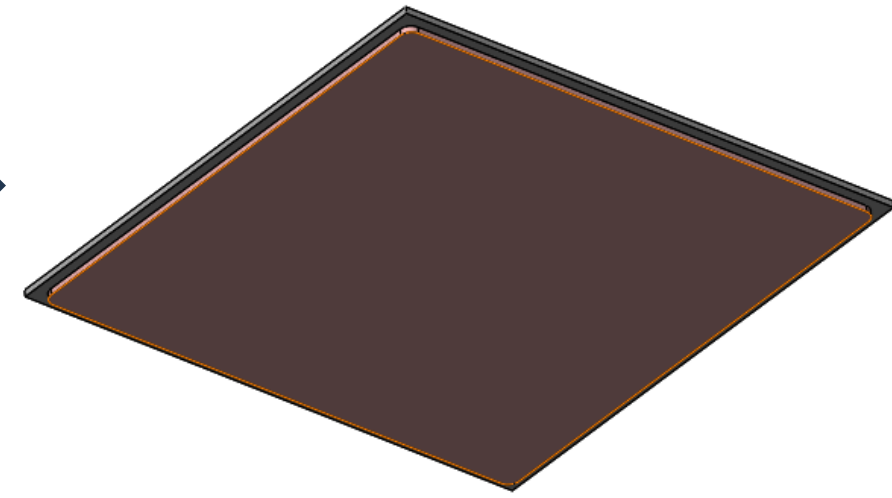
ECAM's Key Features For Power Electronics Substrates

Current Technology Direct Bond Copper (DBC) Substrate

Flat circuit
no features on either side



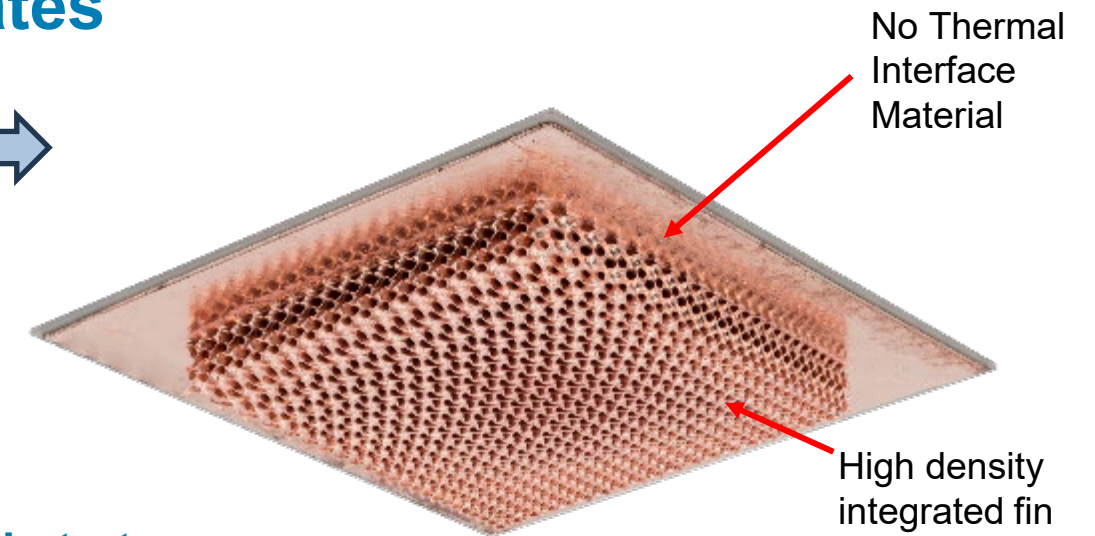
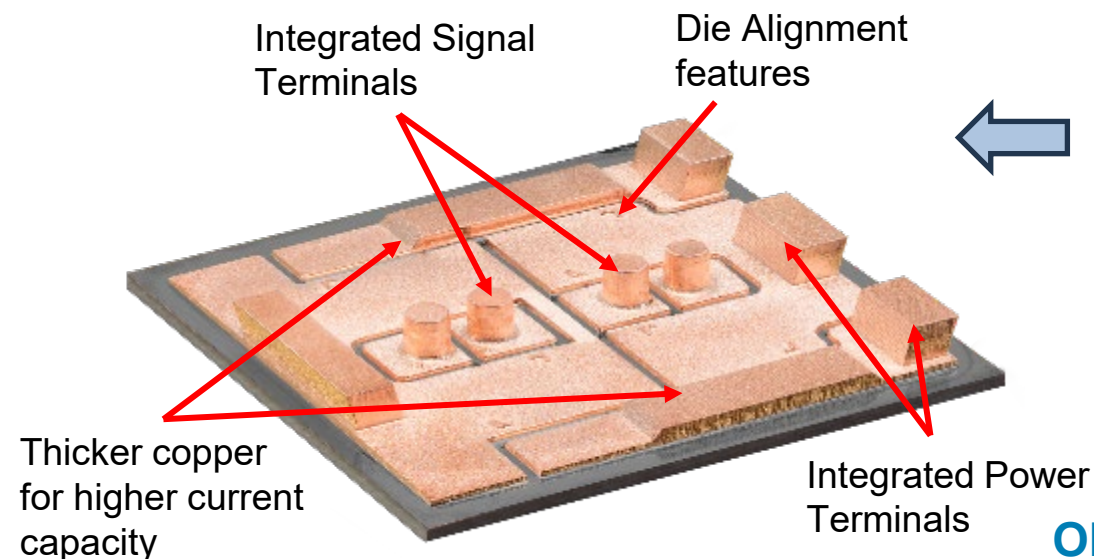
Circuit / Component Side



Heat Dissipation Side

ECAM 3D Substrates

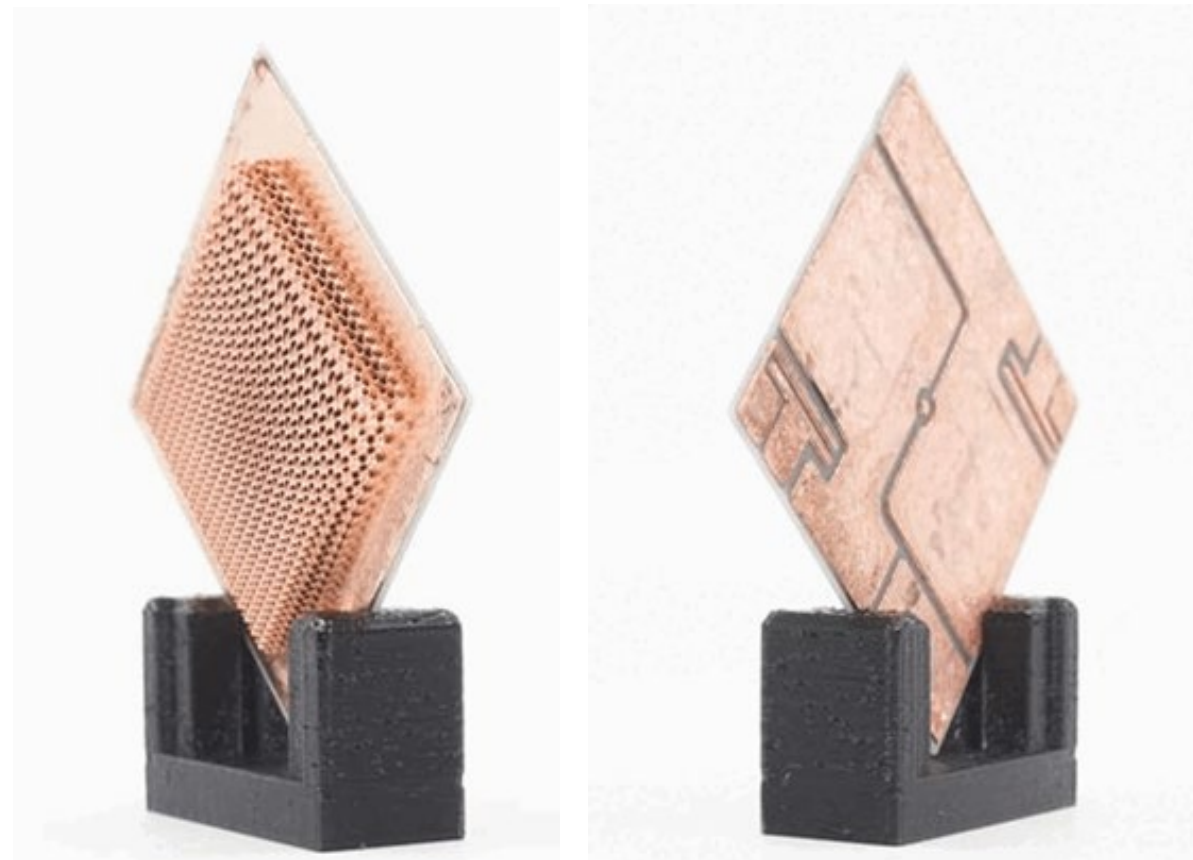
Enhanced Features on
both sides



**Objective: Next Gen DBC Substrates
with Electrical And Thermal
Performance Improvements**

Thermal Performance and Total Cost Improvement

Remove Baseplate & Thermal Interface Materials for Thermal Efficiency and Lower Cost



Liquid Cooling Structures
Directly Printed onto DBC Substrate

ECAM Enables Thermal Resistance Reduction

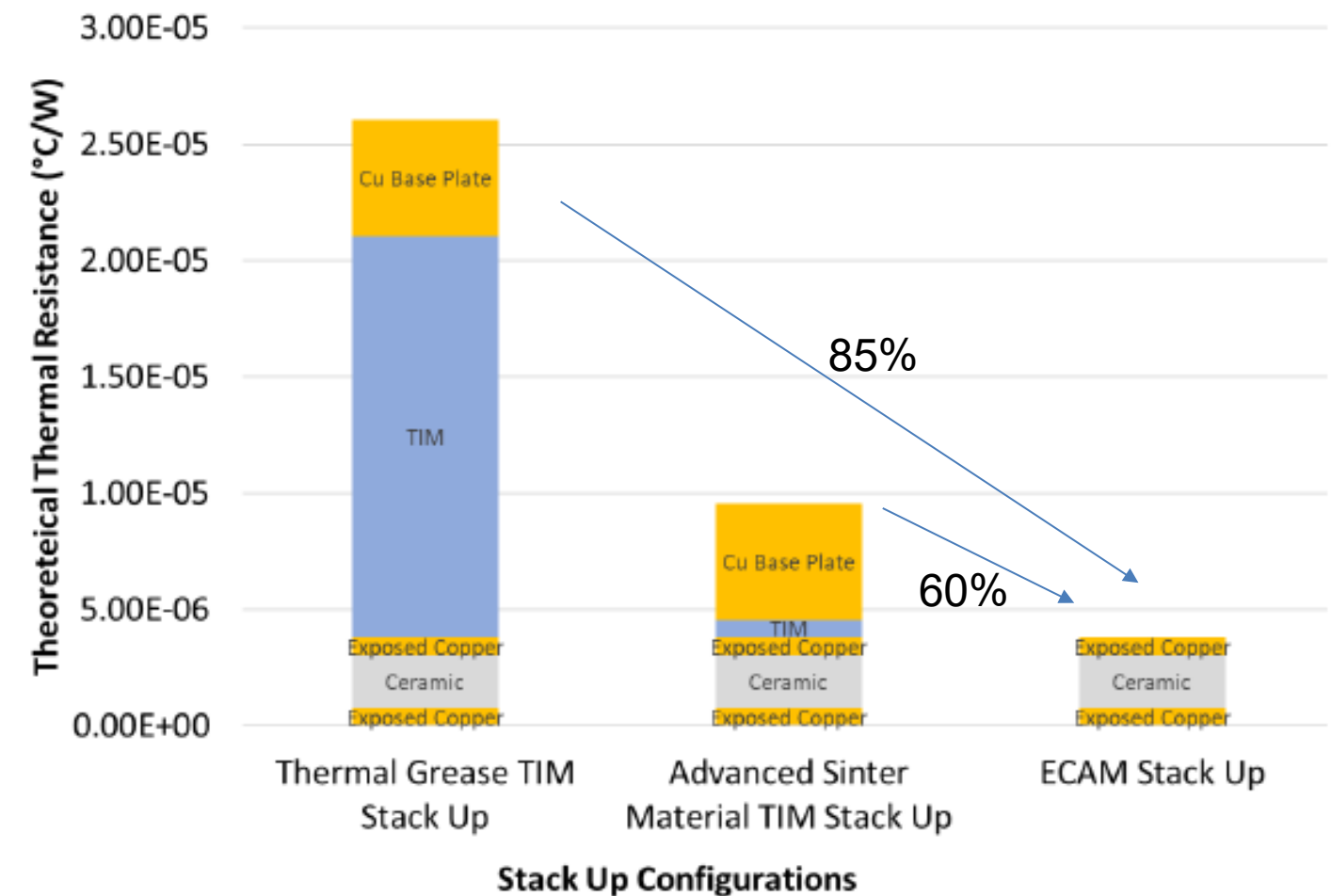
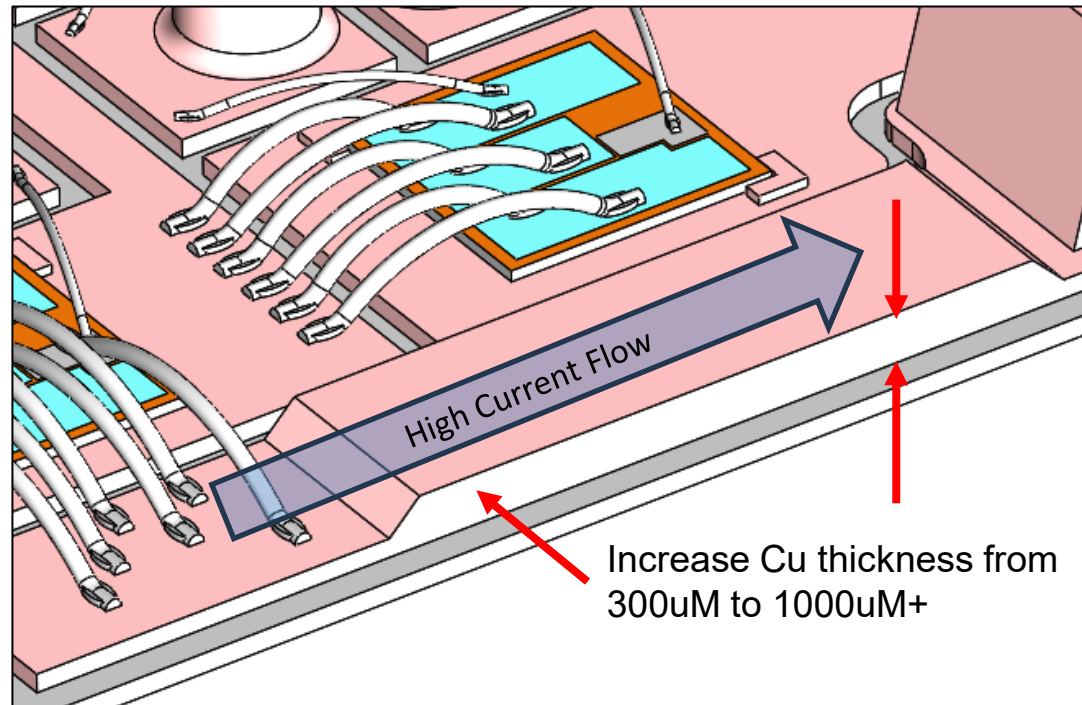


Figure 5 - Theoretical thermal resistance of various stack up configurations

ECAM Key Features Enhance Thermal & Electrical Performance

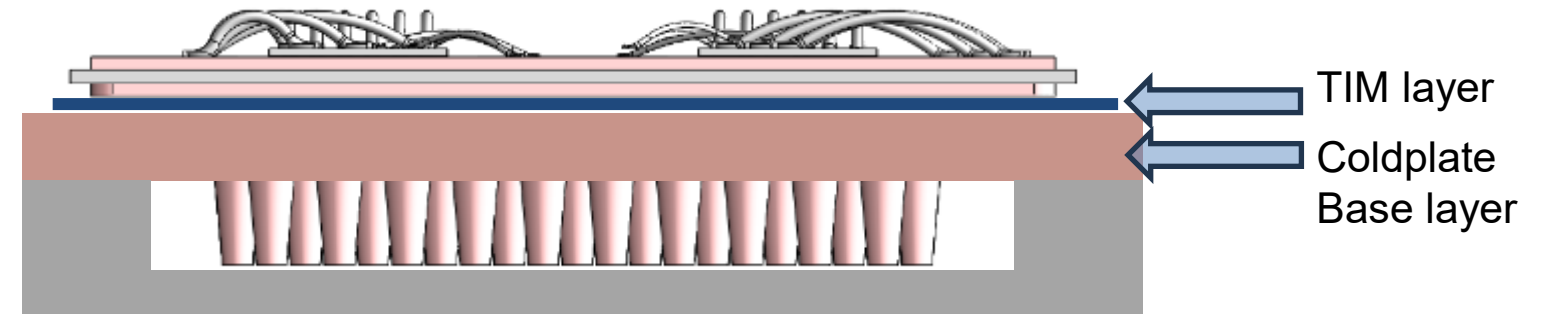
High Current Carrying Capacity



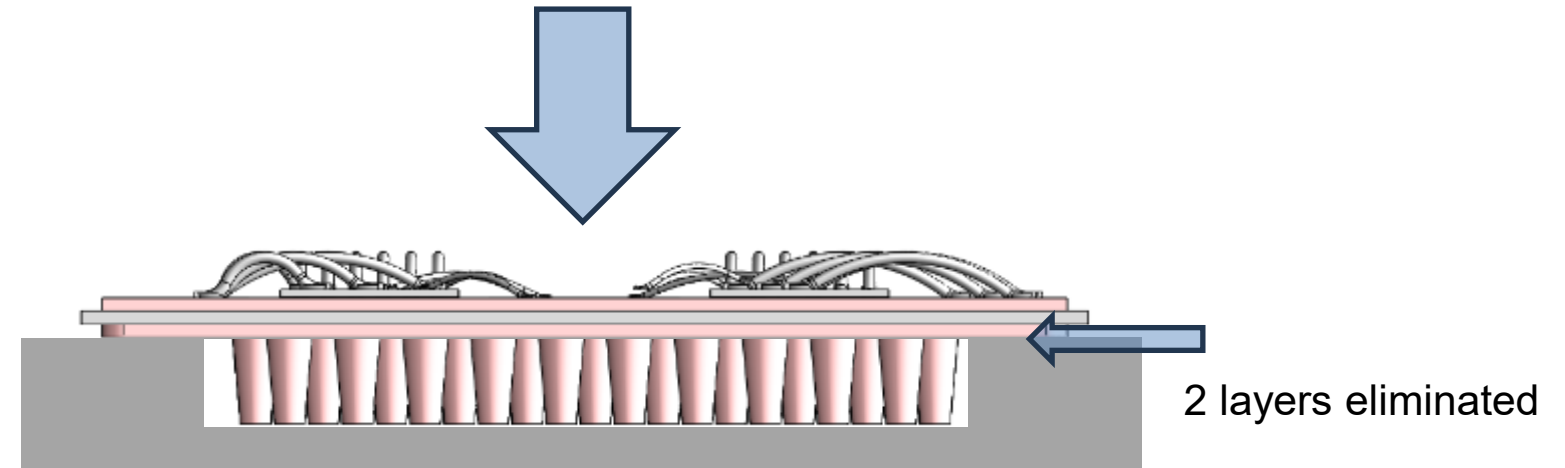
Increasing Cu trace thickness in specific regions reduces current density and Joule heating, improving current rating in those areas by 50%.

This also reduces thermal influence on the die (less proximity heating) and can enable a smaller package size.

Improved thermal resistance



Standard Configuration

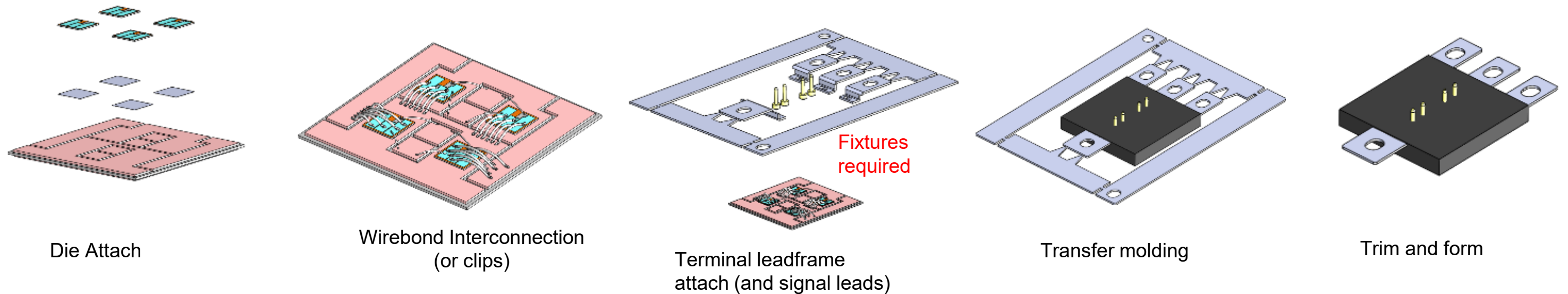


ECAM "Direct Fin" Configuration

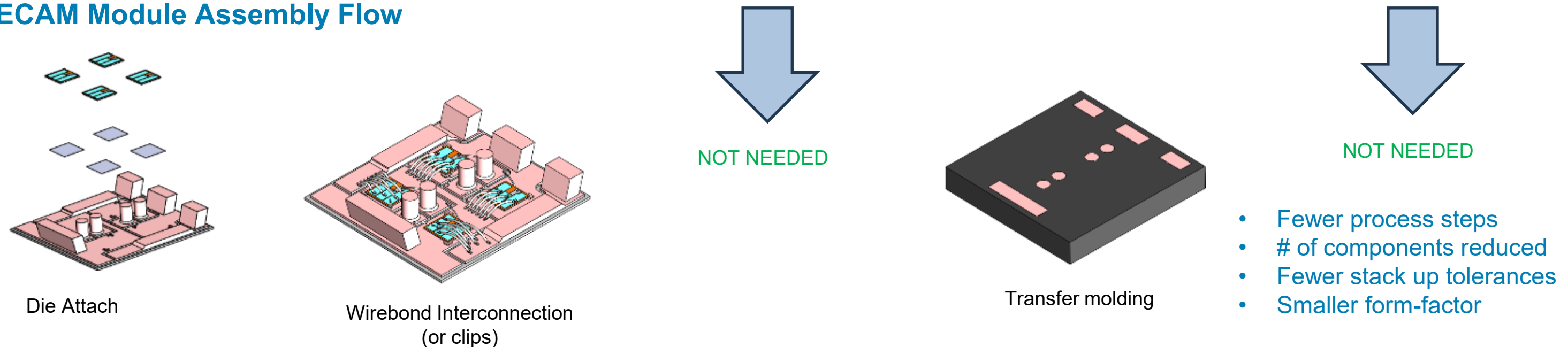
Eliminating the TIM and coldplate base layer improves thermal resistance, allowing for higher current rating (more output power), or higher power density.

ECAM Power Electronics: Manufacturing & Cost (TCO) Benefits

Standard Assembly Flow



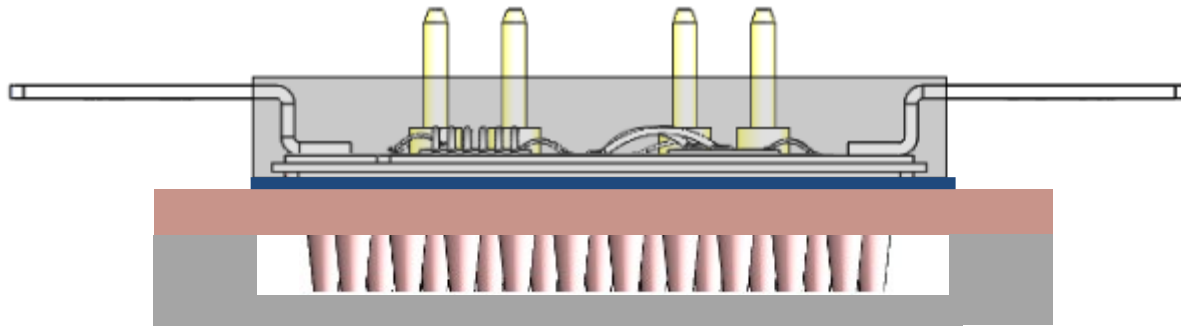
ECAM Module Assembly Flow



- Fewer process steps
- # of components reduced
- Fewer stack up tolerances
- Smaller form-factor

ECAM Power Electronics: Reliability Benefits

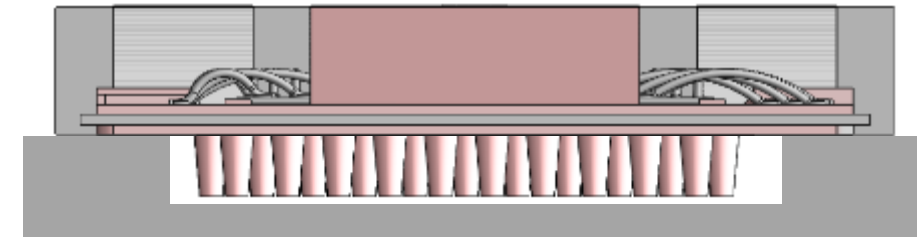
Standard Power Module



Attachment layers and CTE mismatches:

1. Die to substrate (2.5ppm to ~6ppm)
2. Terminal leadframe to substrate (17ppm to ~6ppm)
3. Signal terminals to substrate (17ppm to ~6ppm)
4. Mold compound to DBC/Die (~11ppm to ~6ppm/2.5ppm)
5. Mold compound to leadframe and signal terminals (~11ppm to 16ppm)
6. DBC to coldplate/heatsink (~6ppm to 16ppm or 22ppm)

ECAM Power Module



Attachment layers and CTE mismatches:

1. Die to substrate (2.5ppm to ~6ppm)
2. Mold compound to DBC/Die (~11ppm to ~6ppm/2.5ppm)
3. Mold compound to integrated power and signal terminals (~11ppm to 16ppm)

ECAM Technology results in:

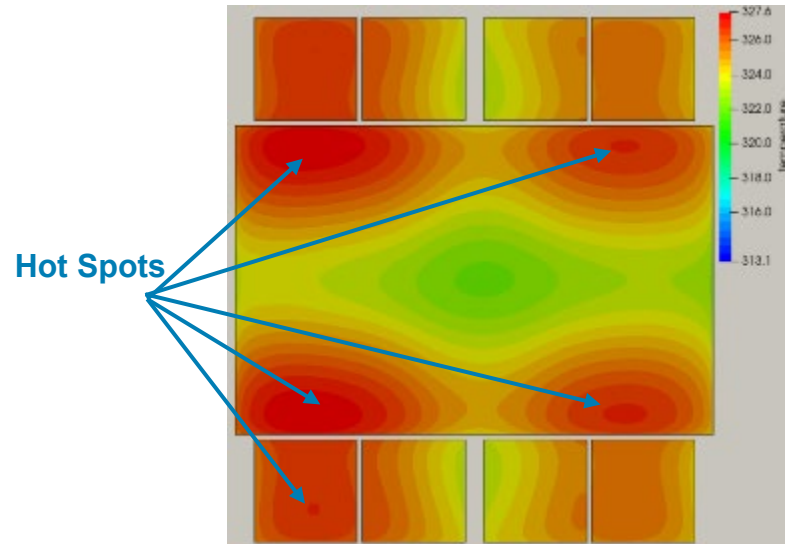
- Reduced component count
- Fewer attachments
- Significantly reduced CTE mismatch throughout package stack

Fabric8labs Has Ongoing Work To Build And Test Modules To Validate Reliability Benefits.

Customized Cooling ‘Case Study’ for Next Gen AI Chip: B200

Chip-layout specific cooling structures address hot spots and reduce TCO

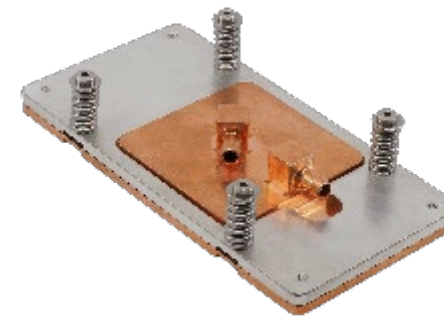
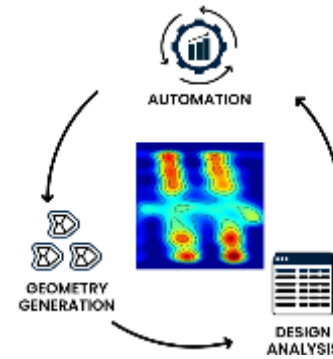
Current Liquid Cooling is limited by
Skived Microchannels
(Example: 250/250 μm wall/gap)



Max Baseplate Temp (°C)	Thermal Resistance, Rth (°C/W)	Temperature Variance, (°C ²)	Pressure Drop (psi)
54.5	0.0145	1.6	0.28

Power: 1000W
Coolant H₂O, 1.5 L/min, 40°C

Design Optimization for
Chipset Power Map



27% improvement in
Thermal Performance

139% improvement in Cold
Plate Temperature Variance

Customized ECAM Solution, Optimized
Thermal-Hydraulic Performance
Optimized Fin Structures

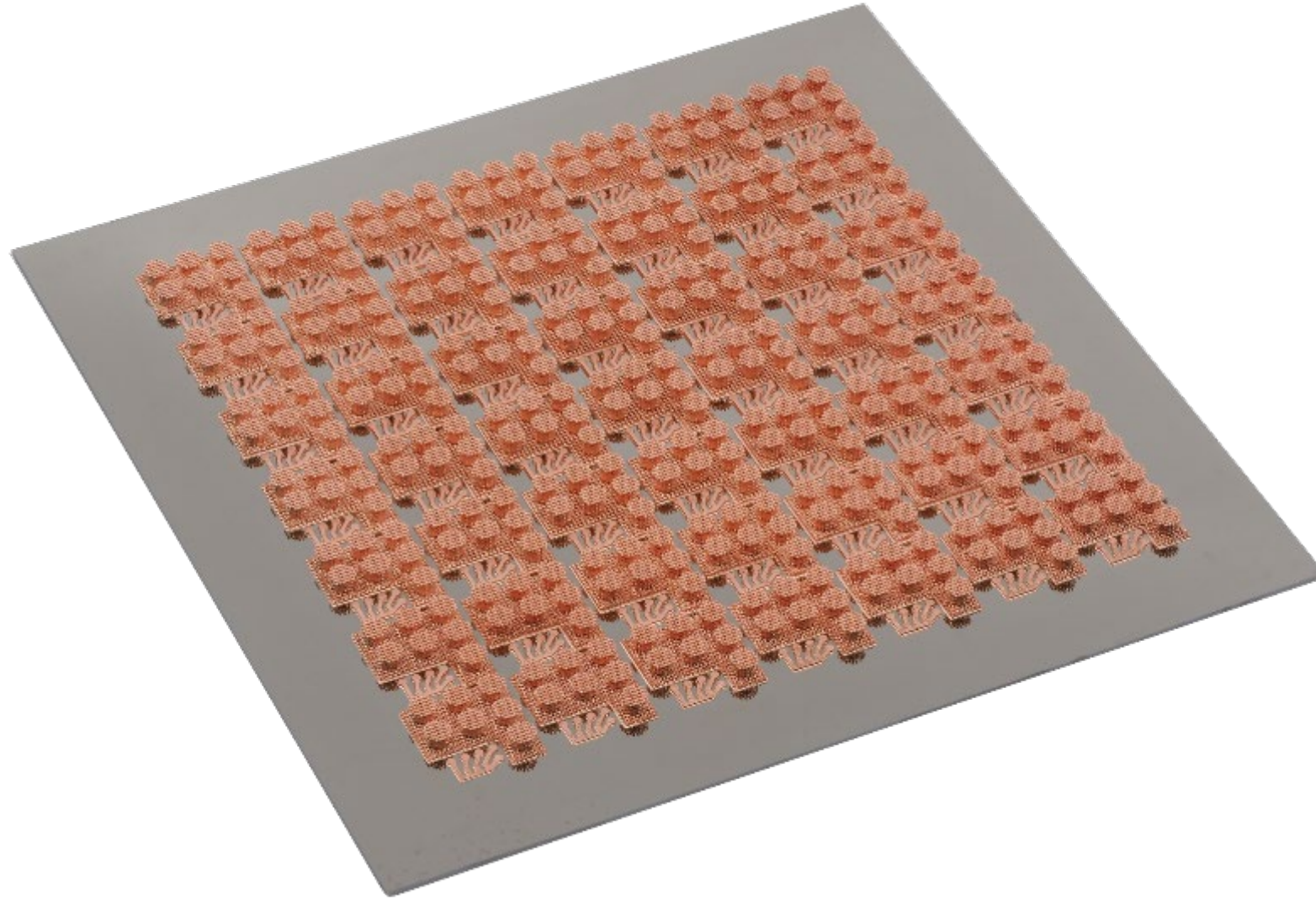


Eliminates Hot
Spots

Max Baseplate Temp (°C)	Thermal Resistance, Rth (°C/W)	Temperature Variance, (°C ²)	Pressure Drop (psi)
51.4	0.0114	0.67	0.78

Power: 1000W
Coolant H₂O, 1.5 L/min, 40°C

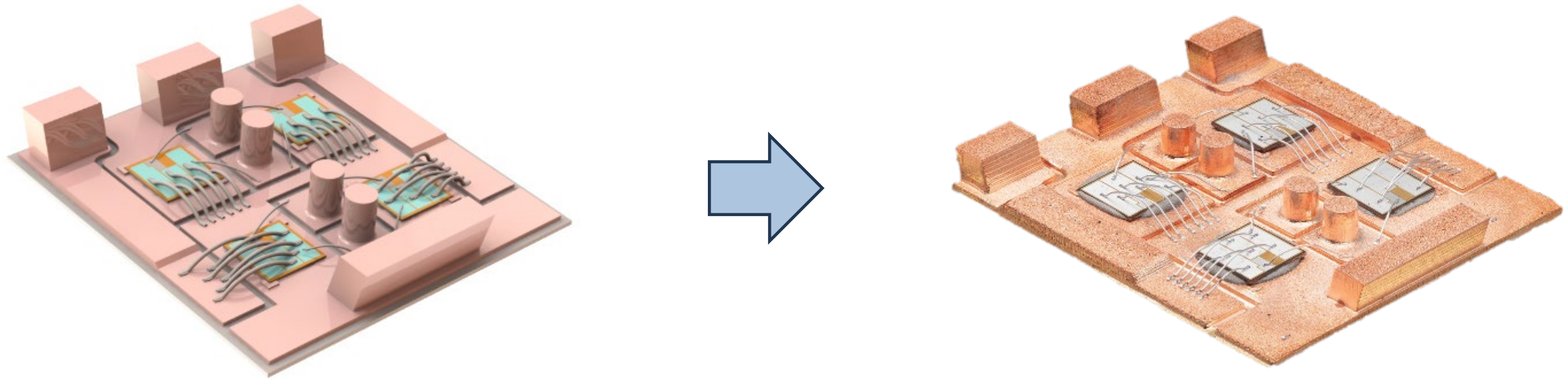
Potential for Wafer Scale Processing



112 x 112 mm Silicon with printed structures

Summary & Next Steps

Prototyping & Early Customer Engagement



- Power electronics is a large growing market where ECAM-enabled substrates and cooling components have potential
- Initial prototypes have been produced with ECAM features, initial testing of performance and reliability to be performed
- Demonstration parts being used to discuss value proposition with customers

Contact Us

Michael Matthews – VP Commercialization – Michael.Matthews@fabric8labs.com

Ian Winfield – VP Product and Applications – Ian.Winfield@fabric8labs.com

Nichole Romine- Sr. Project Engineer – Nichole.Romine@fabric8labs.com

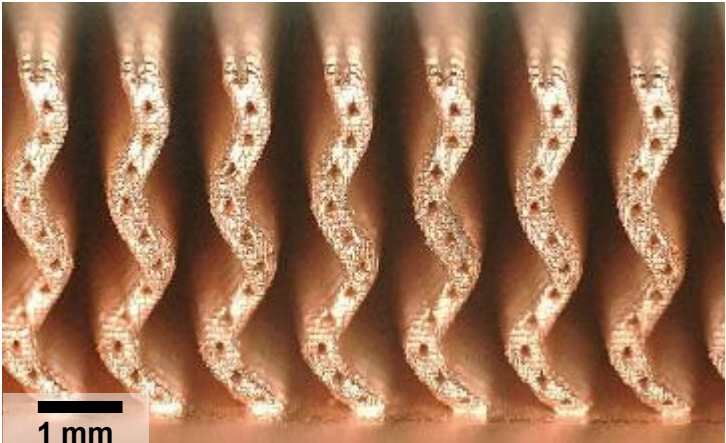
FABRIC8LABS



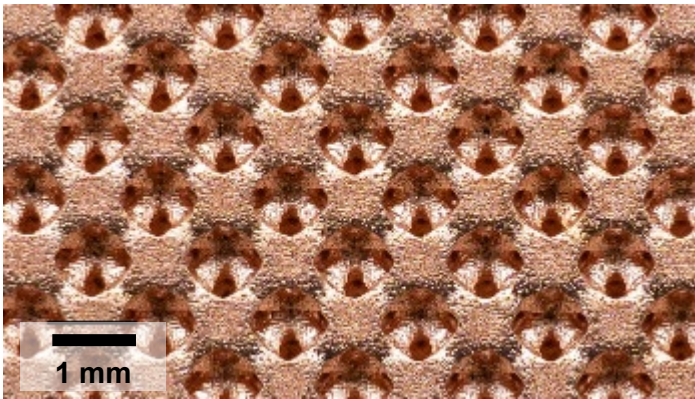
ECAM Copper Performance and Capabilities

ECAM Pure Copper

Attribute	Performance
Purity	>99.95% Cu
Tensile Strength (UTS)	45-55 ksi
Electrical Conductivity	93-98+ %IACS
Thermal Conductivity	380 W/m-K
Grain Size, Avg.	500 nm
Surface Finish, Ra	≤ 50 micro-inches



High-Resolution
Ultra-Precise Features
in Pure Metal



Complex Lattice Structures
for Light-Weighting Designs
and Maximizing Surface Area

ECAM Printer Platform

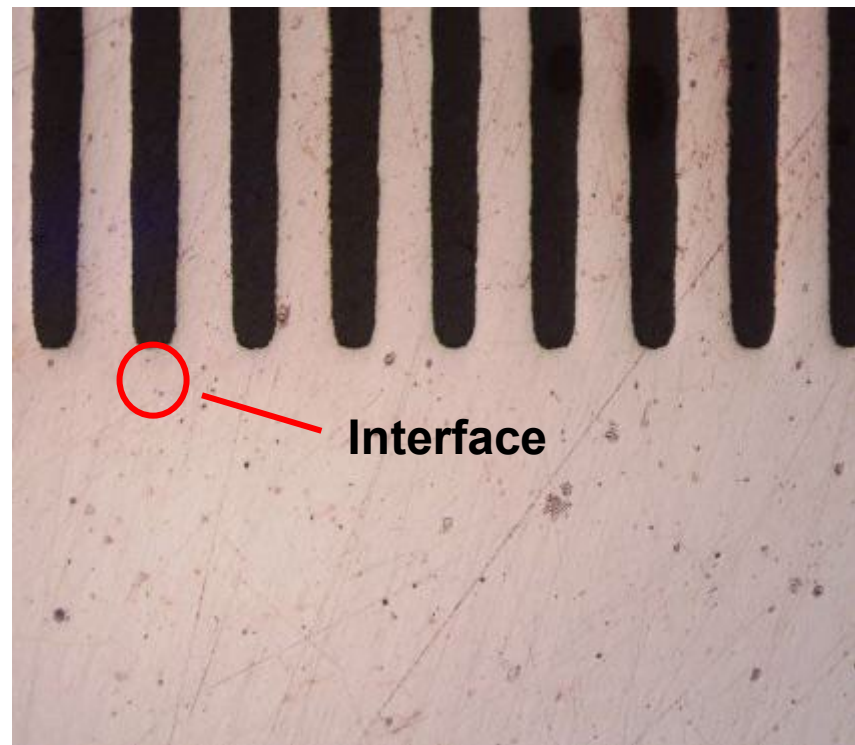
Resolution (Voxel Size)	33.33 µm
Minimum Feature Size	67 µm
Build Area	120 x 120 mm



Direct Printing onto
Temperature Sensitive
Substrates

ECAM Copper Microstructure and Interface Analysis

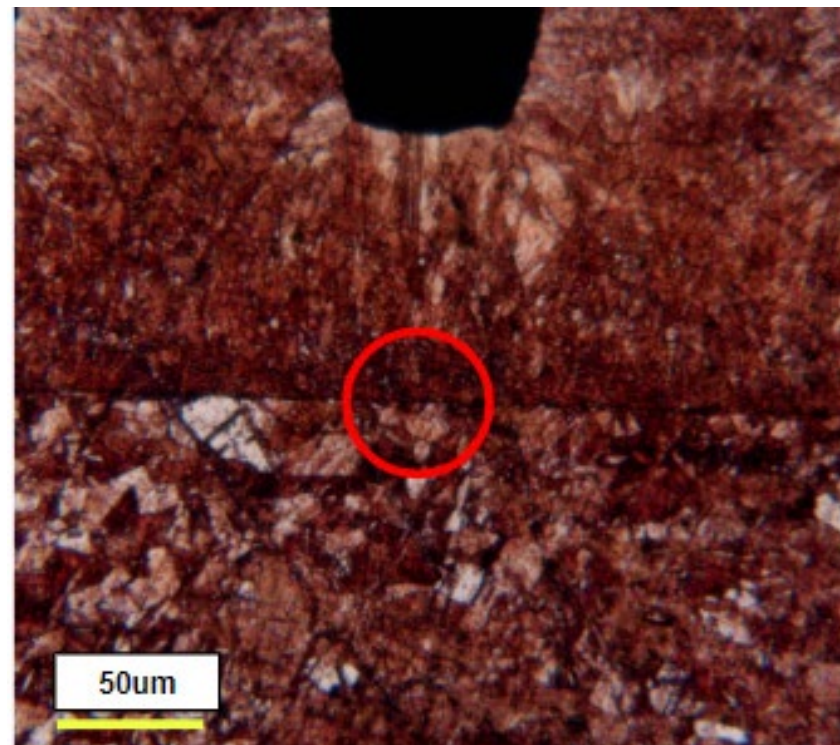
Copper cooling fins printed onto copper substrate



Mount and mechanical polish
optical inspection

Printed
Structure

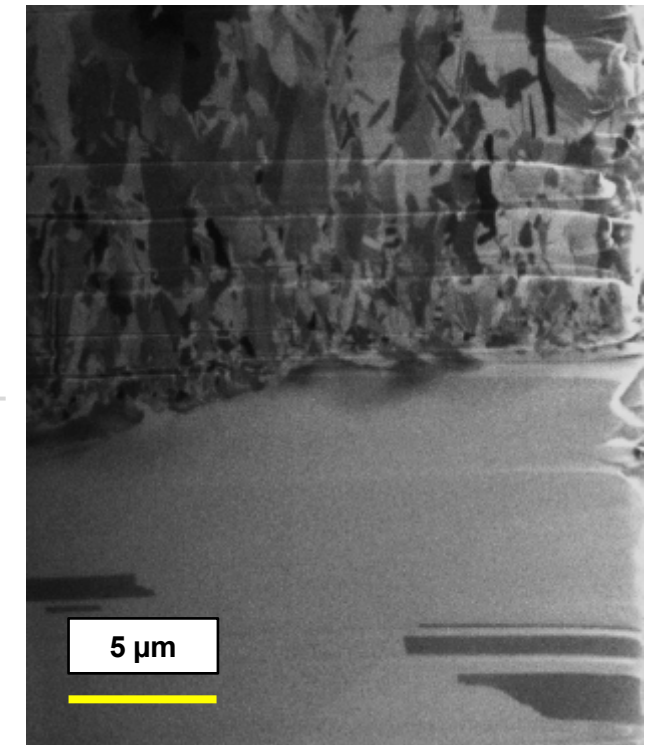
OFHC
Substrate



Etched Surface: $\text{FeCl}_3(\text{H}_2\text{O})_x + \text{HCl}$
50x Magnification

Printed
Structure

OFHC
Substrate



Focused Ion Beam
Cut + Imaging

Metallurgically bonded, fine grained Cu microstructure

ECAM: Scalable And Sustainable Manufacturing

L-PBF

Laser Powder Bed Fusion

REFINED COPPER



COPPER BILLET



COPPER POWDER



3D PRINTING



POST-PROCESSING



FINISHED PRODUCT



COPPER ORE

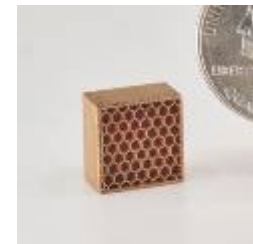
SCRAP COPPER



3D PRINTING



FINISHED PRODUCT

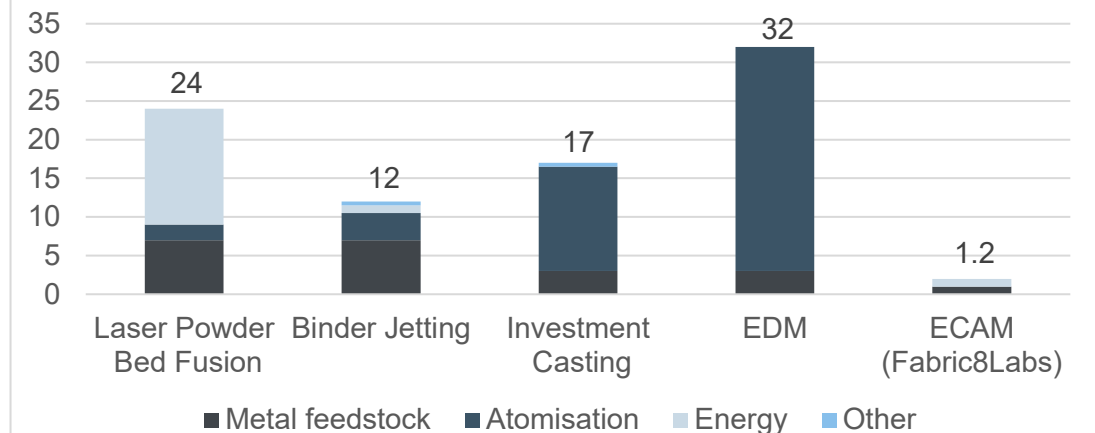


COPPER OXIDE

ECAM

Electrochemical Additive Manufacturing

GHG Footprint By Manufacturing Method
kg CO₂e per kg Copper Produced



>90% Reduction in GHG emissions vs. alternative methods

Low-cost feedstock and no post-processing requirements enable mass scalability