HETEROGENEOUS INTEGRATION ROADMAP

Heterogeneous Integration Roadmap Symposium 2024

Additively Manufactured Electronics (AME) for Heterogenous Integration

Kris Erickson

Meta

Feb '24

IEEE · IEEE photonics Society · semi · IEEE Electronics Packaging Society · ASME · Electron Devices Society

Agenda

1. AME for HIR Chapter Update
2. AME Applications
3. AME Growth Needs
4. Chapter Engagement & Next Steps

Large collaborative team for creating full content!

Finalizing as a Chapter within HIR 2024

HETEROGENEOUS
INTEGRATION ROADMAP

Technical Working Group Contributing Members

Kris Erickson
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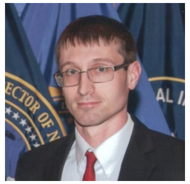
Dishit Parekh
(Intel)

Alex Cook
(Nextflex)

Jeroen van den Brand
(Holst Center)

Mike Newton
(Sciperio)

Annette Teng
(Promex)



David Bowen
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Mark Poliks
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(Jabil)

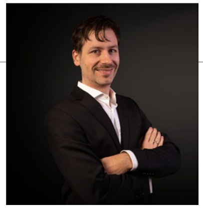
Martin Hedges
(Neotech AMT)

Dean Turnbaugh
(NTV)

David Weins
(Siemens)

Richard Neill
(ADVPES)

David Rosenfeld
(Celanese)



Markus Scheibel
(Heraeus)

Chapter Layout

Number	Section	Sub-Section	Write-up Lead
1.1	**Introduction**	Executive Summary	Kris Erickson
1.2		Overview	Kris Erickson
1.3		AME Benefits & Drawbacks	Jeroen van den Brand; Rich Neill
2.1	**AME Fabrication Methods**	FFF/FDM	Martin edges
2.2		Powder Bed-based	Jarrid Wittkopf
2.3		SLA/DLP	Kris Erickson
2.4		Screen Print	Girish Wable
2.5		Additive + Subtractive	Alex Cook
2.6		Aerosol Printing	Martin Hedges; Rich Neill
2.7		Electrohydrodynamic Jetting	Dean Turnbaugh
2.8		Thermoforming/MID	Christine Kallmayer
2.9		Piezo Valve	Martin Hedges
2.10		Inkjet	Kris Erickson
2.11		Laser Direct Structuring	David Bowen
3	**AME Design Tools**	Design Tools - 2D, 3D	David Weins; Martin Hedges
4.1	**AME Materials**	Conductive Materials	Markus Scheibel
4.2		Printed Thick Film	Dave Rosenfeld
5.1	**AME Applications**	Printed Passives	David Bowen
5.2		Thermal	Ercan M. Dede
5.3		Optical/Photonics	Annette Teng
5.4		AME for Wearables	Dishit Parekh
5.5		Printed Sensors	Christine Kallmayer

Additively Manufactured Electronics (AME)

AME = Printed Conductor + (Printed/Existing) Dielectric + (optional) Additional Processes

AME Deposition
Dot Deposition
Line Deposition
Area Deposition

Direct-write & Conformal**

Dispensing & Extrusion Print

Non-contact Jetting Methods

Inkjet Print
Aerosol Print
Electrohydrodynamic Print
Piezo-Valve Jetting
Laser Induced Forward Transfer (LIFT)

*** can deposition on 2D or 3D substrate*

3D Print Methods

Fused Deposition Modeling
SLA (Stereolithography)
2-photon SLA
Digital Light Processing (DLP)
Powder Bed Fusion

Contact 2D Print Methods*

Screen/Stencil Print
Gravure Print
Flexographic Print

** 2D only substrate*

Additively Manufactured Electronics (AME)

Structural Electronics

Pick & Place
Laser Direct Structuring (LDS)
Electroplating

In-Mold Electronics

Pick & Place
Thermoforming

Flexible Hybrid Electronics (FHE)

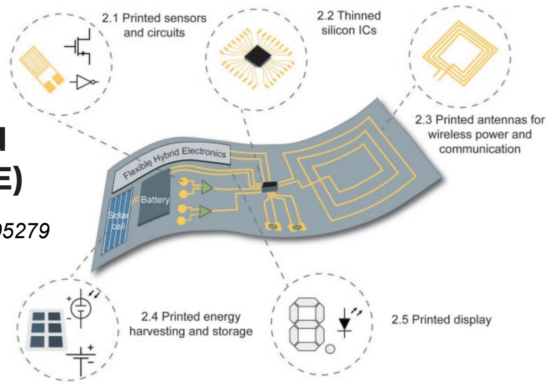
Pick & Place Solder Deposition
Lithographically Defined Features
Over-molding

Additional Supporting Processes

Pick & Place (Si, passives, etc.)
Curing/Sintering
3D Scanning
Metrology
Subtractive (Laser, Milling)

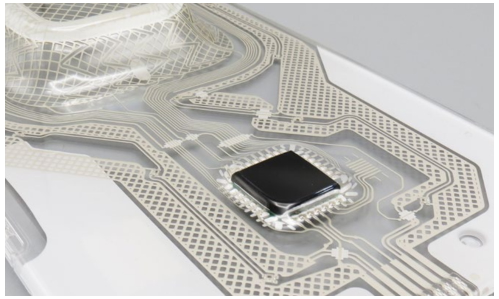
Flexible Hybrid Electronics (FHE)

DOI: 10.1002/adma.201905279



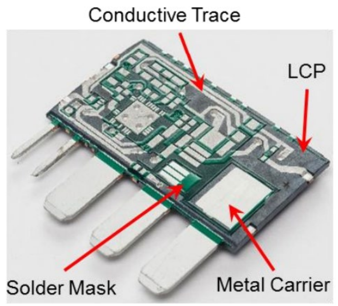
In-Mold Electronics

Project "*Origami*", 02/2018 - 01/2021,
Innovations with Organic 3D Electronics.
#thanks & with permissions from
@Christine Kallmayer and Fraunhofer IZM

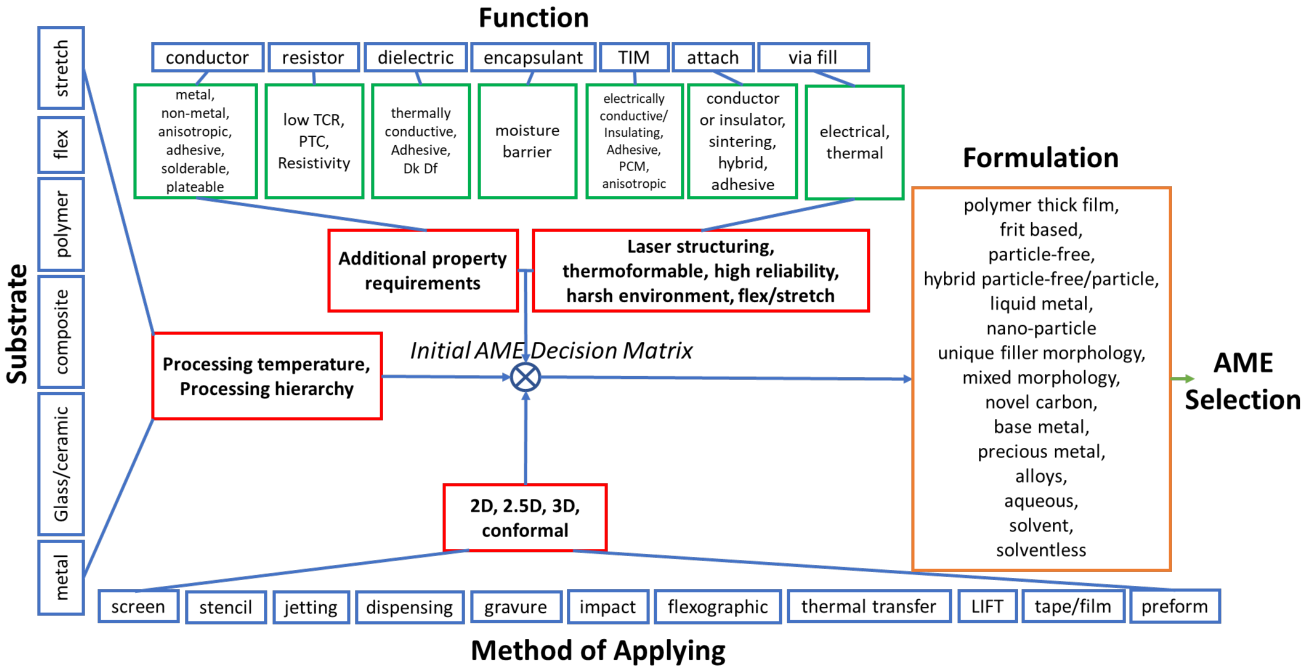


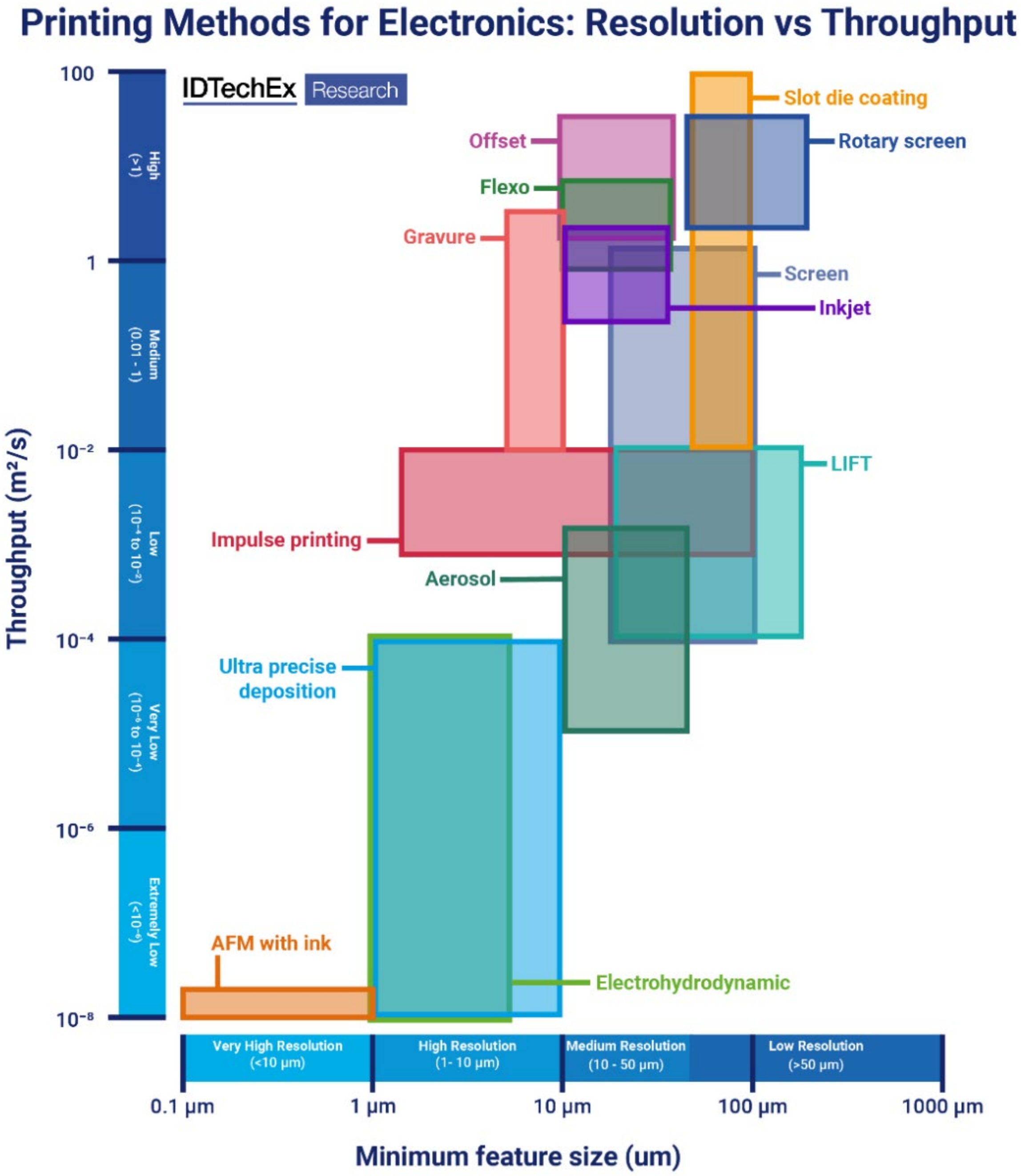
Structural Electronics

DOI: 10.1109/MID50463.2021.9361621



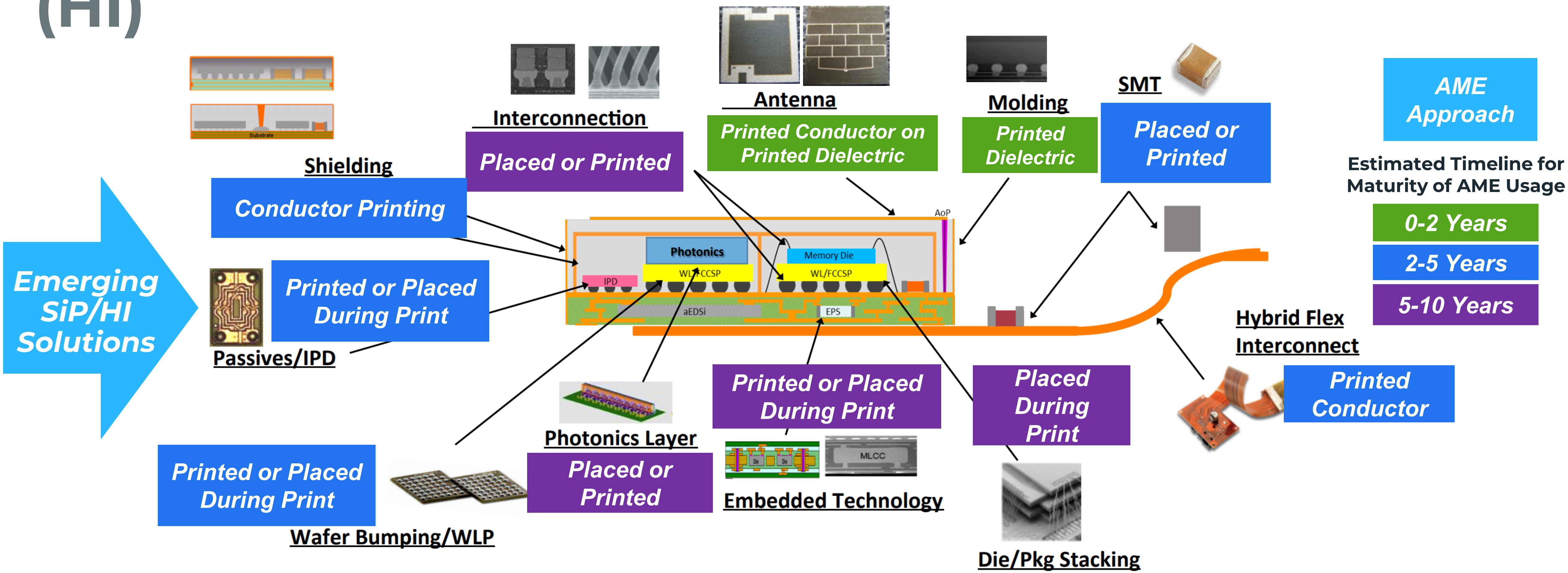
AME Considerations





#thanks to Dave Rosenfeld, Celanese, and AME for HIR group

AME for Heterogenous Integration (HI)



[HIR 2021 version (eps.ieee.org/hir), Ch. 8, Single and Multichip Integration]
In-progress *2024 on HIR Chapter on AME*

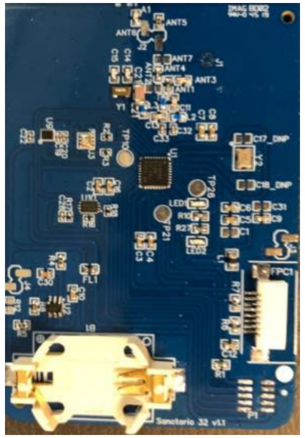
AME Comparison Table

***Legend: X** Typical; **O** Case-dependent; **-** Not typical; **Greyed cell** - Not applicable*

Type	Process	Feature Created				Resolution				Material Properties			Manufacturing Properties		
		Conductive	Dielectric	Conform-ality	Structural	Resolution X,Y (micron)	Resolution Z (micron)	Features sizes (Line/Space[L/S]; dielectric[E]) (micron);	Vias possible	Deposited Materials Forms	Multi-Material?	Max Bulk Conductivity	Build Height per pass (micron)	Deposition Speed (m2/s - areal; mm/s - linear)	Build Dimensionality (0D,1D, 2D, 3D)
	Inkjet Printing	X	X	X	X	20	17	L/S,E - 40/40	X	*inks, photo-resin*	*Y*	2.7E7 S/m	17	0.1-1 m2/s	1D
	Aerosol Printing	X	X	X	O	10	2	L/S - 20	X	*inks, photo-resin*	*Y*	2.7E7 S/m	*0.5-5*	5-30 mm/s	*0D*
	Electrohydrodynamic Jetting	X	X	X	O	0.5	0.5	L/S - 0.5	X	*Inks, pastes, photo-resin*	*Y*	2.7E7 S/m	*0.25-1*	50 mm/min	*0D, 1D**
	Dispensing/Extrusion Printing	X	X	X	O	100	100	L/S - 100	X	*Inks, pastes*	*Y*	2.7E7 S/m	*1-50*	50-500 mm/s	*0D*
Direct Write & Conformal	*Piezo/Valve Jetting*	X	X	X	O	320	5-25	L/S - 320/200	X	*ink, pastes*	*Y*	2.7E7 S/m	*15-25*	15-50mm/s	*0D*
	Powder Bed Fusion	O	X	-	X	100	80	E - 100	O	*powders*	*Y*	2E6 S/m	80-150	**3D -** 25 mm/hr	*0D, 1D*
	Stereolithography (SLA)	-	X	-	X	50-100	50-100	E - 150		*photo-resin*	*N*		20-100	20-36 mm/s	0D
	2-photon SLA	-	X	-	X	0.1-1	0.1-1	E - 1		*photo-resin*	*N*		0.1-10	100-600 mm/s	0D
	Digital Light Processing (DLP)	-	X	-	X	50-100	50-100	E - 150		*photo-resin*	*N*		20-100	**3D -** 10-300 mm/hr	2D
3D Printing	*Fused Form Fabrication (FFF/FDM)*	O	O	O	X	150	50	E - 150	O	*filament, granualte*	Y		20-100	50-150 mm/s	0D
	SLM					50-250	50-250	200-400		*metal powder*	N	*thermal* - Cu** 400 W/mK			0D
	Binder Jet					100	80	150		*metal powder*	N	*thermal* - Cu** 400 W/mK	80-150	**3D -** 25 mm/hr	1D
Thermally conductive 3D Print	*ECAM*					30	30	60		*metal electrodeposition*	N	*thermal* - Cu 400 W/mK			2D
Planar 2D Print	*Screen Printing*	X	X			10-50	25-40	L/S, E - 50/50	X	*pastes*	Y	2.7E7 S/m	1-50	0.01-1 m2/s	2D
	*Laser Direct Structuring****	X	O	X	O	1	1	L/S - 25/25	X			3.48E7 S/m			0D
Hybrid & Structural Electronics	*Additive + Subtractive*	X	X	X	X	10		L/S - 15/15	X					1,000 mm/s **OD** 1E-6 m2/s **2D**	0D

AME HI Applications Flex Use-case

RIGID PCBA



Board: Rigid FR4

Subtractive process

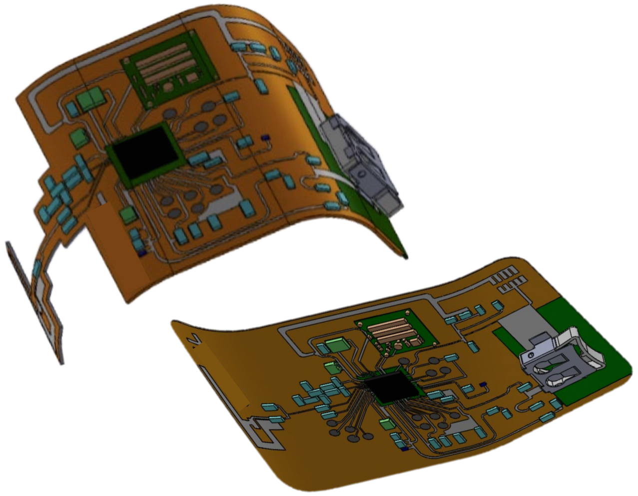
Copper traces

Weight (board): 17 grams

Assembly Temperature – 220 – 250 deg c

Cost: Baseline
PCF - Baseline

RIGID-FLEX or FLEX PCBA



Flexible Polyimide Substrate

Subtractive process

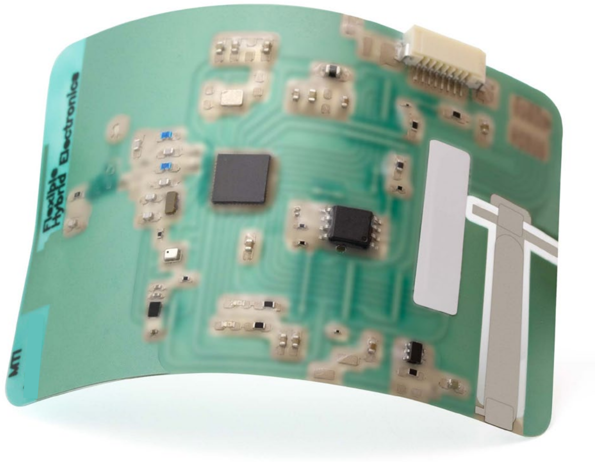
Copper traces

Weight: 6 grams

Assembly Temperature – 220 – 250 deg c

Cost: Higher
PCF - Baseline

FLEXIBLE HYBRID ELECTRONICS



Flexible Plastic Substrates

Printing (additive) process

Silver/Copper traces, Sensors

Weight: 2 grams

Assembly Temperature – 120 deg c

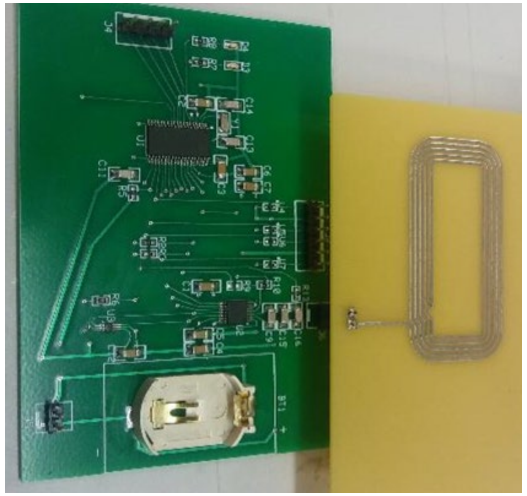
Cost*
Lower compared to Rigid Flex or Flex
PCF – Significantly Better*

*** - more data needed**

#thanks and with permissions from Girish Wable, Jabil

Benefits Leveraging Flexible **Weight** **Temperature** **Cost**

AME HI Applications Wearable Use-case



VALUE TRANSFORMATION

FLEXIBLE BENDABLE CONFORMAL

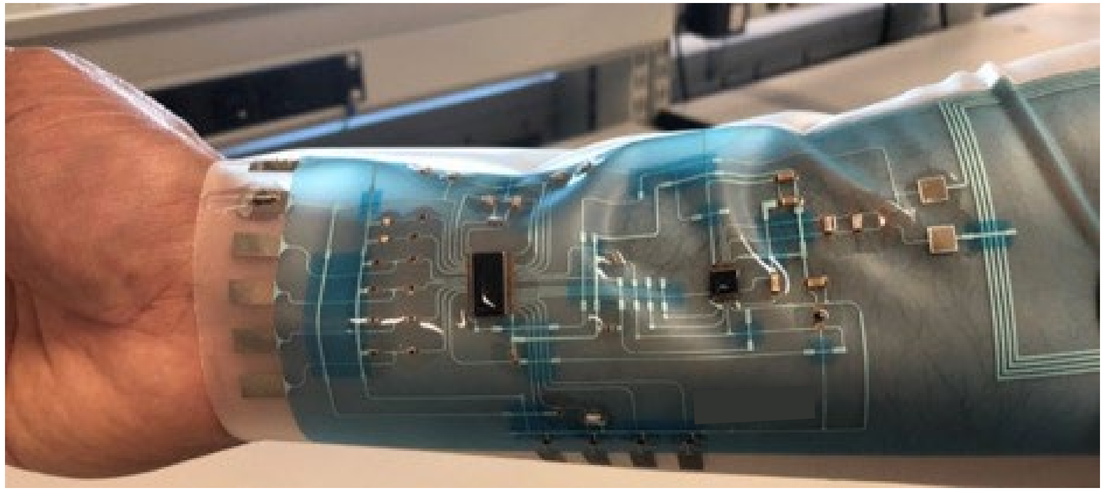
STRETCHABLE LIGHT TWISTABLE

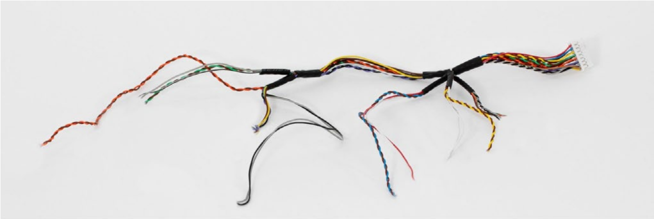
THIN DIRECT-DEPOSITED 3D

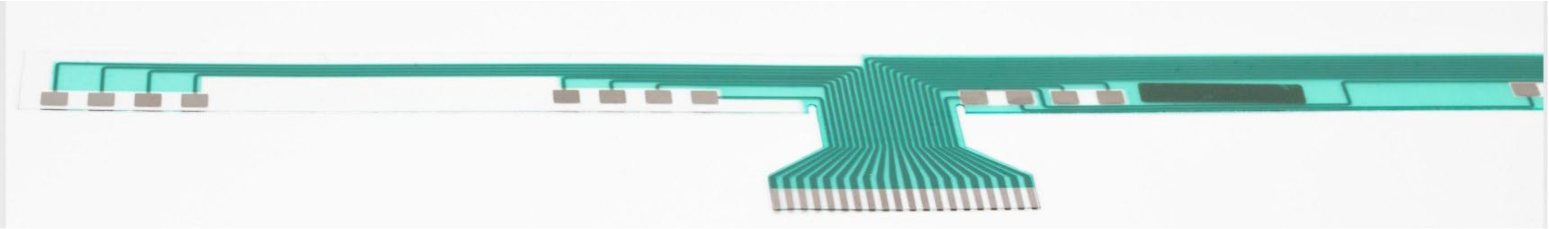
COST BENEFITS

BOM CONSOLIDATION

ASSEMBLY INTEGRATION



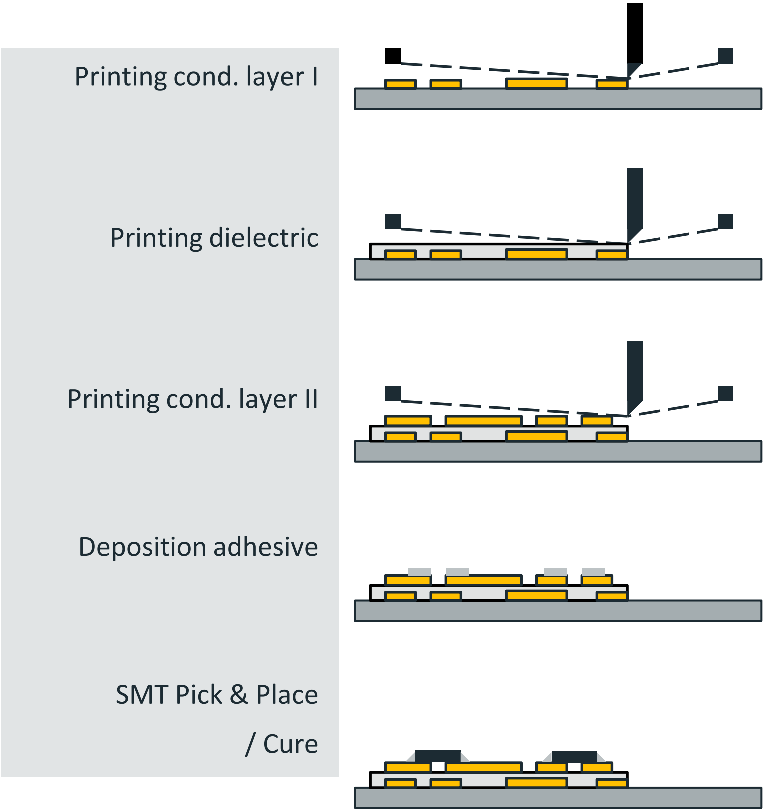


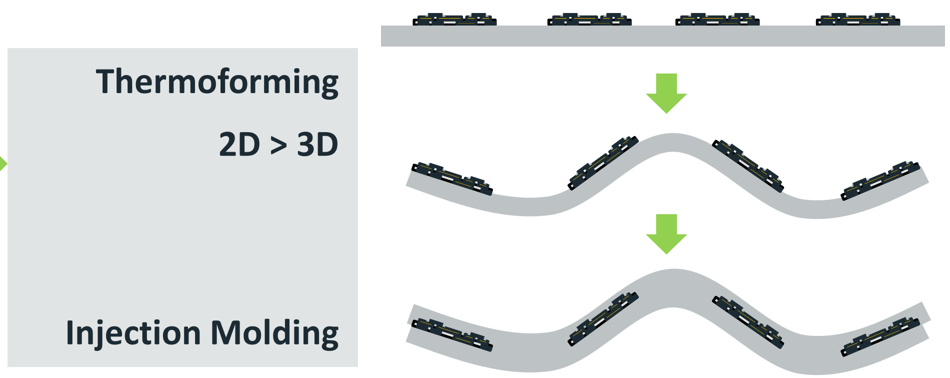


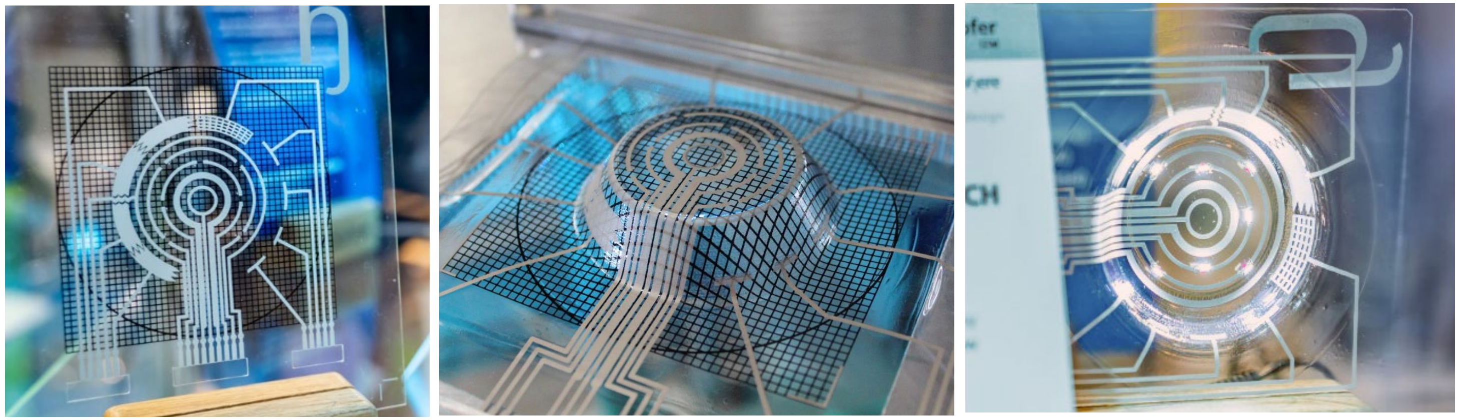
#thanks and with permissions from Girish Wable, Jabil

Benefits Leveraging **Wearability** **Integration** **Cost**

AME HI Applications Structural Electronics



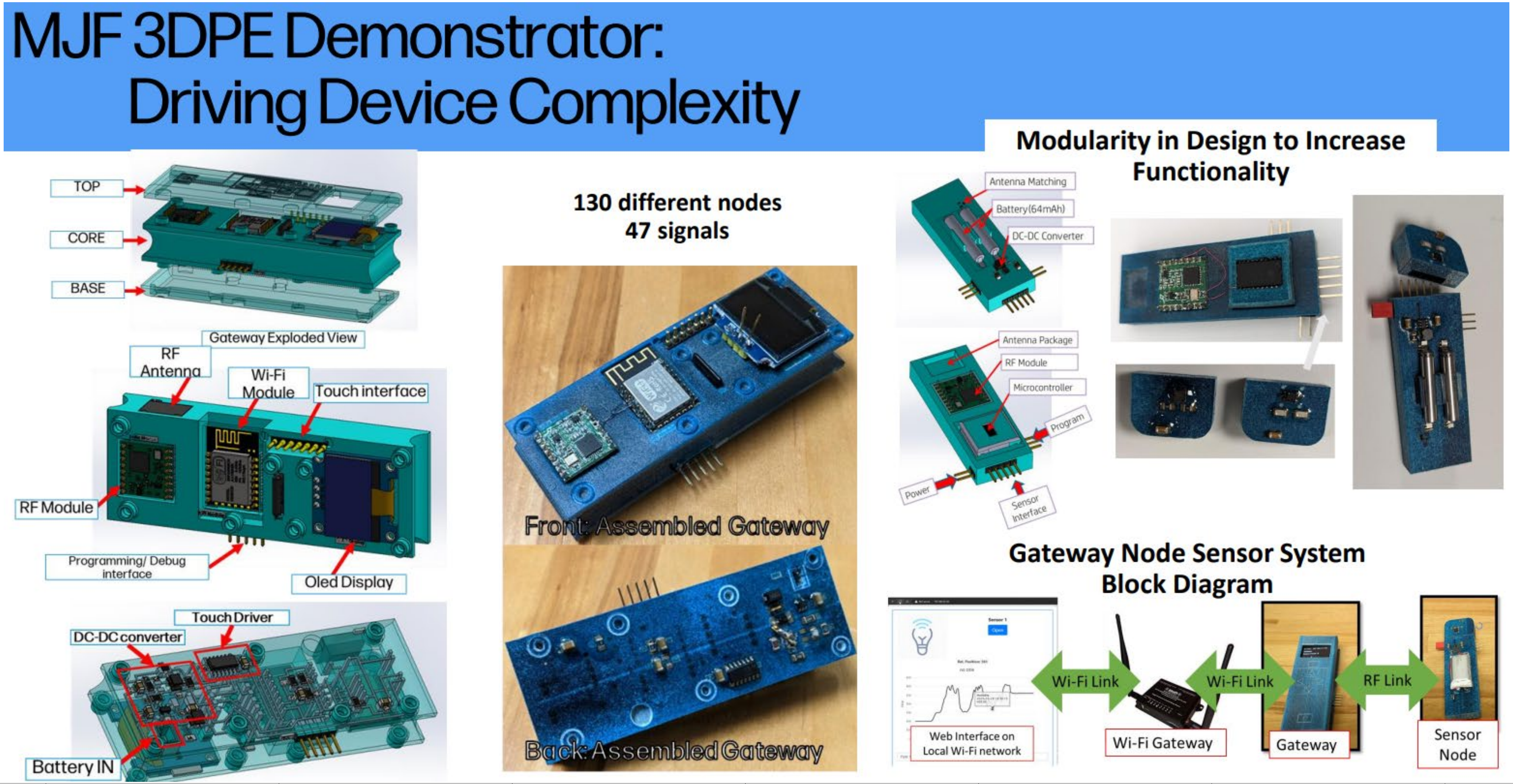




Demo of thermoformed PC foil with printed Ag-conductors and LEDs
Project "*Origami*", 02/2018 - 01/2021, *Innovations with Organic 3D Electronics.*
Funded by BMBF, Germany
#thanks & with permissions from @Christine Kallmayer and Fraunhofer IZM

Benefits Leveraging **Design Freedom**

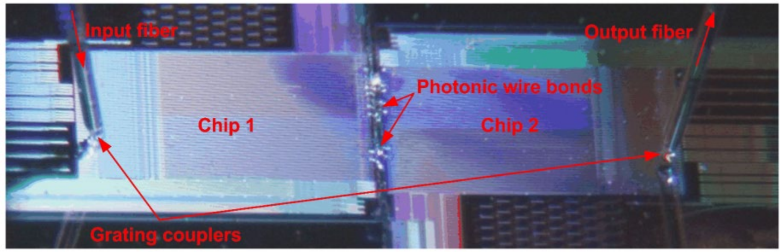
AME HI Applications 3DPE Demonstrator



Benefits Leveraging **3D Integration**

AME HI Applications Optical Wirebond

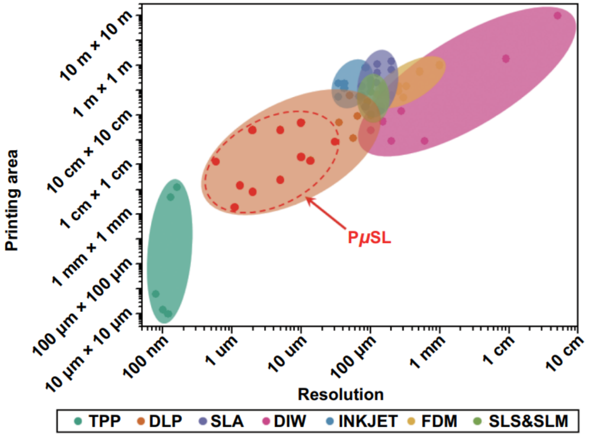
Specific Unmet HI Need
Interconnection Between Optical Chips & Output Fibers



DOI *10.1364/OE.20.017667*

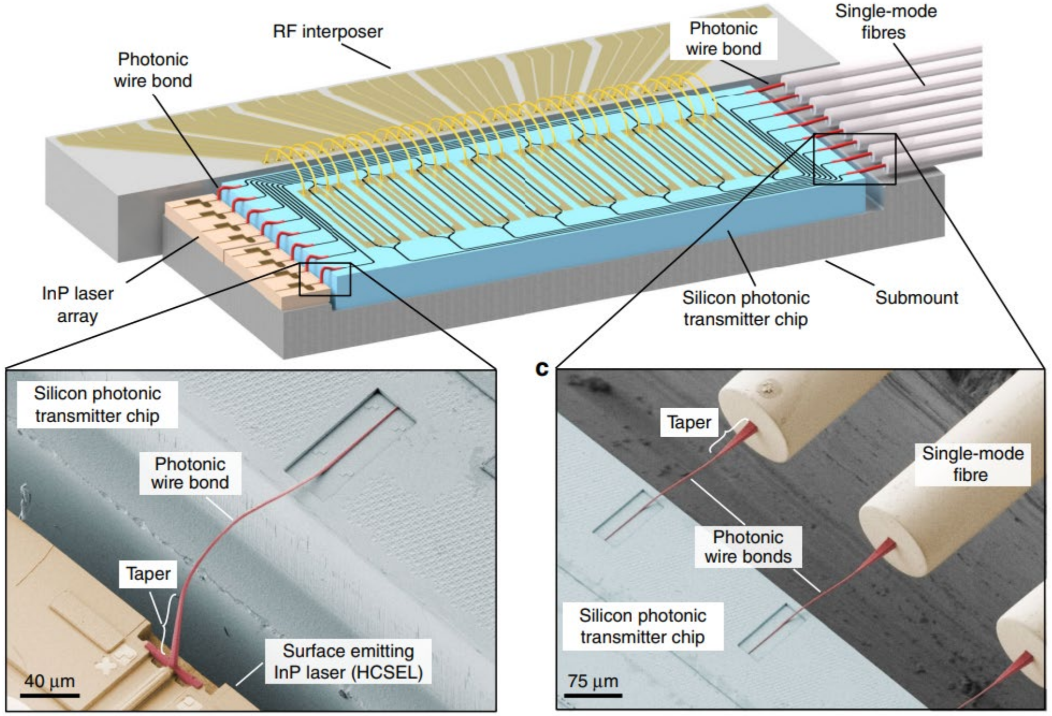
Ultra-high Resolution 2-photon AME
TPP - Two-Photon Polymerization

DOI *10.1088/2631-7990/ab8d9a*



Unique Solution Space

Index Matched Photo-resin
Automated Fabrication, Low losses, Passing Reliability Testing
400-700 GB/s Data Rate Demonstrations



Photonic Wire-bond *doi.org/10.1038/s41377-020-0272-5*

Benefits Leveraging **Unique Need + Unique Solution**

AME HI Applications Thermal

Air Cooled Heat Sinks

[https://www.shutterstock.com/]

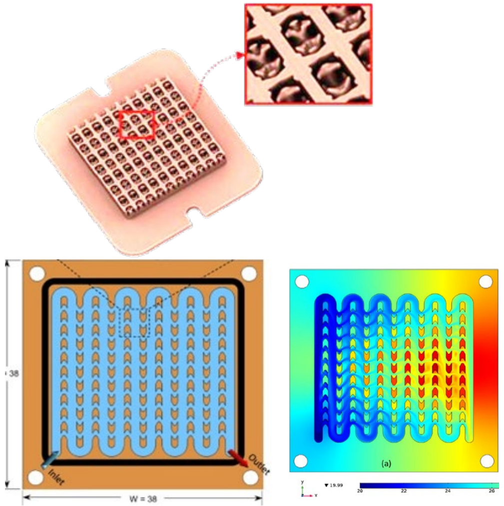
Current

[Lazarov BS, Alexandersen J. Appl Energy. 2018;226(February): 330-339]

AM Thermal

Liquid Cooled Heat Sinks

Current

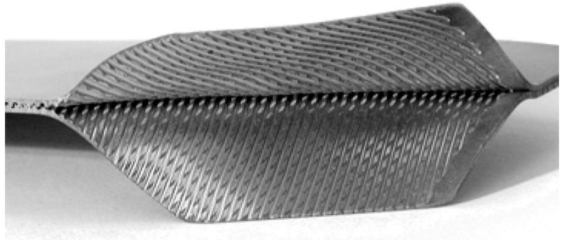


AM Thermal

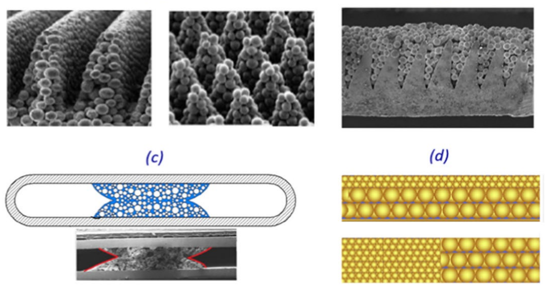
[Al-Neama AF, Thompson HM. Int J Heat Mass Transf. 2018;120:1213-1228]

Two Phase Convective Cooling

Current



[DOI: 10.1109/ITHERM.2006.1645335]



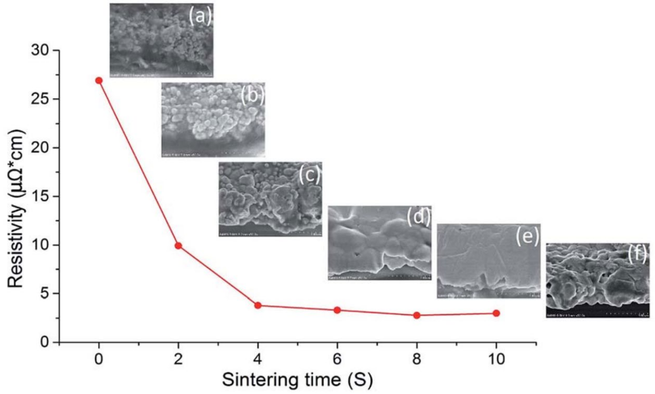
AM Thermal

[Jafari D, Wits. Renew Sustain Energy Rev. 2018; 91(April 2017):420-442]

Benefits Leveraging **3D & Design Freedom**

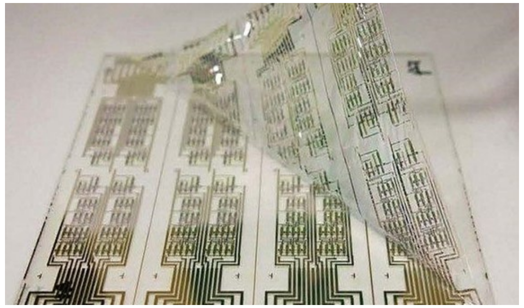
AME Growth Needs

Material Properties



[W. Gu, W.Yuan, et al. **RSC Adv.**, 2018,**8**, 30215-30222]

Productivity & Yield

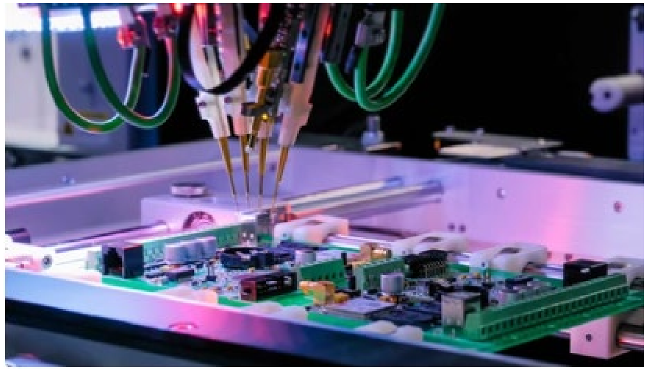


[https://commons.wikimedia.org/wiki]

Product-Level Reliability

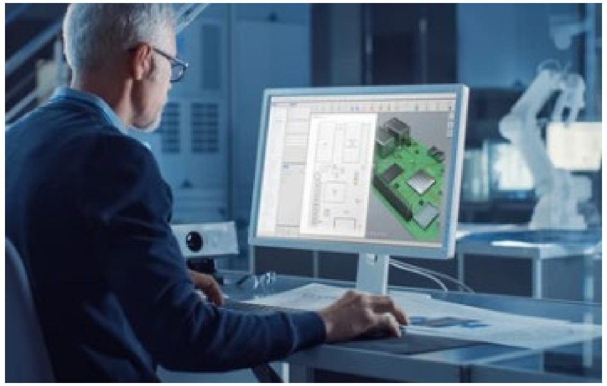
[https://commons.wikimedia.org/wiki]

Automated Inspection & Correction



[https://www.shutterstock.com/image-photo]

Design Tools



[https://www.shutterstock.com/image-photo]

Integrated Manufacturing

Leveraging CapEx Investment & Adaptability to Current tooling

- Panel Sizes
- Planarity
- Alignment
- Form Factor
- Thermal Processes

[https://www.microwavejournal.com/articles/31986]

Engagement with Chapter & Next

1. X-TWG engagement

Requesting X-TWG Feedback & Intersections

Requesting X-TWG guest Speakers - Connect/present to AME chapter

2. What's Next?

I. Finalized Version 1

II. Determining additional areas of interest for Revision

Applications *EMI shielding, RF/Antennas*

Manufacturing *Spray Coat*

Reliability *Expanding on Reliability improvement needs*