Multi-axis Process integration for Wafer Scale and Substrate-Like Printed Electronics

C. Mike Newton[1], Dr. Rudy Ghosh[2], Grant Wachtel[1], Connor Whitley[1]

[1] nScrypt, Orlando, FL, USA. [2] PulseForge, Austin, TX, USA

www.nscrypt.com
mnewton@nscrypt.com

https://pulseforge.com/
rudy.ghosh@pulseforge.com

About Sciperio : Advancing Technology

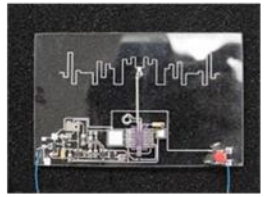
Focus Areas: BioEngineering, Printed Electronics, Mechatronics

1st to print conformal antennas

1999

1st and ONLY to print on a living ant

20+ years of first

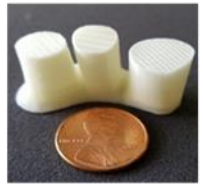


1st to print 900MHz transmitter

2000

1st to commercialize a bioprinter

2001



1st to put linear motors on a 3D printer for superior prints

2002

1st to print multi-layer, multi-material electrically functional structures

2003

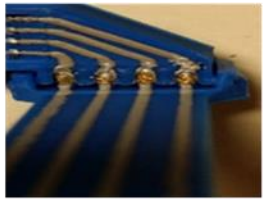
1st to add precision milling and pick and place on a single platform

2010

1st Scalable Bioreactor for On Demand Blood w/ IIOT

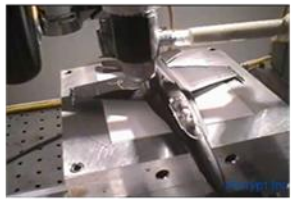
2011

1st to combine 3D printing and printed electronics



2012

1st to commercialize Z tracking for conformal printing

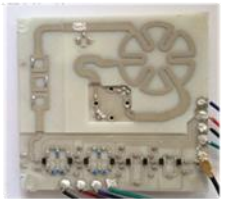


2014

1st to use a paste to print metal 3D structures

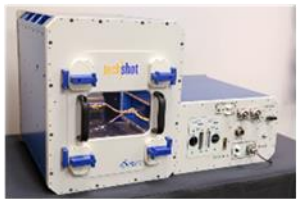
2015

1st to print a Phased Array Antenna



2016

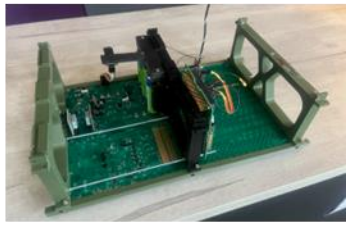
1st Bio Printer in ISS



2019

2020

1st 3D Printed Electronic 6U Cubesat



2023

About nScrypt

- Founded in 2002, spun off from Sciperio, Inc.
- Headquartered in Orlando, FL, USA
- Capital equipment and solution provider

Wafer Scale Packaging | System Level Electronics | 3D Printing

3D Manufacturing

SiP/MCM (WSP Series) | AME (DDM Series)

Die Attach | Surface Mount | High Performance Plastic

Die Interconnects | Assembly | Metal

Encapsulation | Ceramic

3D Packaging | Adhesives | Solders

Via Filling | Antennas | PEEK | Ultem

Interconnections | Titanium | Biological

nSCRYPT will make mass, complicated manufacturing, personalized and simple

Standard Manufacturing Processes

Generates individual parts through single process

+

nScrypt Additional Functions:

- High Precision, 10µm Accuracy
- Multi-Axis Functionality
- Automatic Tool Changes
- Conformal Motion Tool Pathing
- Digital Control
- High Speed
- Open Source Material

=

3D Manufacturing

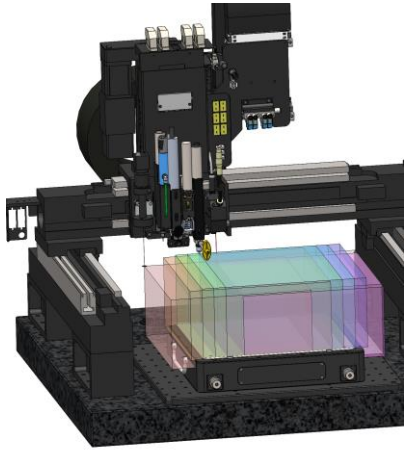
Create Finished Products Anywhere, Any Time, with Minimal Labor

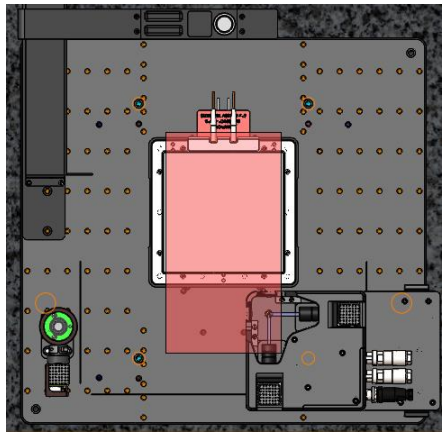
CERTIFIED ISO 9001:2015 COMPANY

System Overview

- nScrypt Systems:
  - Designed to produce additively manufactured electronic circuits and Application Specific Electronic Packages
  - All operations are set in CAD, executed on single system, through nStudio, nScrypt's in house UI
  - 3/4/5/6 Axis Motion Platforms
  - Automatic Tool Changing

	Tabletop	300	500	700	1000
X/Y Accuracy	**± 10 µm**	**± 5 µm**	**± 1.5 µm**	**± 1.5 µm**	**± 2.5 µm**
X/Y Bidirectional Repeatability	**± 1 µm**	**± 2 µm**	**± 0.5 µm**	**± 0.5 µm**	**± 1 µm**
X/Y Maximum Acceleration	.5g	2g	5g	5g	5g
X/Y Maximum Speed	300 mm/s	500 mm/s	500 mm/s	500 mm/s	500 mm/s
X/Y Travel Range	300x150 mm	300x300 mm	500x500 mm	700x700 mm	1000x1000 mm
X/Y Resolution	**100nm**	**5nm**	**3nm**	**3nm**	**1nm**
Z Accuracy	± 6µm	± 5µm	± 3µm	± 3µm	± 3µm
Z Bidirectional Repeatability	± 1µm	± 1µm	± 1µm	± 1µm	± 1µm
Z Maximum Speed	50 mm/s	100 mm/s	300 mm/s	300 mm/s	300 mm/s
Z Maximum Travel Range	100 mm	150 mm	150 mm	200 mm	200 mm
Z Resolution	100 nm	100 nm	100 nm	100nm	500 nm





Travel Range: 300x300
Fully Loaded Build Area:145mmx 276mm

Machine Floor Weight: 2000lb Approx.
Depth: 61", 40" without StrongArm
Width: 48"
Height: 69" without HEPA Filter

Recommended two foot spacing on all sides

Tool Plate and Tool Heads

Many Feedstock Formats

- Inks, Pastes, Elastomers
- Thermoplastics
  - High Temp (450C)
  - Loaded or Unloaded
- Thermosets
  - Conductive
  - Dielectric
- Metals and Ceramics
- Energetics
- Electronic Components
  - SMT
  - Packaged
  - Bare Die

Integrated Process Available and Enclosures Add-ons:

- Plasma Cleaning,
- Aerosol Jetting
- Custom Integration
- Enclosure exhaust
- Enclosure HEPA Filter
- Light Tight Laser Enclosure
- Cleaning station
- Rotational stage
- Pulse Forge
- Rigid Cylinder Fixture
- Flexible Cylinder Fixture

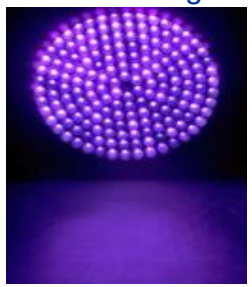
Tool Heads

Pre/Post Processes

Thermal Curing

Photonic Sintering

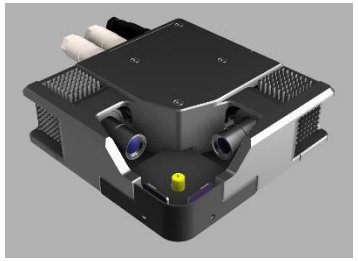
UV Curing



Laser Processing

In Situ Metrology

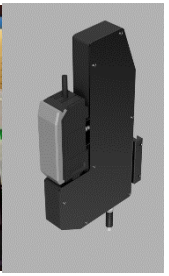
Calibration Pit



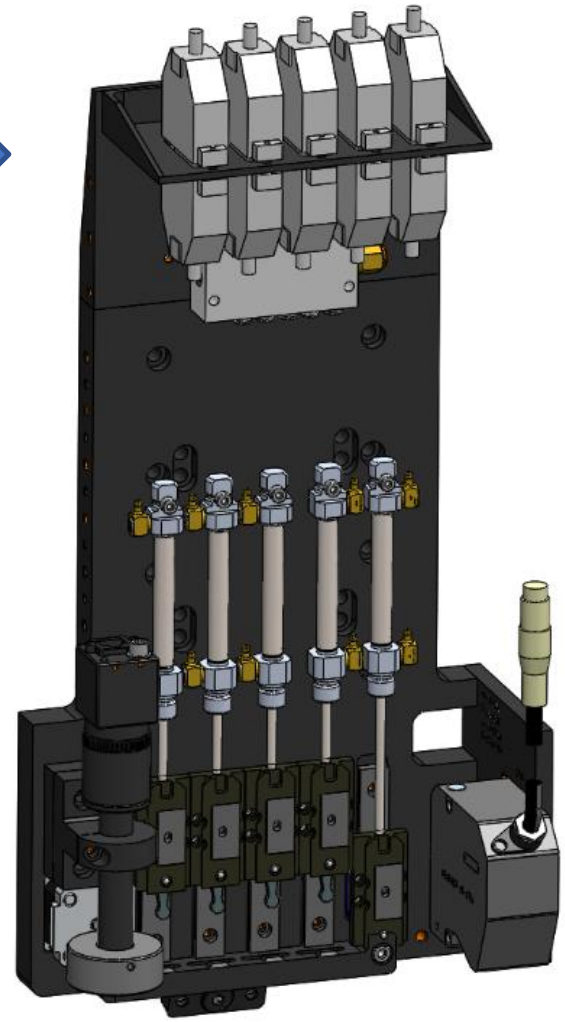
Displacement Sensor

Process View

Gauge



Tool Plate



Five Tool-Slots

Who We Are

PulseForge® Digital Thermal Processing™

PulseForge, Inc. utilizes applied energy in a precise and targeted manner to enable innovation in industrial manufacturing. Our expertise and tools empower our customers to explore novel materials and manufacturing methodologies, driving dynamic and efficient production at an industrial scale.

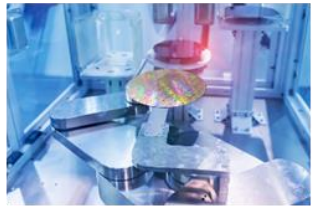
- Established – Jan, 2022
  - Spinout of NovaCentrix (Founded in 1999)
  - First PulseForge tool deployed in 2008
- Headquarters – Austin, TX, USA
- Demo centers
  - Austin, TX, USA
  - Seoul, South Korea
  - Radeberg, Germany
  - New Taipei City, Taiwan
- Installation footprint: > 20 countries

Manufacturing using PulseForge

PulseForge® Digital Thermal Processing™

Critical factors to consider during manufacturing

- ✓ Lower cost of operation.
- ✓ Improved throughput.
- ✓ Energy savings.
- ✓ Real estate savings.
- ✓ New products enabled.
- ✓ Better material properties.
- ✓ Reduced waste.

Applications	Industries	Products
- Debonding		
- Soldering		
- Curing/ Sintering		
- Advanced Materials R&D	 	

nScrypt

PulseForge® Soldering Tools

PulseForge® Digital Thermal Processing™

Invent series
Standalone R&D/batch tool

In-Line series
Standalone inline tool

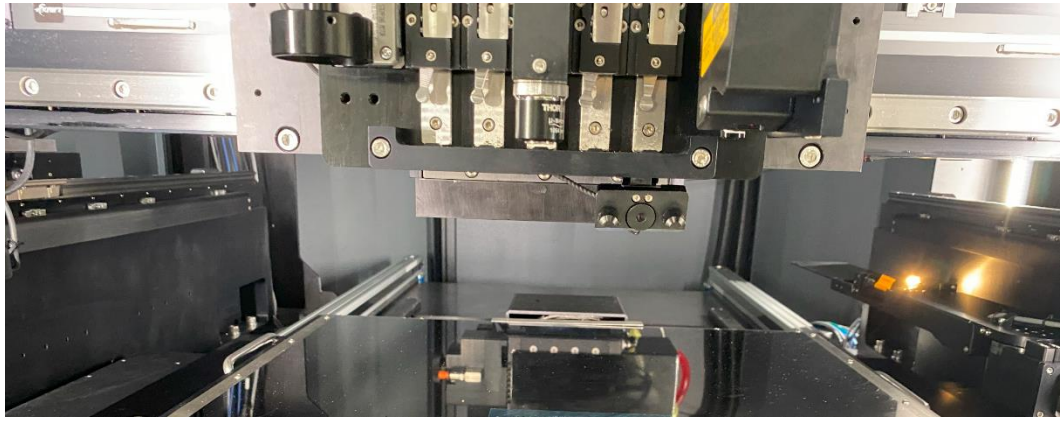
PulseForge® Embed series
accommodates custom integration projects

nScrypt

PulseForge Standard System Integration

3Dn-500 System with PulseForge Unit

View of Light Tight Area for PulseForge Processing

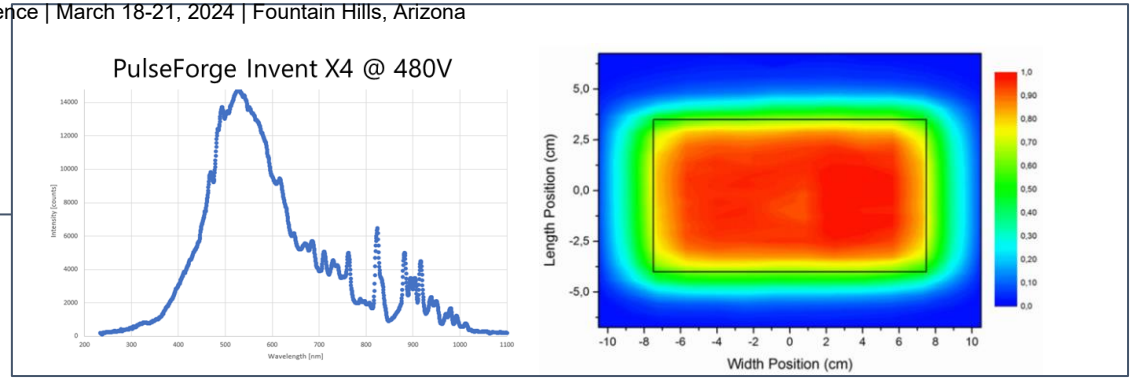


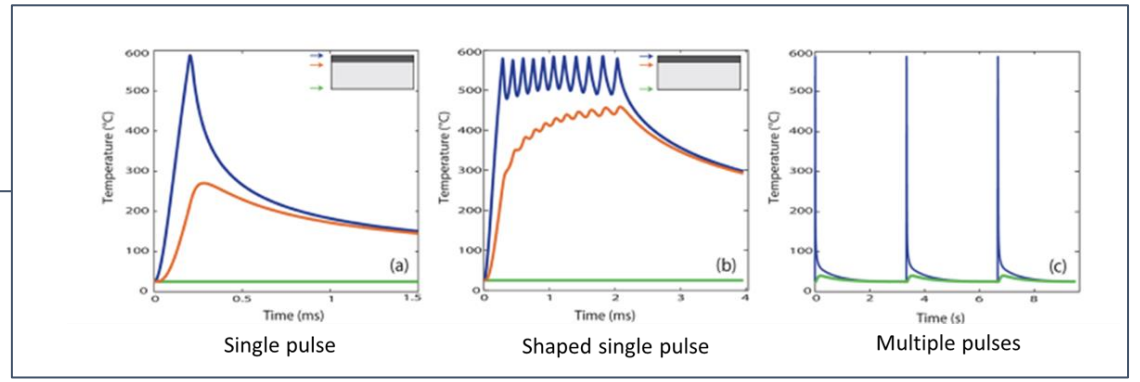
Build Plate with High Precision Axis for Movement into PulseForge Flash Area

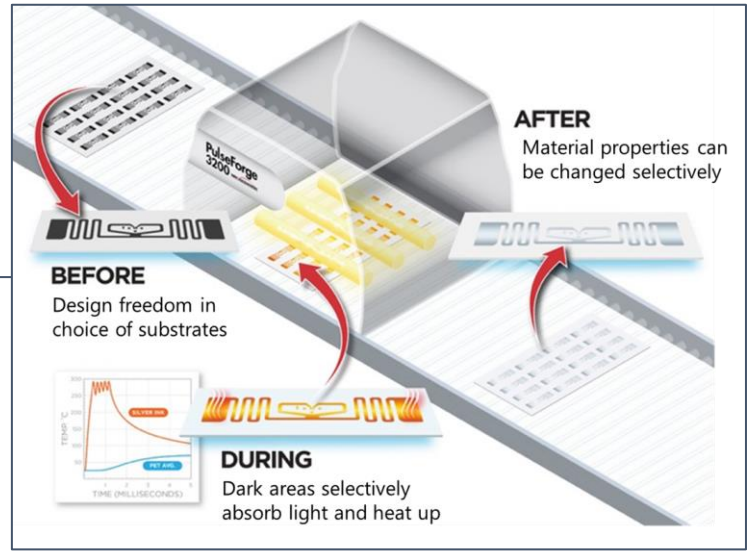
PulseForge®
Digital Thermal Processing™

Proprietary technology delivers thermal energy in milliseconds – not minutes

- **Utilizes broadband white light**
- **Wide area illumination**
- **Precise control for light pulse manipulation**
- **Processing in non-equilibrium state with no volumetric heating required**







PulseForge® Digital Thermal Processing™

What is PulseForge® Soldering?

- A **Digital Thermal Processing™** method for **component attachment**
- **Rapid heating** using pulsed white light
- **Wide area processing** with high uniformity and precision

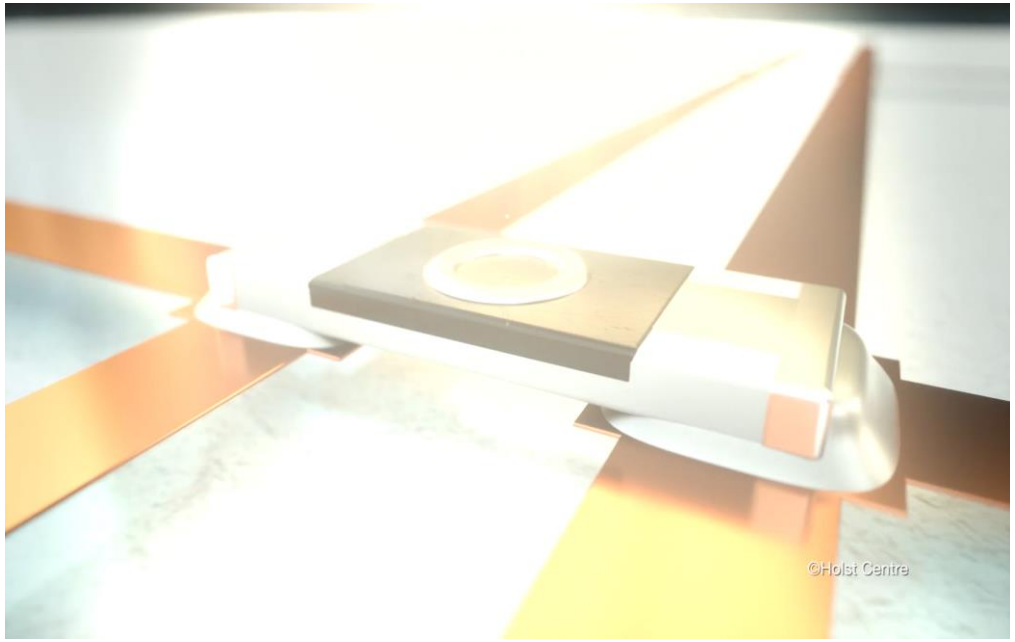
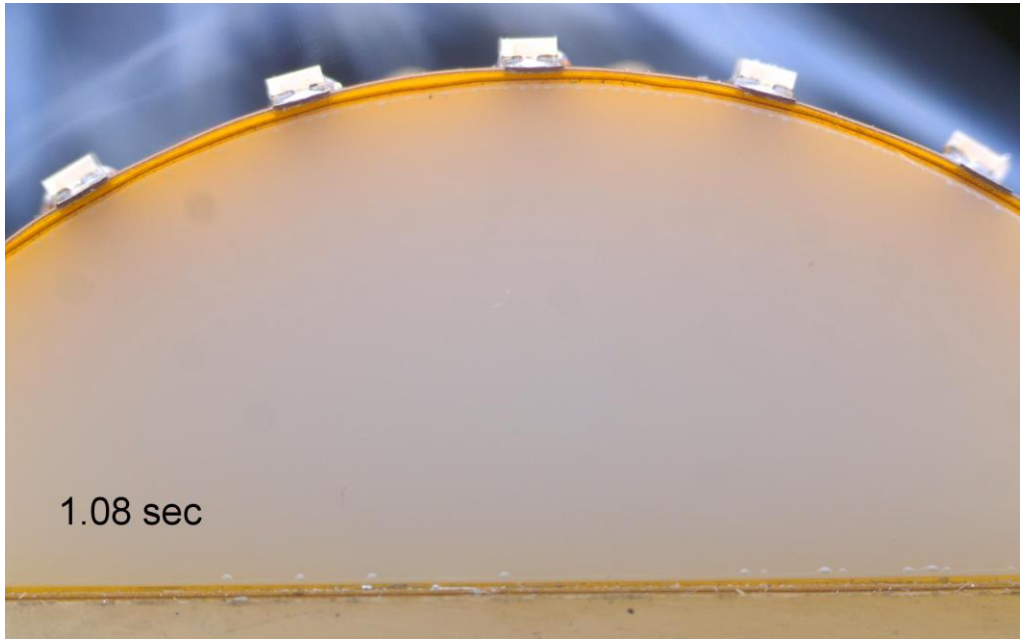


Illustration of PulseForge®solder reflow

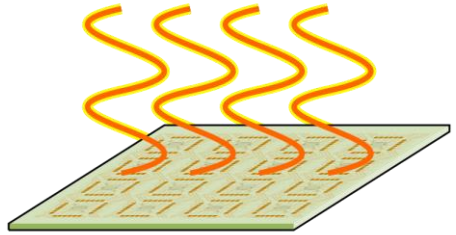


In-situ visualization of solder reflow on flexible substrates.

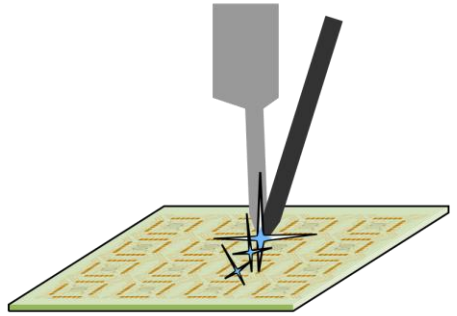
nScrypt

How does PulseForge® Soldering Compare?

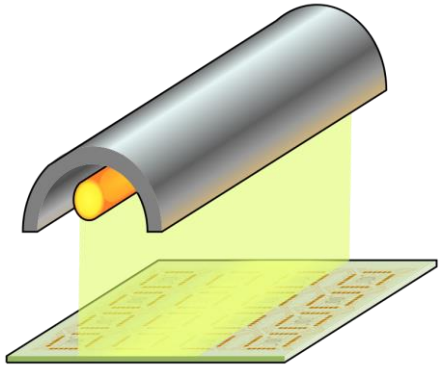
PulseForge® Digital Thermal Processing™



Convection oven



Laser



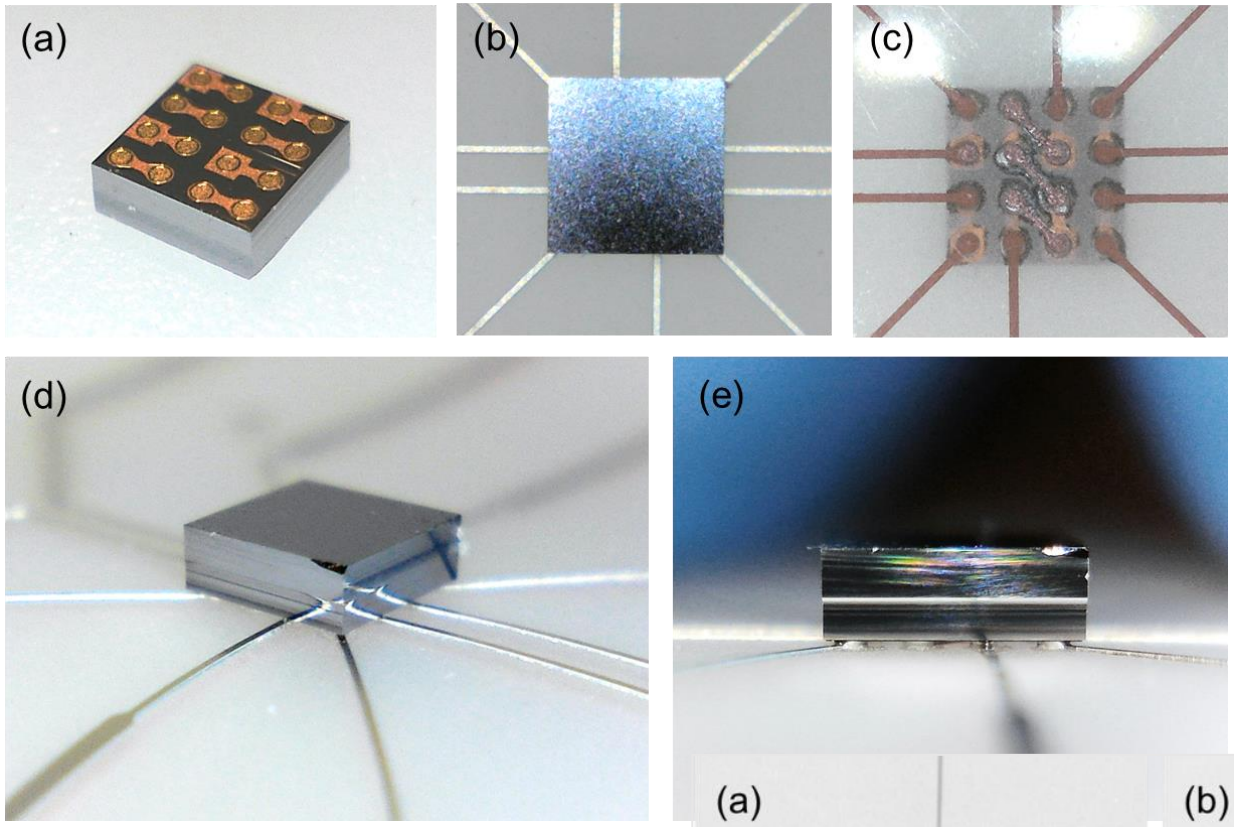
PulseForge®

REFLOW PROCESS CAPABILITY

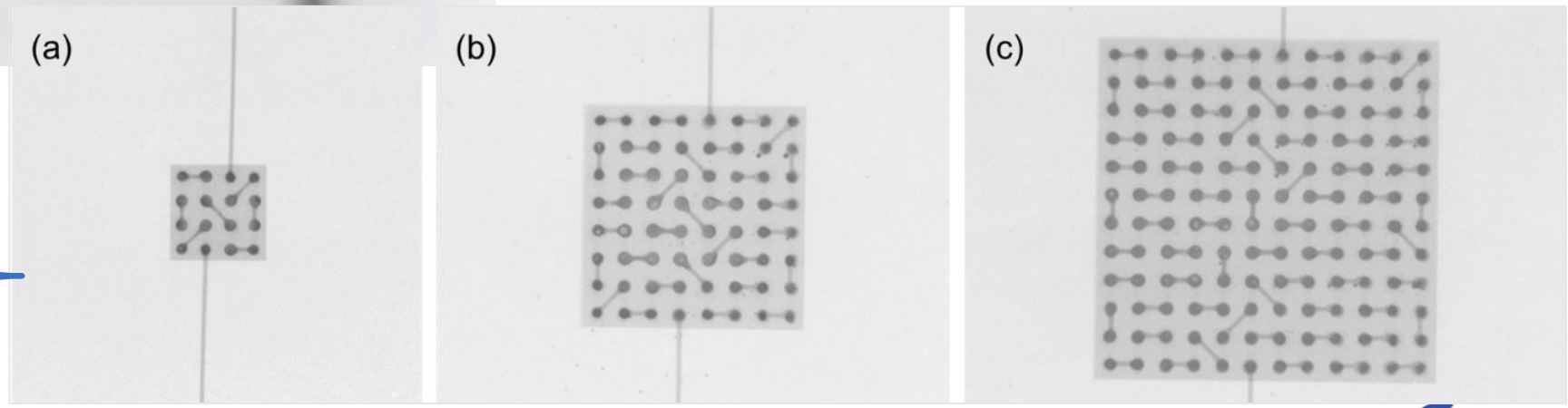
Temperature-sensitive materials	Poor	Good	Good
Energy savings	Poor	Excellent	Excellent
TAKT time	Good	Poor	Excellent
Fast warmup time	No	Yes	Yes
Minimal line programming	Yes	No	Yes

PulseForge Soldering for Wafer Level Chip Scale Packaging

PulseForge® Digital Thermal Processing™



(a) WLCSP component as-received showing pad side. Component after soldering attachment photographs from
(b) top-down
(c) backside bottom-up
(d) tilted view
(e) side-on

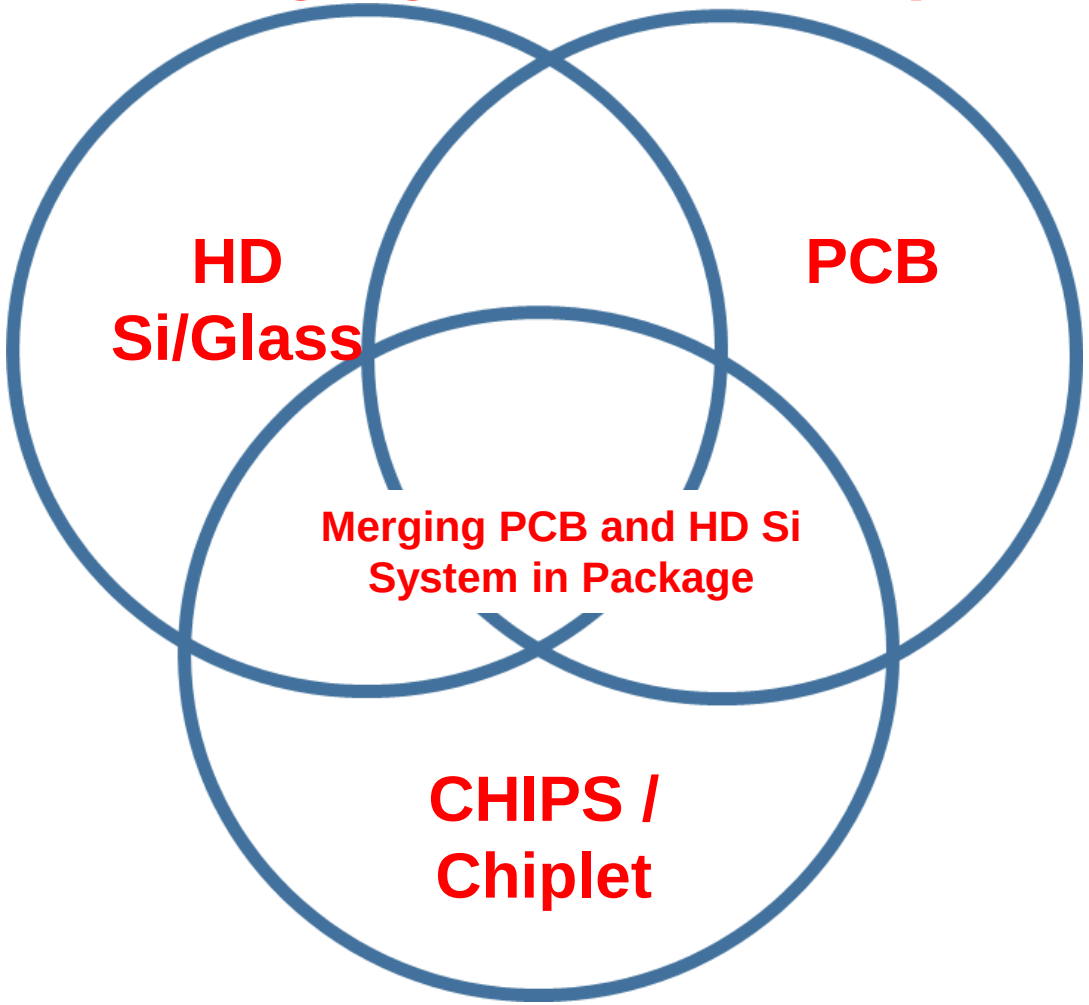


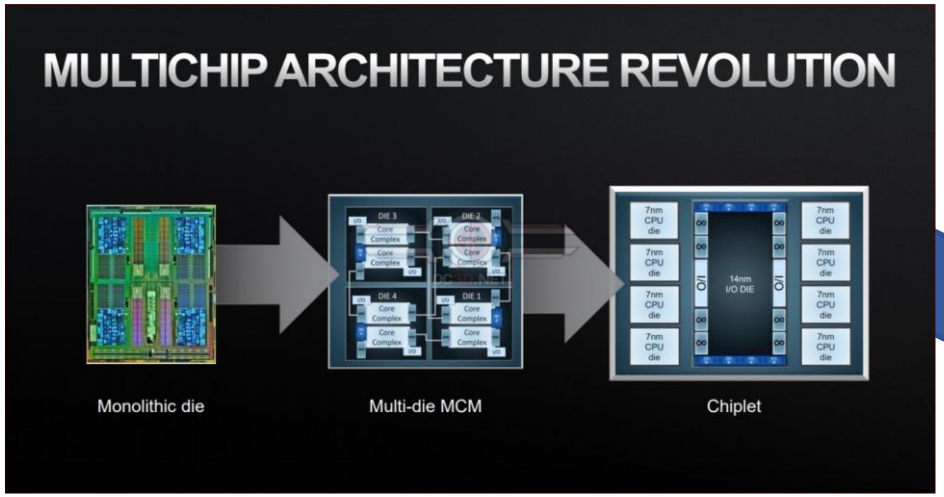
X-Ray images of WLCSP components with varying I/O pads (a) 4x4, (b) 8x8, and (c) 12x12 pads after soldering.

nScrypt

Where do we play: Advanced Micro-E Packaging

Bridging the Scale Gap



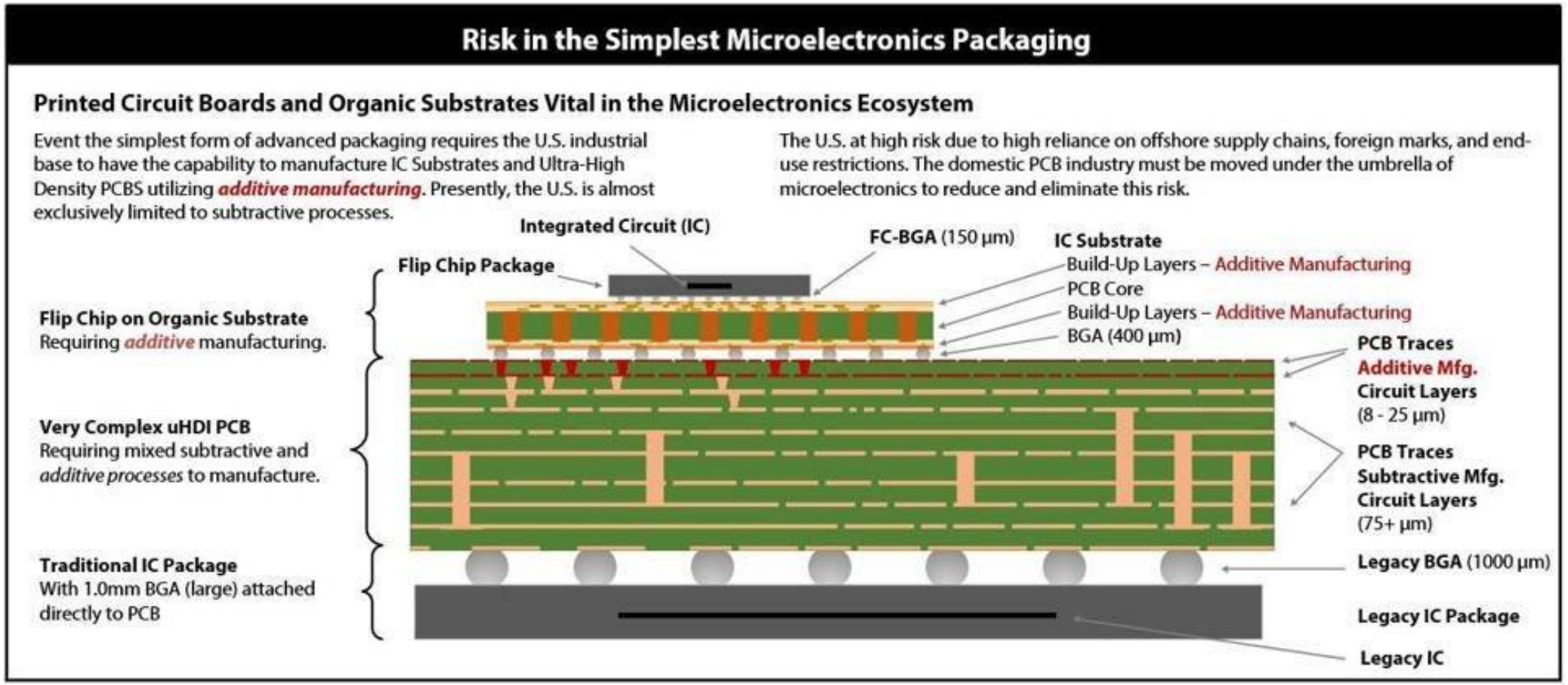


Packaging Next

- SLP's (Substrate Like PCB's)
- Interposers
- Heterogeneous Integration
- SIP
- WSP
- High Mix Low Volume

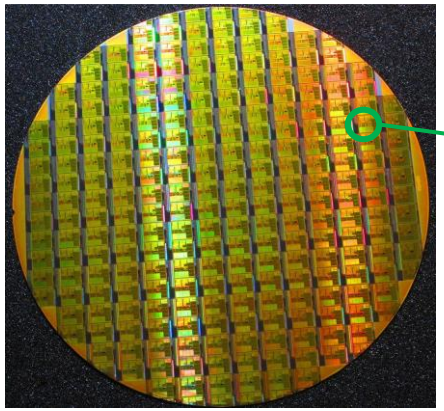
https://www.eetimes.com/advanced-ic-packaging-fundamentals-for-the-more-than-moore-era/

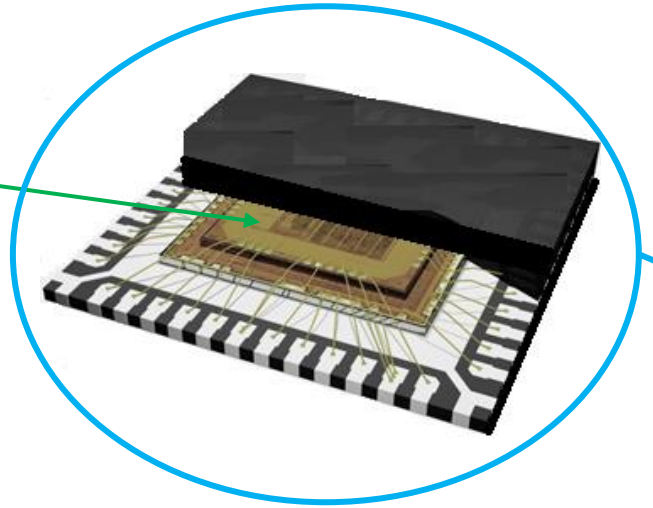
Advanced Packaging Precision Needs

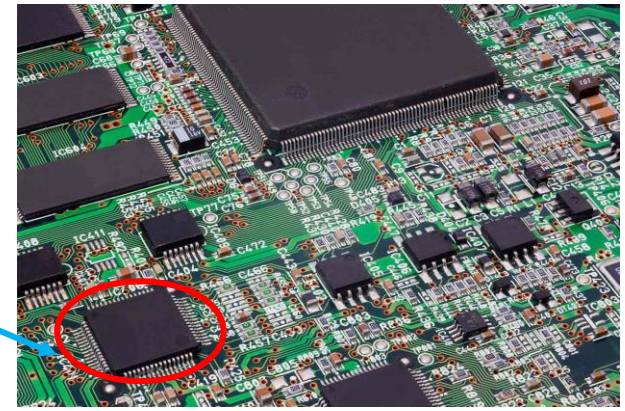


https://www.forbes.com/sites/erictegler/2022/01/07/chips-dont-float-reviving-semiconductor-manufacturing-alone-wont-assure-americas-security/?sh=1bef13869719

CHIPS are simply, not simple







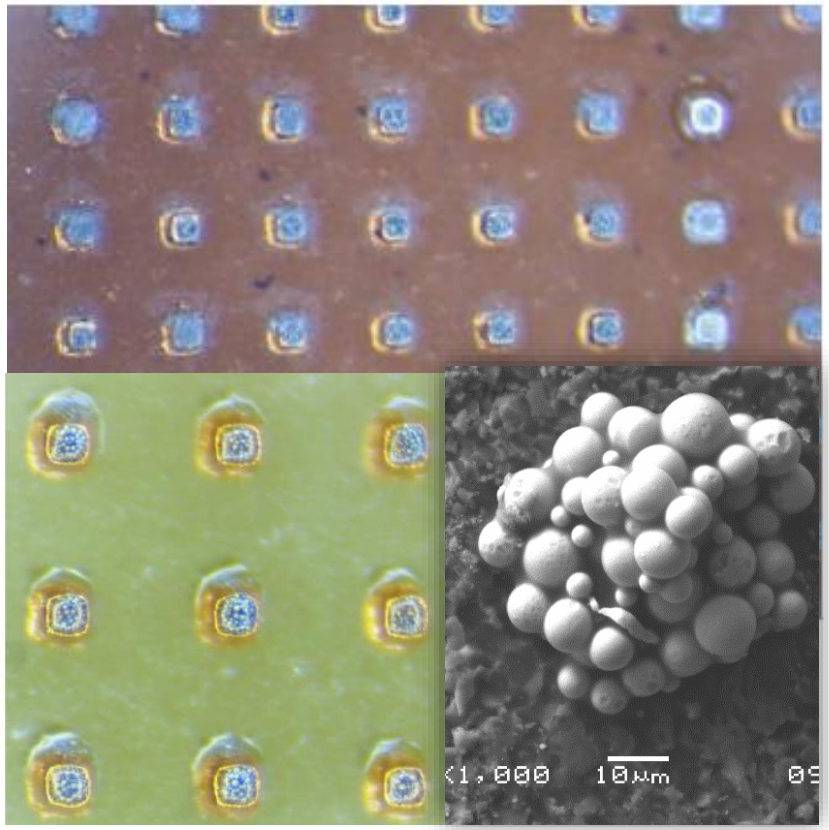
Front-end processes =>
- Wafer (semiconductor)
  - Clean
  - Lithography
  - Etch
  - Implant
  - Cut
  - More…..

Back-end processes =>
- Packaged (semiconductor)
  - Separate
  - Die Attach
  - Wire Bond
  - Overmold
  - Underfill
  - Encapsulate

Printed Circuit Board processes =>
- Assembled PCB
  - Patterning
  - Copper plating (dirty process)
  - Component (packaged semiconductor
  - Reflow soldering
  - Packaging

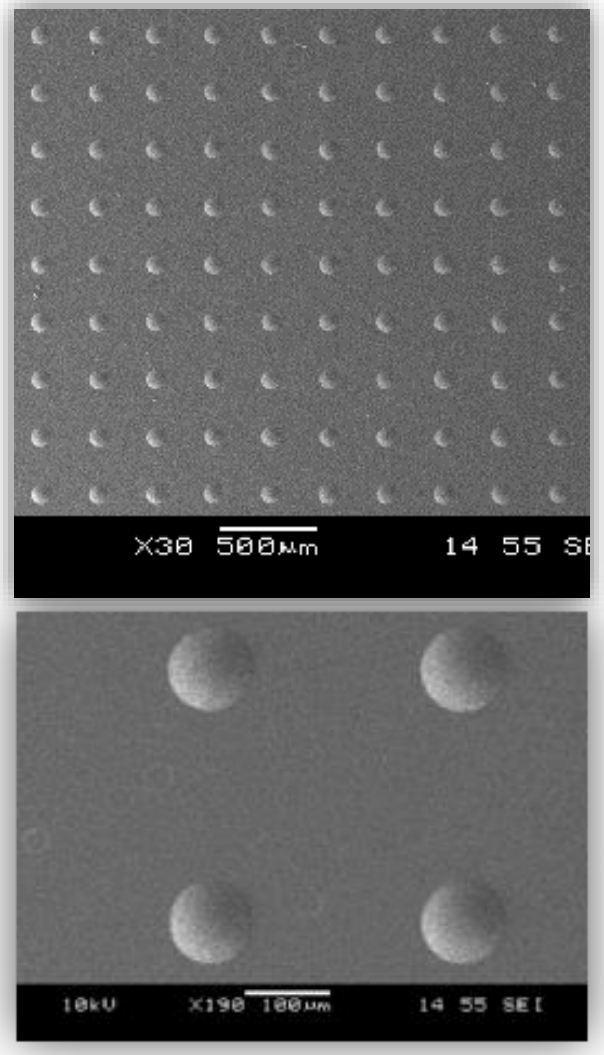
Three separate industry sectors with very different size scales, very different equipment and very different processes. Microprocessors have BILLIONS of transistors (Apple M1 Ultra dual-chip module has 114,000,000,000 transistors, using 5 nanometer technology)

Dispensing Applications with the Smartpump™



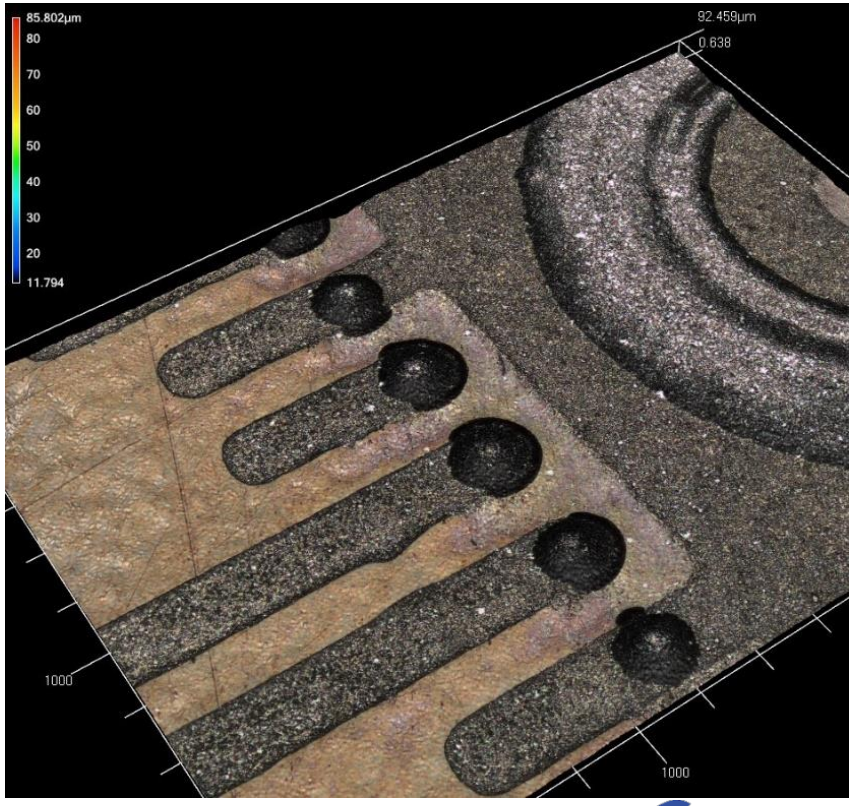
50um Solder Dots on 60um Pads

	50µm Dots	80µm Dots	Units
Pen Tip	50/75	50/75	ID/OD, µm
Dispense Gap	20	20	µm
Air Pressure	10	10	psi
Valve Opening	25	25	µm
Print Speed	5	5	dots/s
Dispense Time	50	75	ms

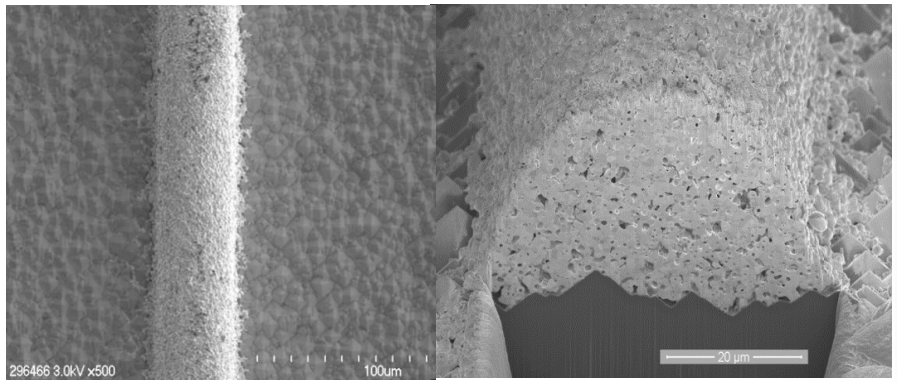


Adhesives Ranging from 10-100um

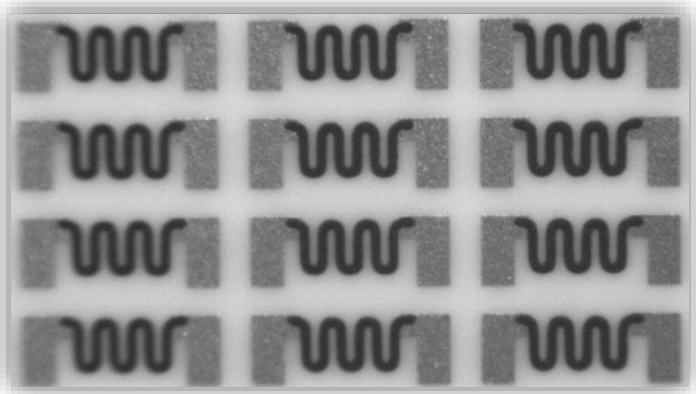
- Fly-by-dots allows for precise conductive epoxy dots
- Enables interconnects for QFN components pads-down onto substrates
- Opens door for flexible circuitry with much finer pad pitch chips
- 200µm wide pads shown here



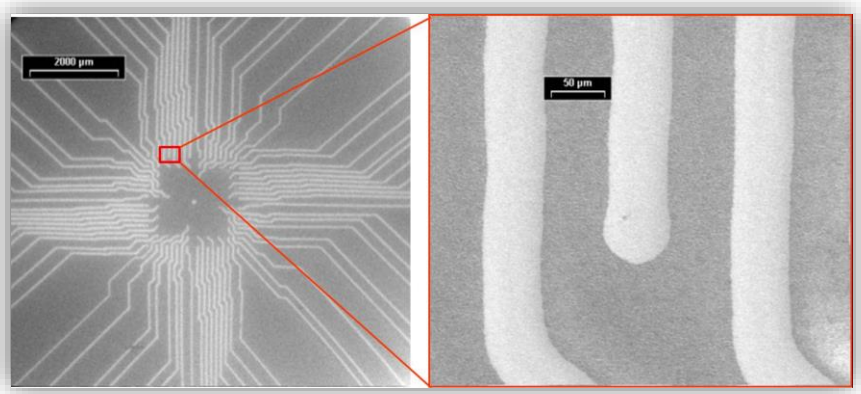
Precision Patterning with the Smartpump™



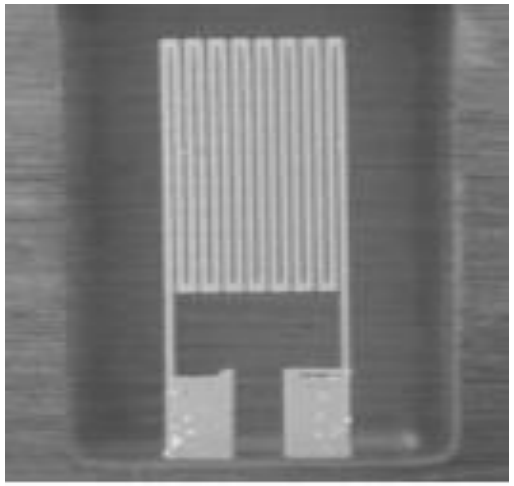
50um wide, 35um tall, 800,000 cPs silver paste on Silicon wafer, solar cell collectors



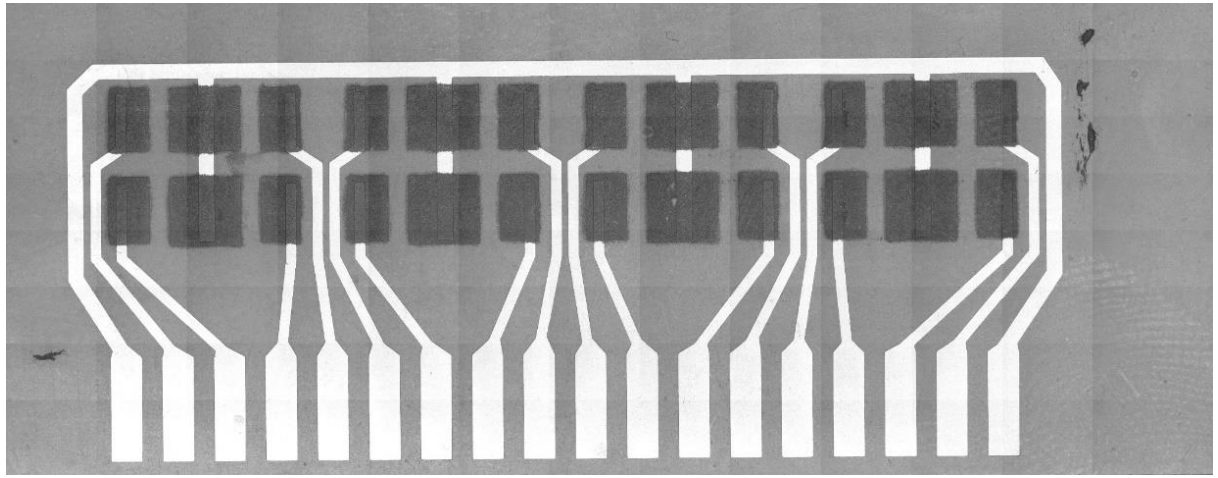
Heaters: Carbon Resistive Serpentine with Silver Conductive Pads



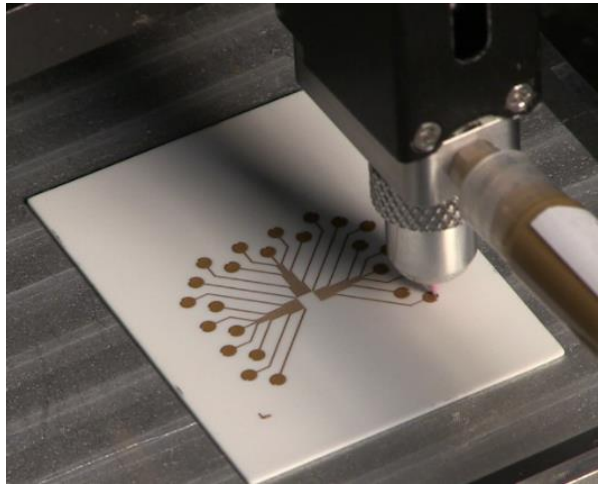
Silver Paste Interposer, 50um Space and Trace



Conductive Silver Strain Gauge on Dielectric Insulator

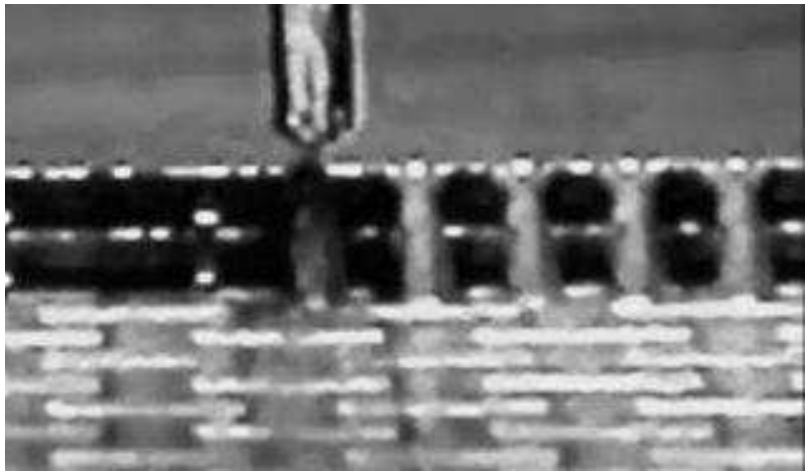


Gold Pads and Traces with Stacked Carbon Resistive Pads Printed on Kapton Substrate

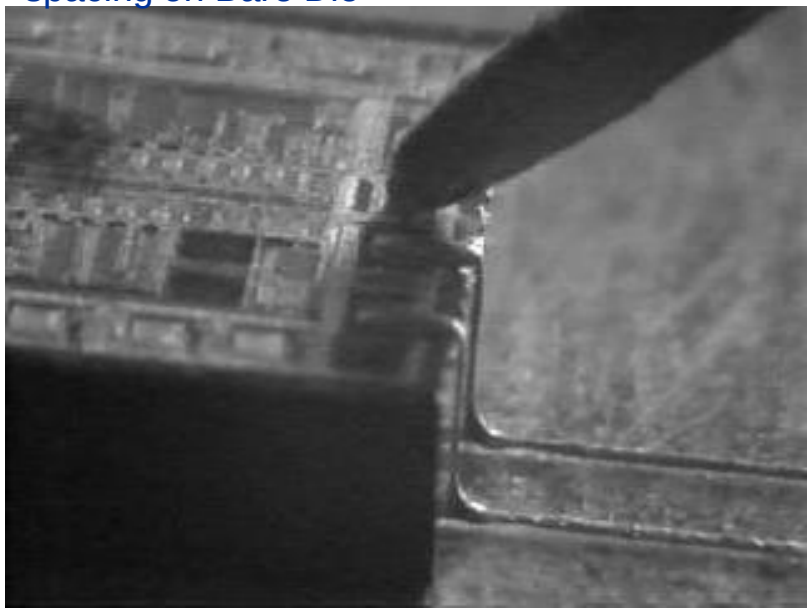


High Operating Temperature (800C) Gold Interposer on Ceramic Substrate

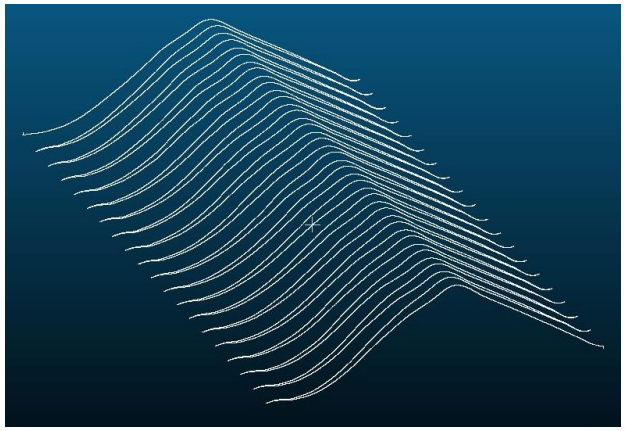
Non-Planar and Step-Up Interconnects

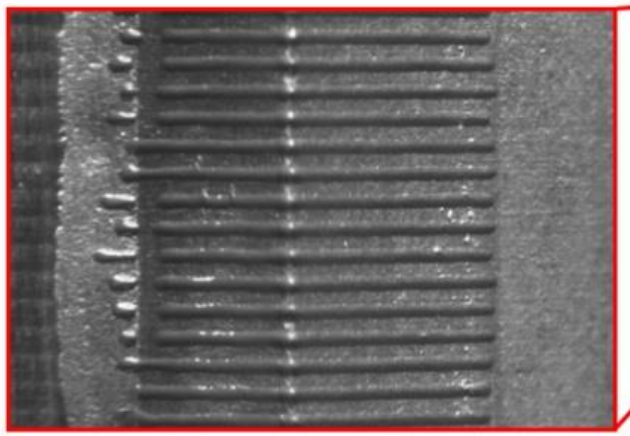


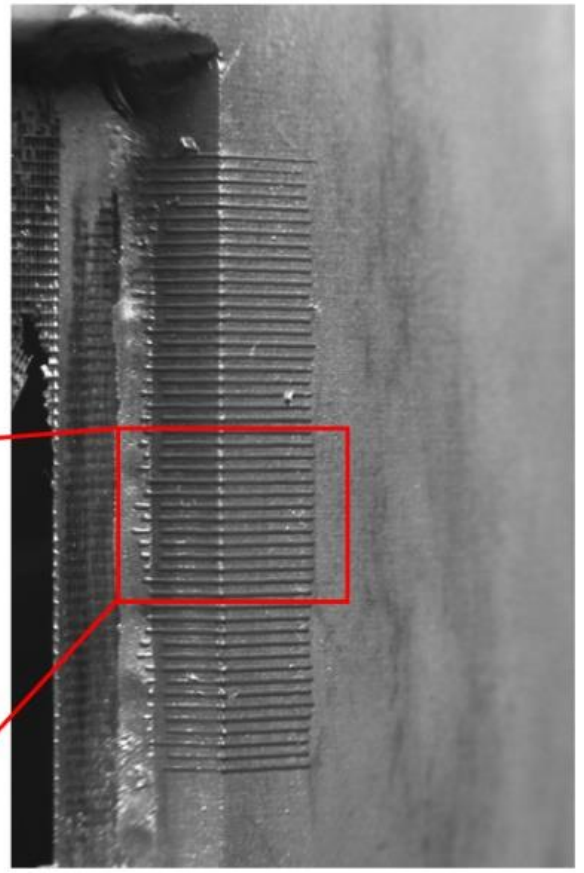
100um Vertical Interconnect with 150um spacing on Bare Die



- Step up interconnect
- Dispense gap of < 30µm during conformal deposition
- 100µm-wide interconnects with 100um spacing
- silicon-dielectric-ceramic partitioned structure
- Chip and Ceramic manufactured to minimize angle at cross over point





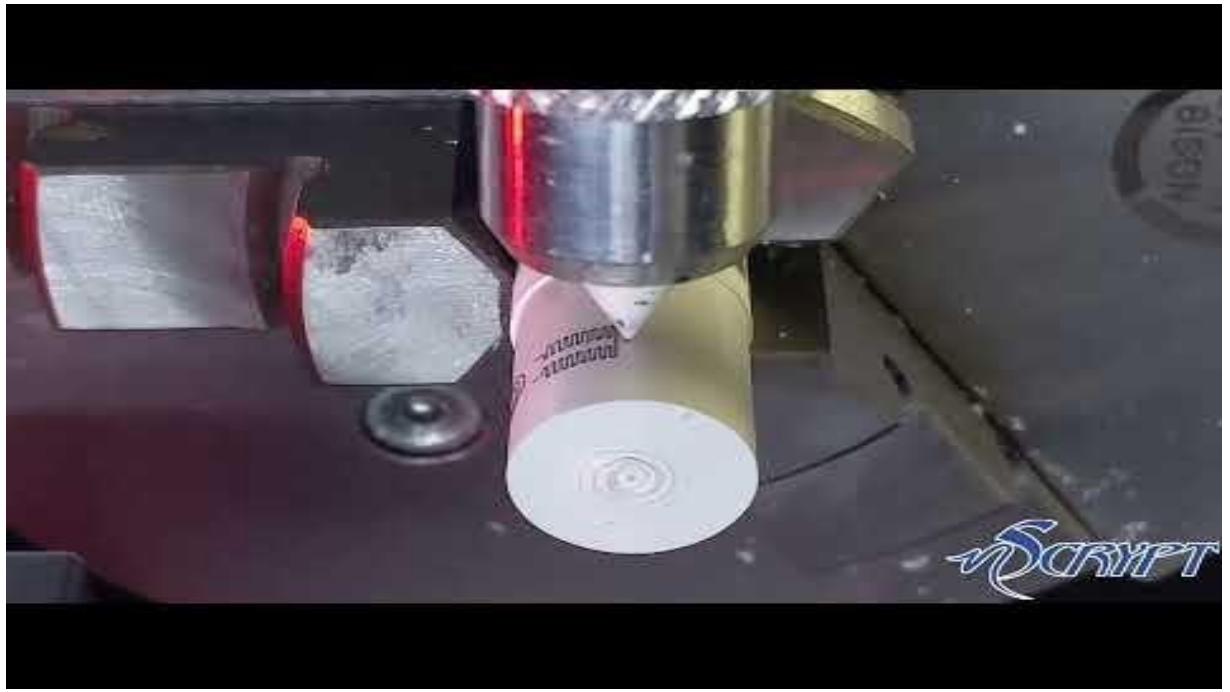


Conformal Multi-Axis Integration

Smartpump Conformal Micro-Dispensing

Highly Conformal Dispensing with
Smartpump on Tabletop Trunnion System

https://www.youtube.com/watch?v=fp6rsUEb87E



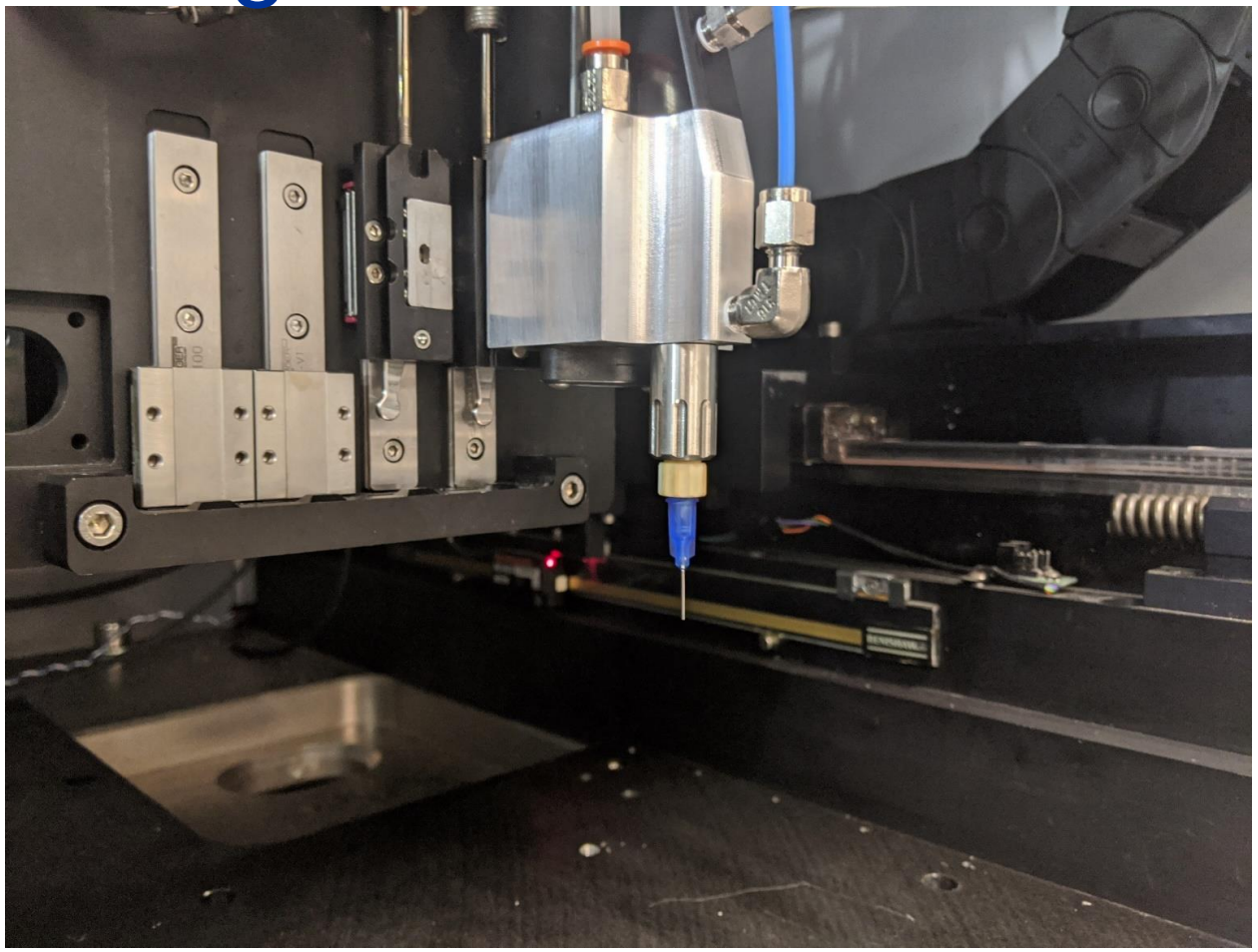
Rotary Micro-Dispensing using 4-axis Upgrade,
Available on all 3Dn Systems

https://www.youtube.com/watch?v=ElqFCUNAt7c

Conformal Multi-Axis Integration

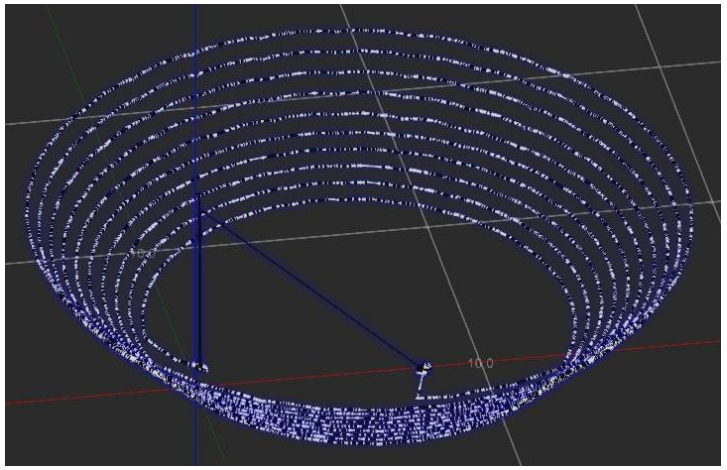
IDS NanoJet Subsystem Integration

IDS NanoJet Subsystem Control Unit
Integrated as Rack Mount

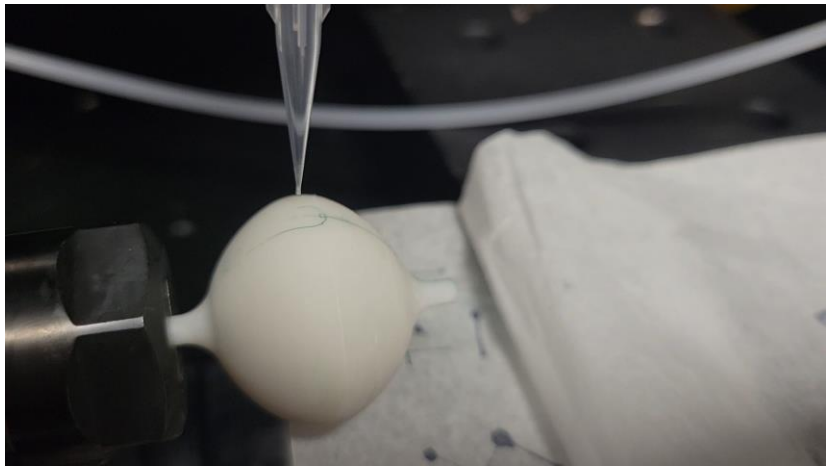


IDS Head Integrated onto Tool
Plate for Automatic Actuation

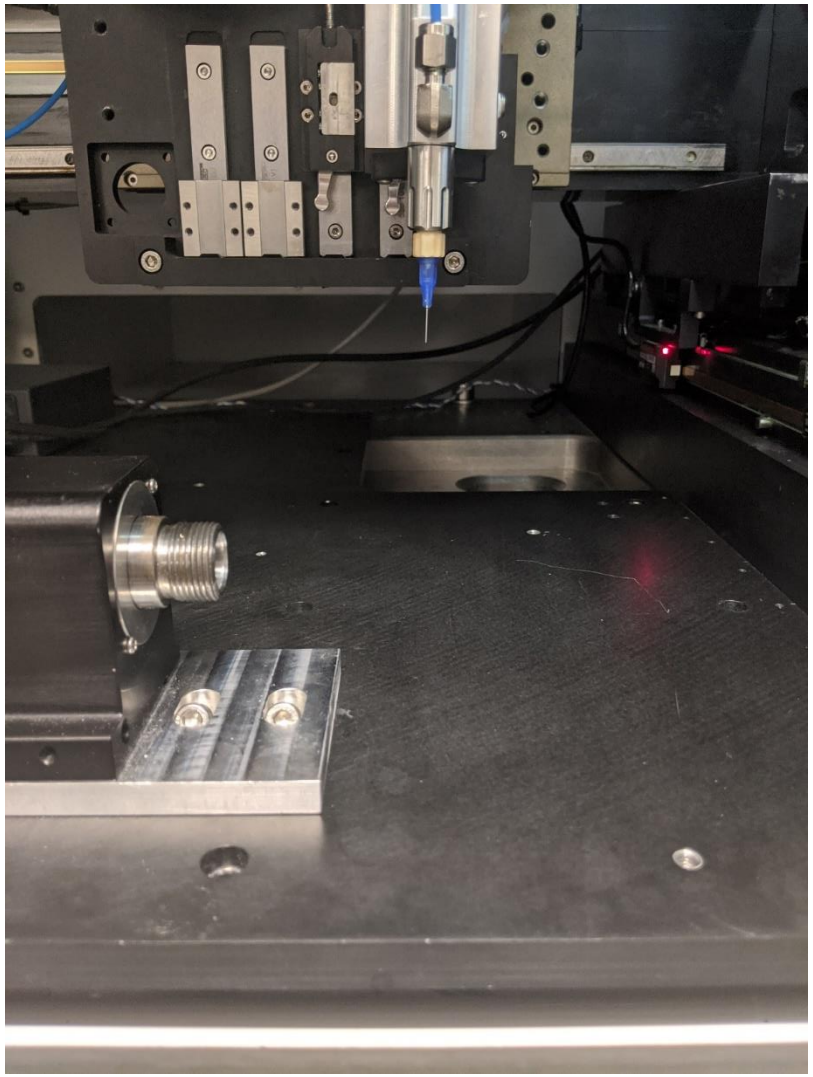
IDS Nanojet Conformal Printing



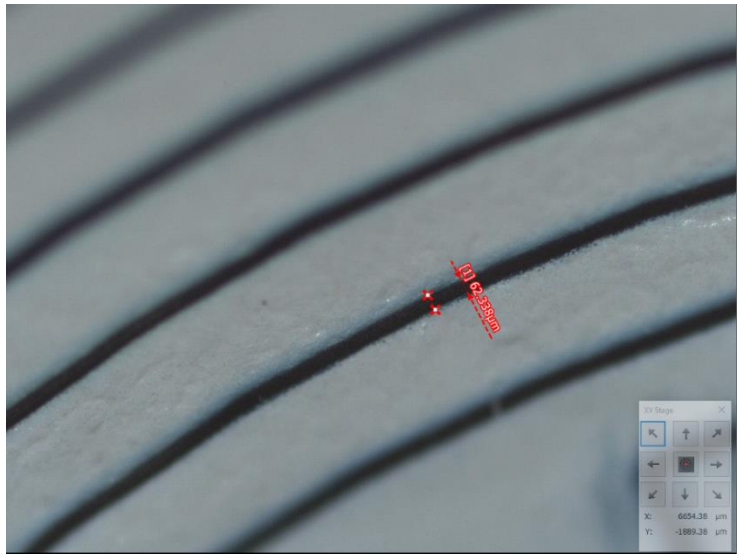
Conformal Path View in nStudio



4-Axis Printing with IDS Head



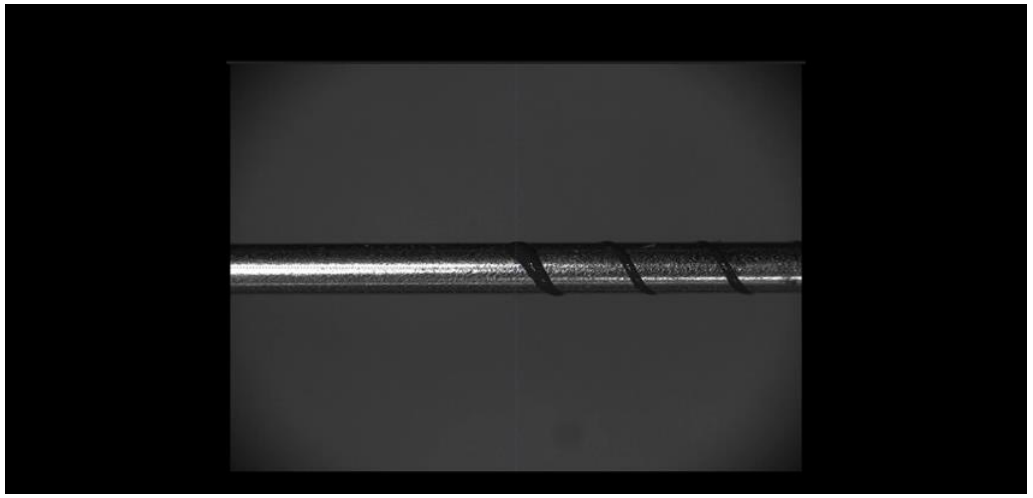
IDS Head Integrated with 4-Axis Upgrade for Rotary Printing



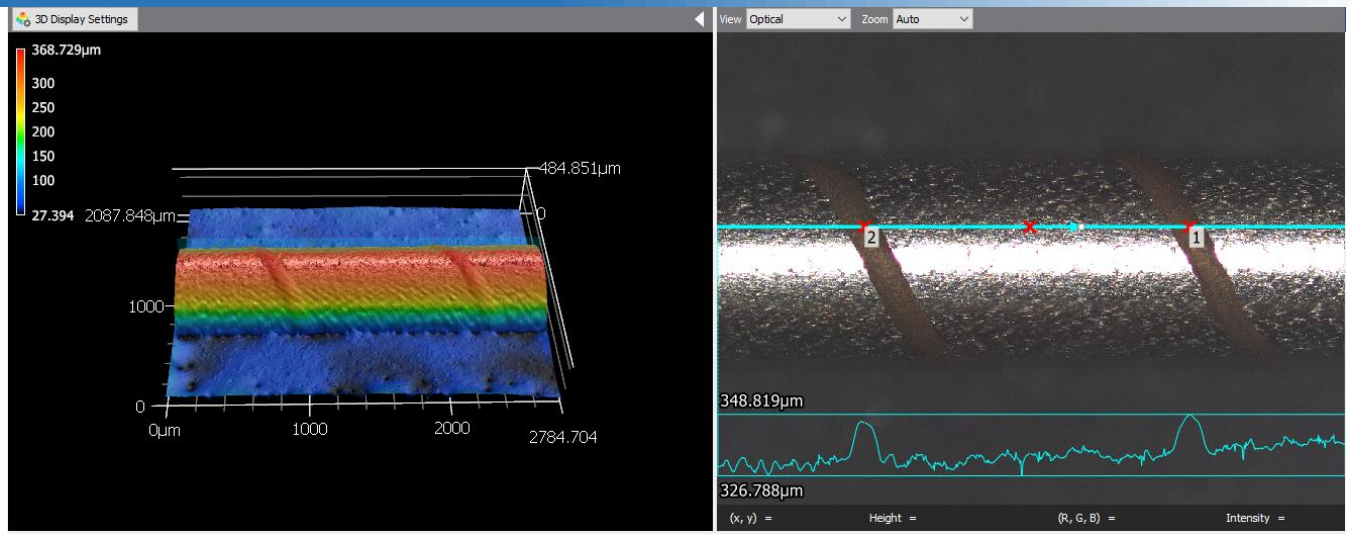
60um Conformal Features using IDS Head

Conductive Material Conformal Printed

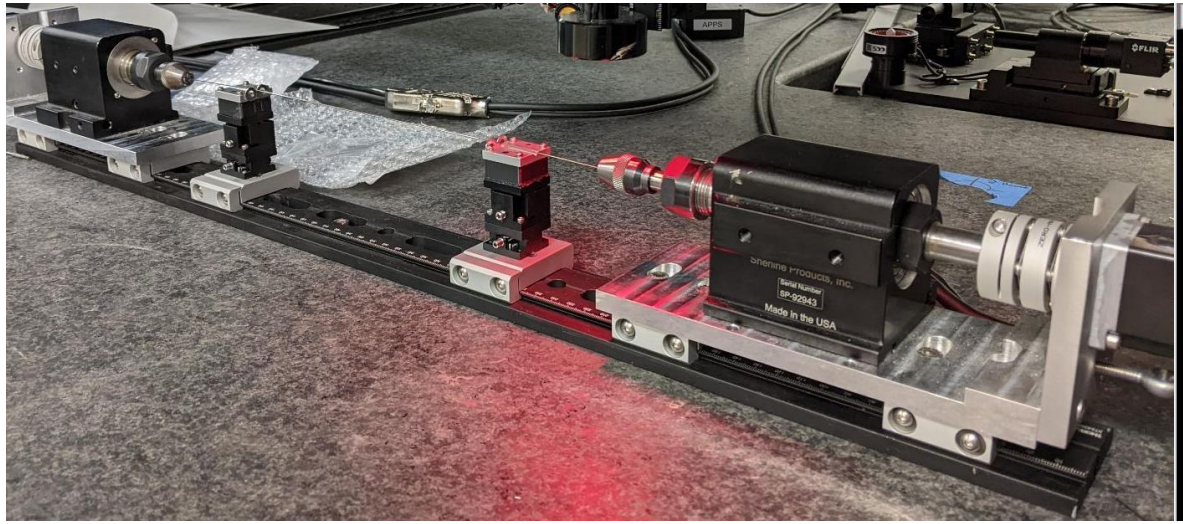
Rigid Cylindrical Micro-Dispensing



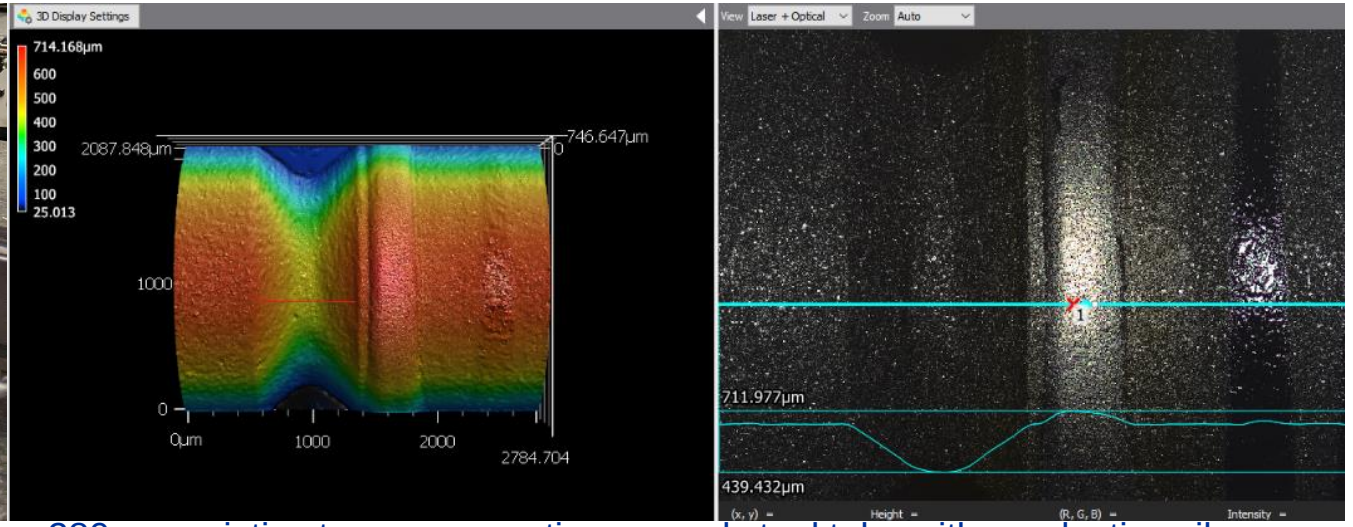
32 Gauge Needle with conductive spiral and 90 degree serpentine



180um wide, 10um tall conductive copper spiral



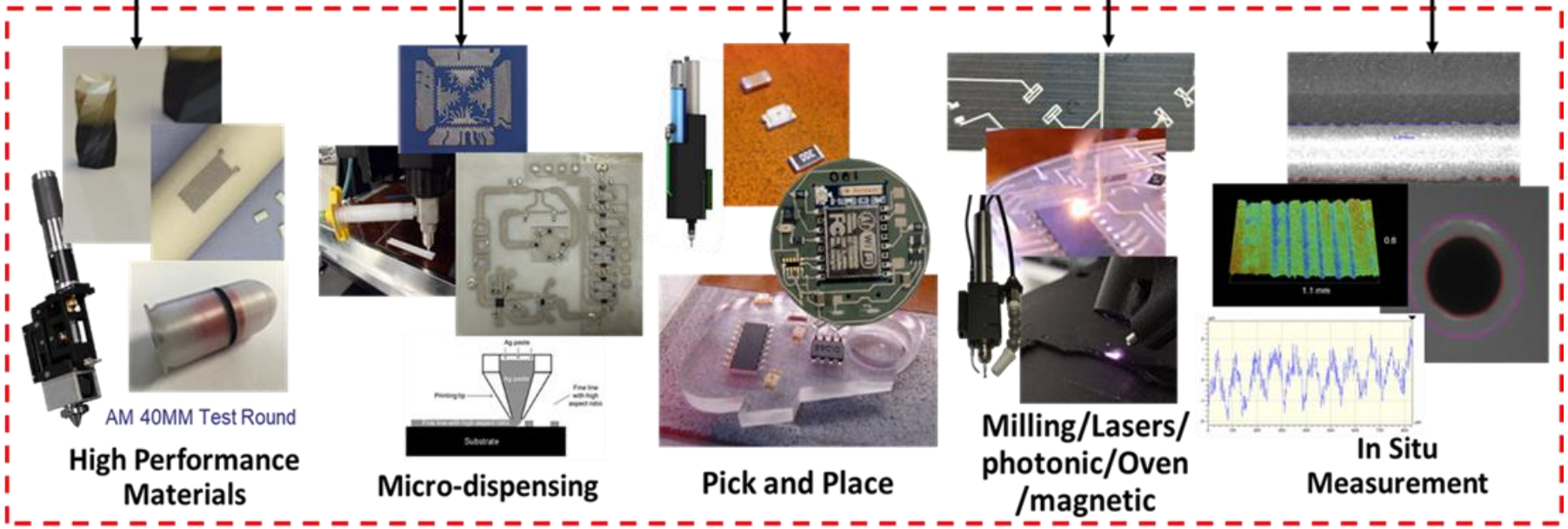
Dual Rotary with Micro Positioners, Fixture Solution for Flexible and Small Rigid Cylindrical



280um resistive traces serpentine around steel tube with conductive silver termination ring pads

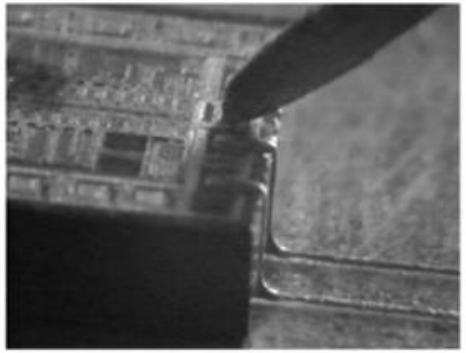
System In Package Workflow

Substrates & Pkgs → Interconnect & Vias → Components → Pre & Post Processing → Metrology

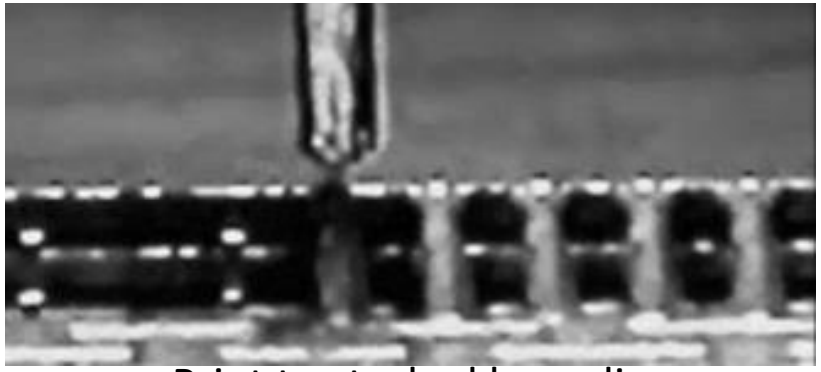


Application Specific Electronic Packaging (ASEPS)

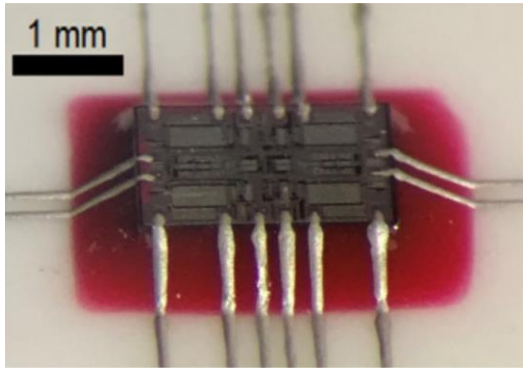
CHIPLET Integration



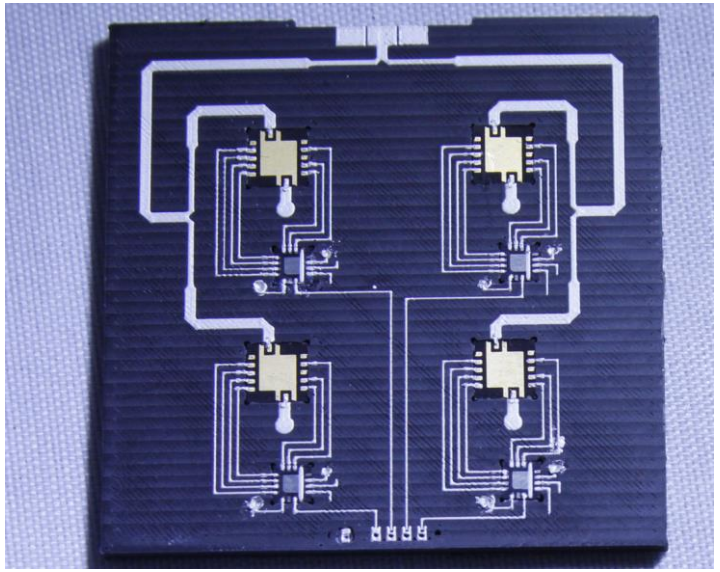
Print to bare die



Print to stacked bare die



Print filler and bare die

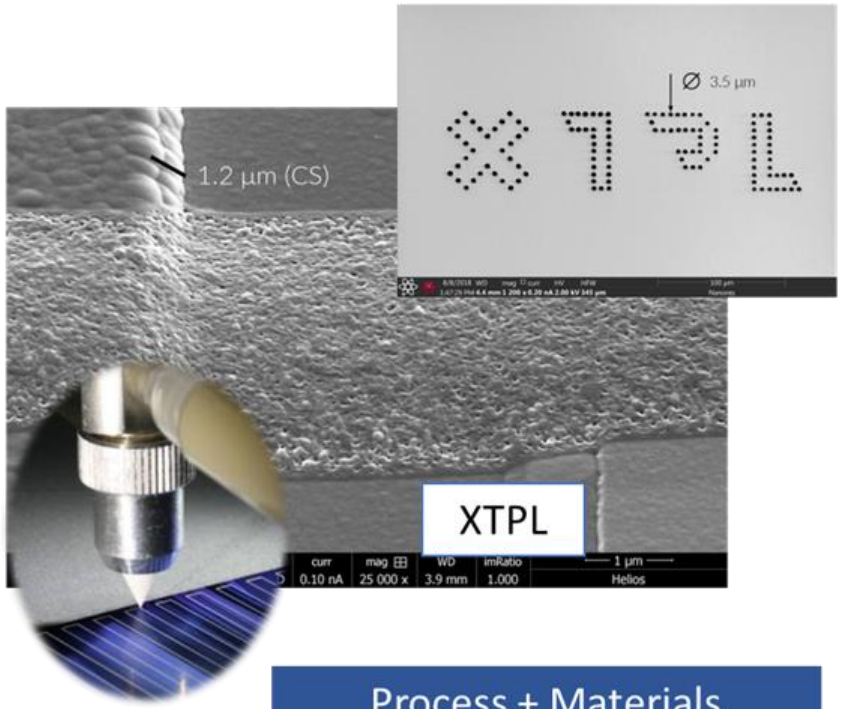


Multi-process/Multimaterial using Additive or 3D Manufacturing

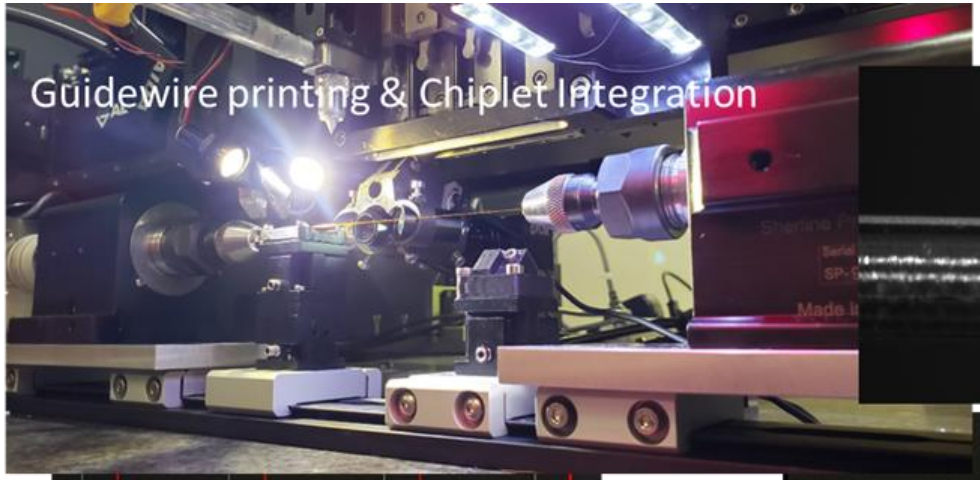
Print the entire circuit using bare die or CHIPS.

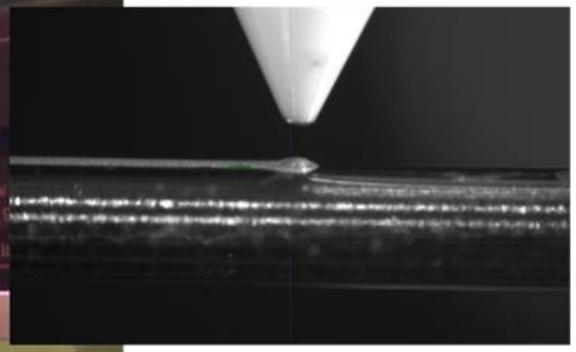
Even though Front, Back and PCB are very different with rigid lines that separate them, a blurring of the lines is emerging because of Additive Manufacturing and CHIPS.

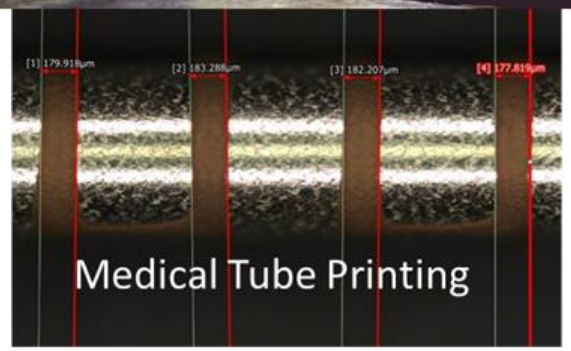
CHIPLET Integration – Medical

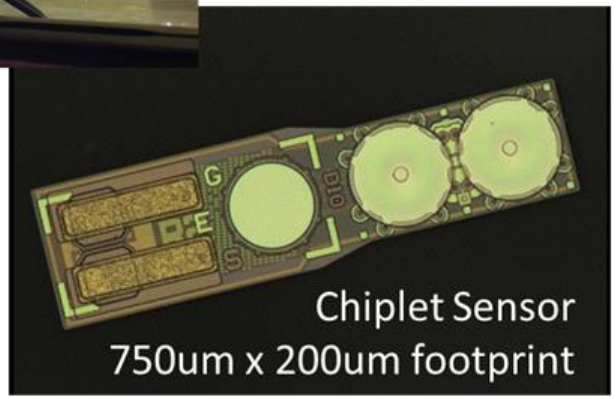


Process + Materials

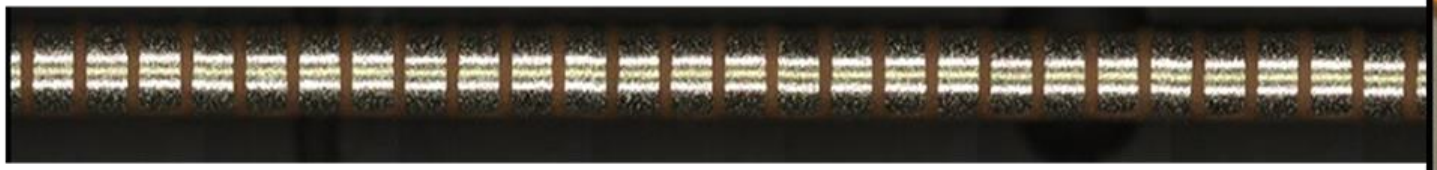


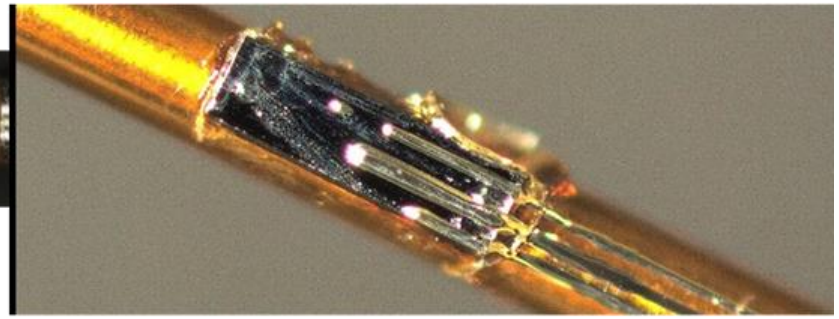






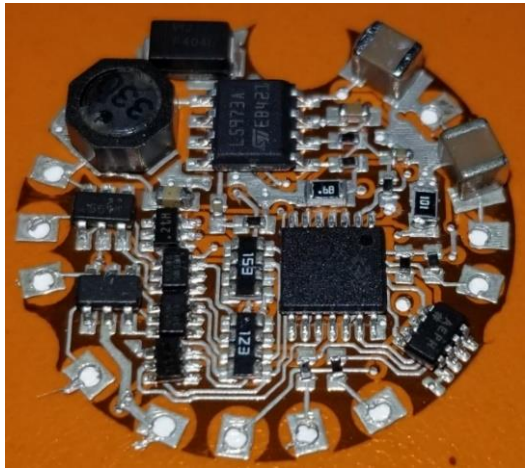
Copper Spiral Average Trace Width: 125.113µm



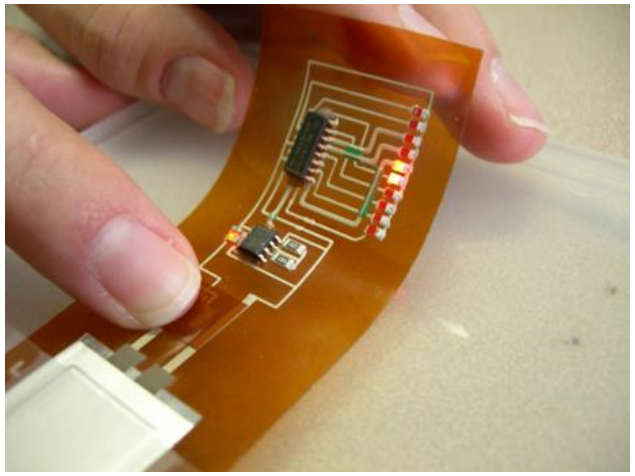


Precision

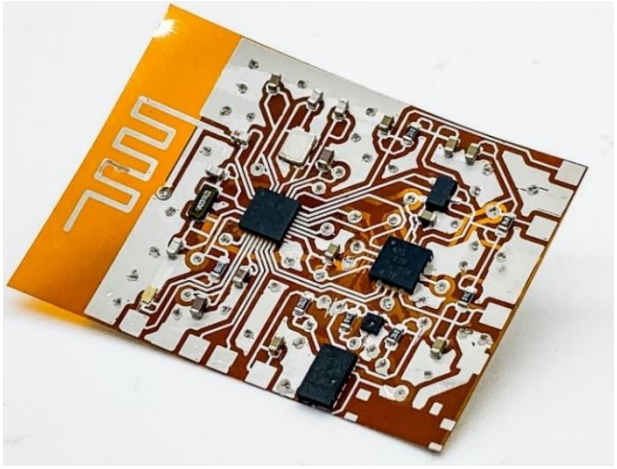
Flexible Hybrid or Additive Manufactured Electronics



Two Layer LED Drive with 0204 Component



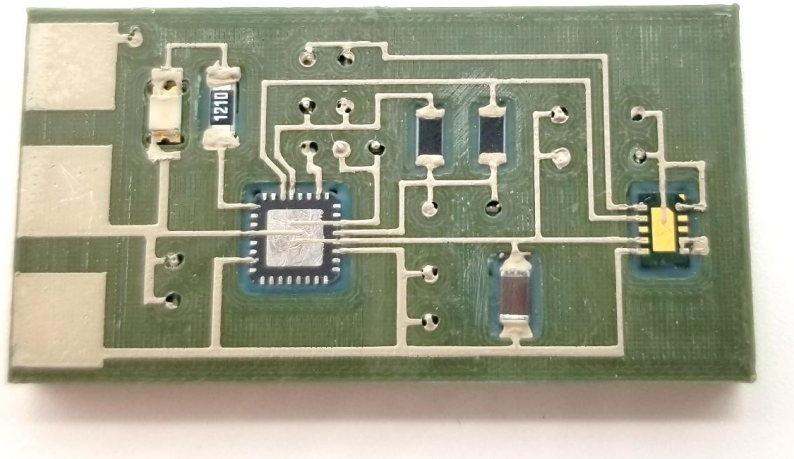
LED 555 Time Working While Flexed



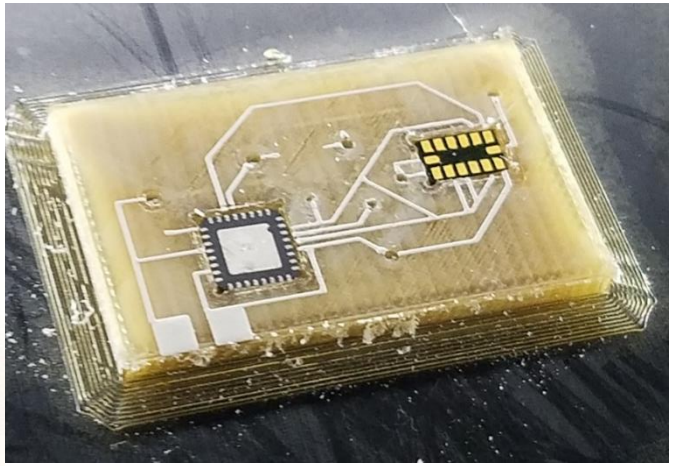
MCU with Bluetooth SoC and Sensor Suite

FHE Advantages:

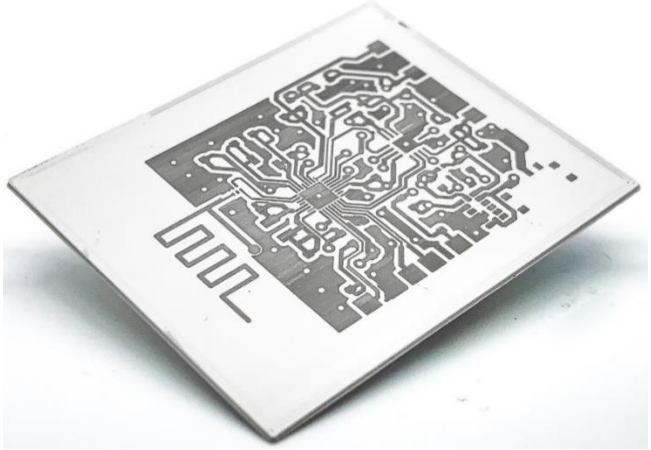
- Bendable
- Better Conductivity then AME (due to processing temperatures)



ABS Substrate, Silver paste, MCU with 3-Axis accelerometer, UV Curable fill for embedded packages



PEEK Substrate, Silver paste, MCU with 3-Axis accelerometer

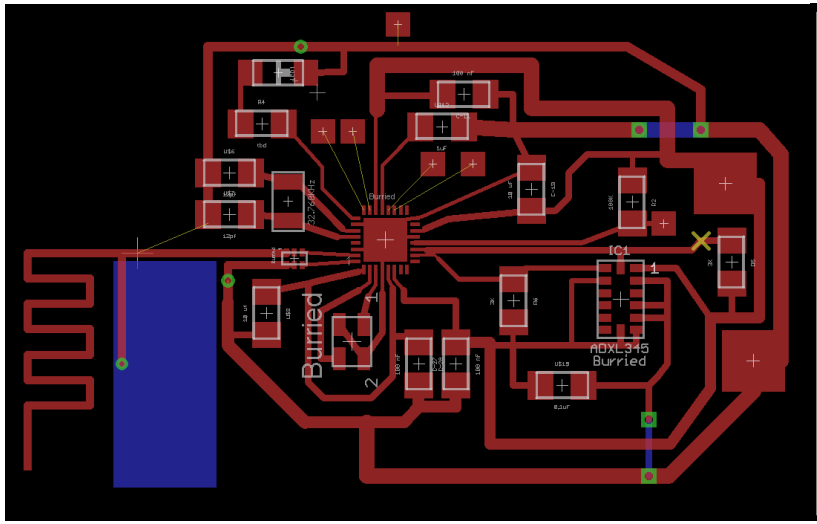


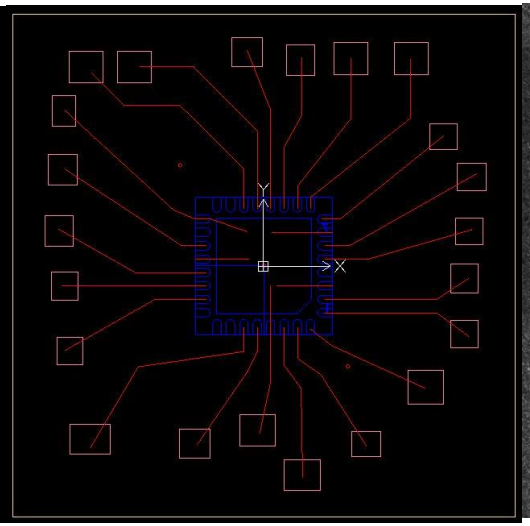
Ceramic Loaded ABS with Trace Pattern of Above Circuit

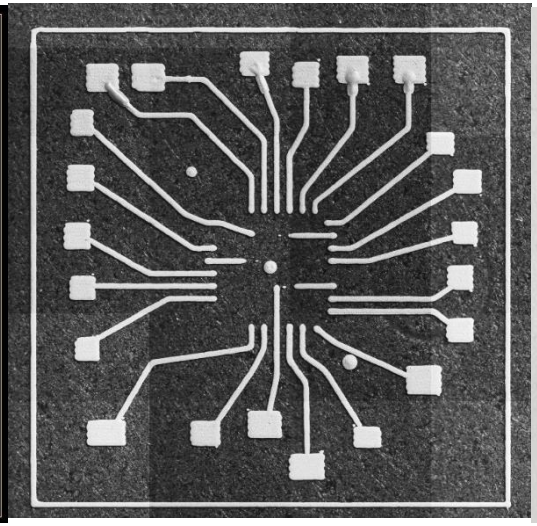
AME Advantages:

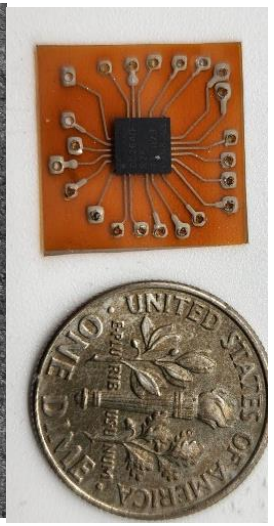
- Multilayer
- Embedded Components
- Blind Vias
- Harsh Environments (10,000gs)

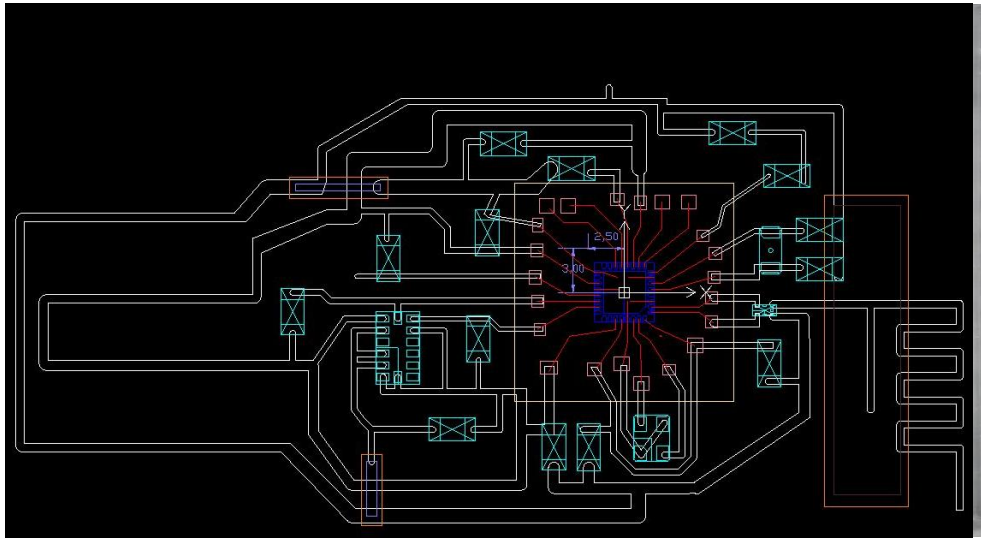
AME and Integrated FHE Interposer

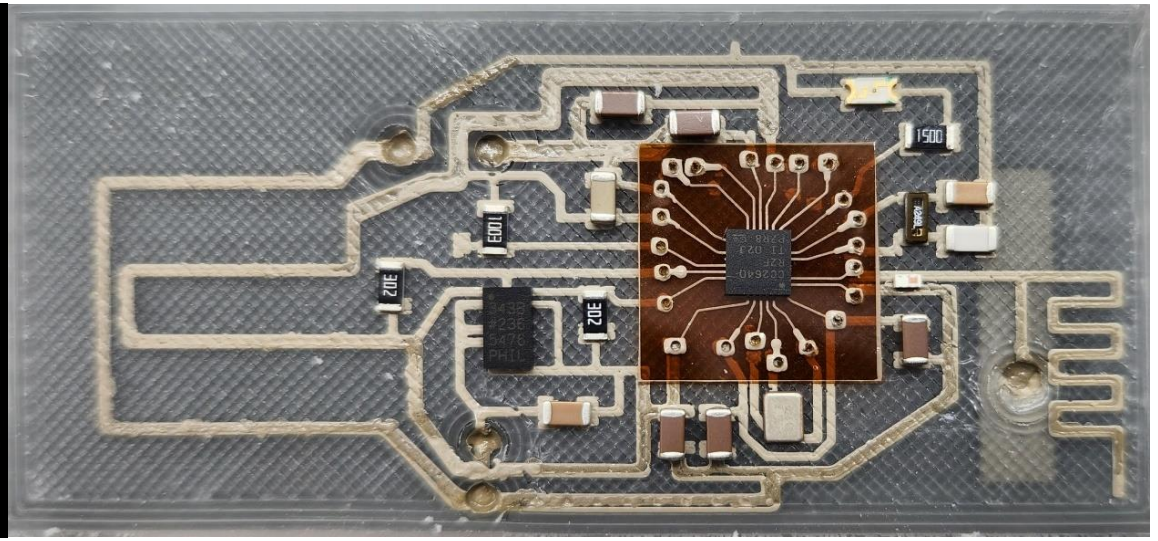












Process:

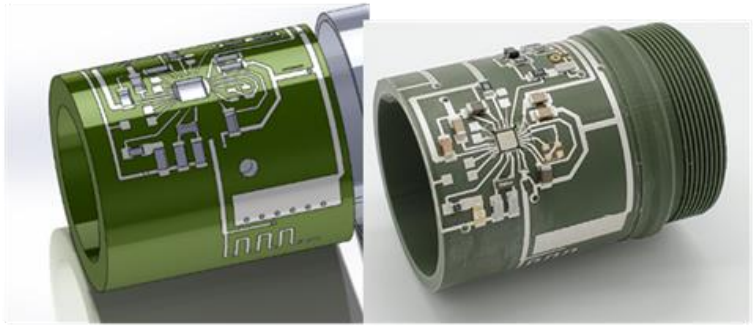
- Print ASEP for die (FHE Interposer)
- Print ASEP for board and traces
- Pick and Place Interposer onto AME

Application:

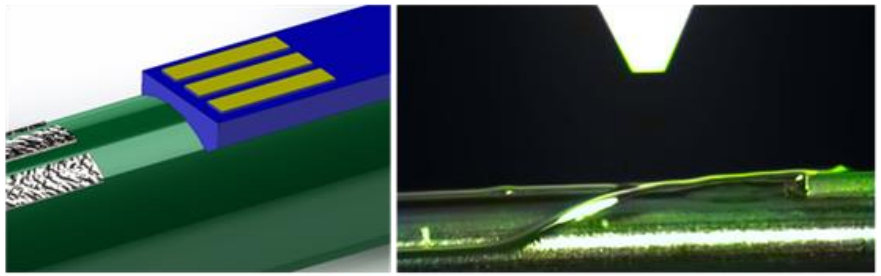
- Same Bluetooth LE Demonstrator Circuit
- TI MCU (Interposer) Board with Embedded components (AME)

Increasing Functional Density

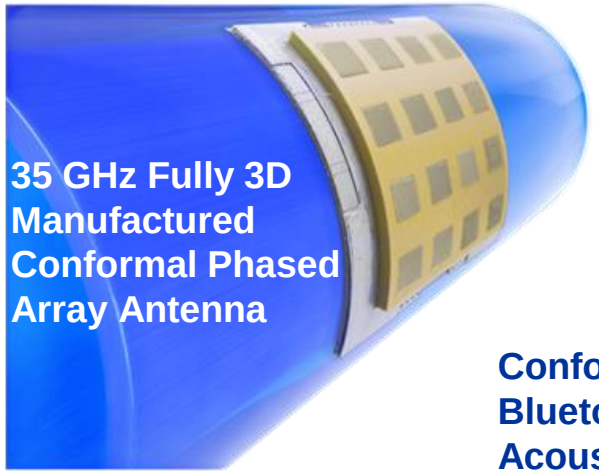
Any Shaped Circuits



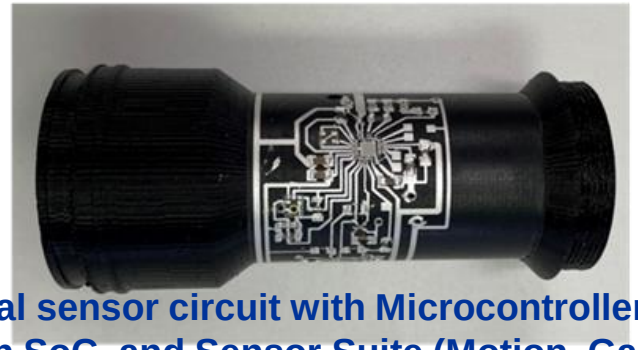
From a Digital File to a Physical Product



Additive Flex Circuits



35 GHz Fully 3D Manufactured Conformal Phased Array Antenna

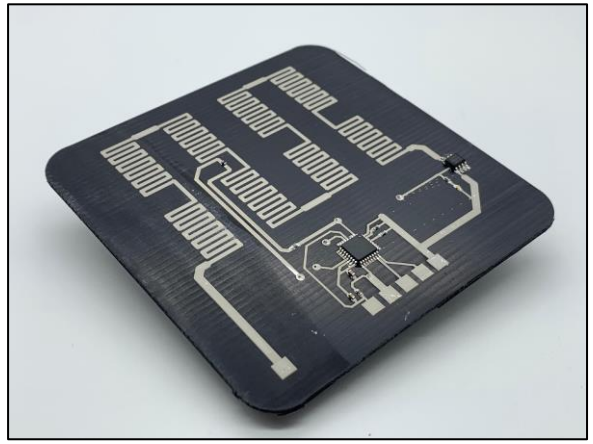


Conformal sensor circuit with Microcontroller, Bluetooth SoC, and Sensor Suite (Motion, Gas, Acoustic, etc.)

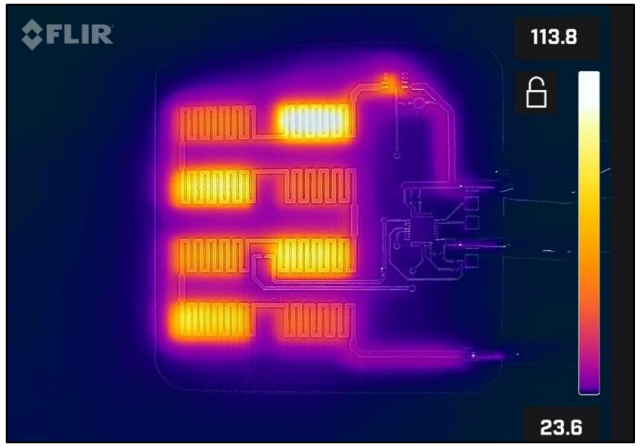
Doubly Curved Surface Micro dispensing

Future products will not be limited to flat boards. Electronics will take on “any” shape, 3D shapes.
Future manufacturing will take a digital file, CHIPS and Additive Manufacturing
and make a new generation of products that are possible to make today, but do not yet exist.

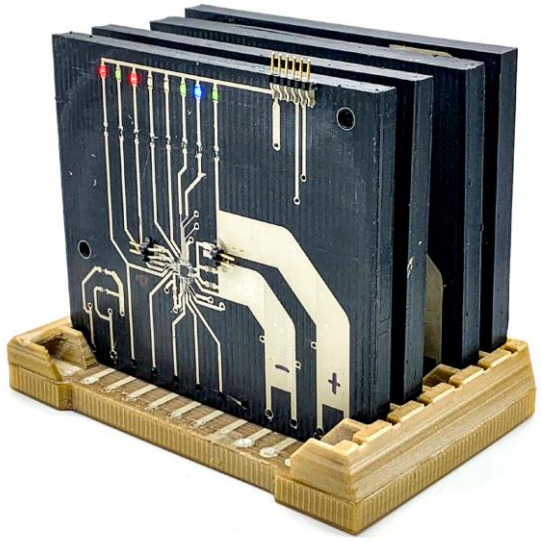
Multimaterial ~ Multiprocess ~ Multifunction

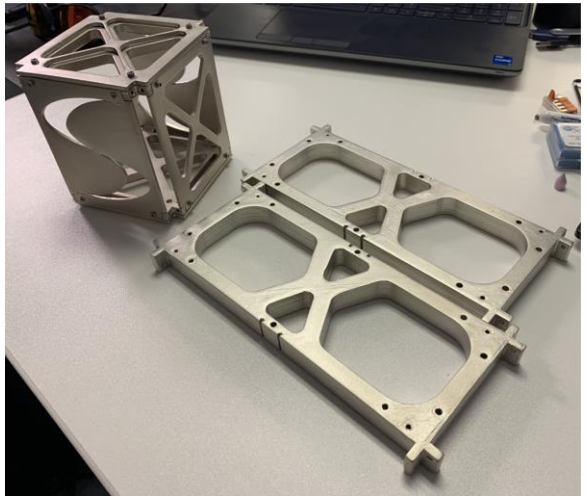


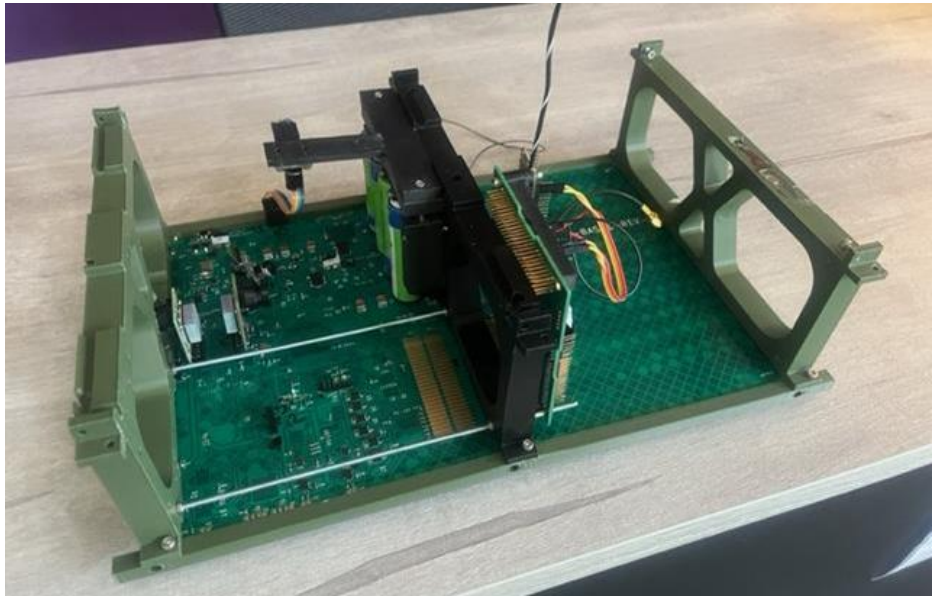
Printed demonstration circuit



Thermal view of variable-resistance traces







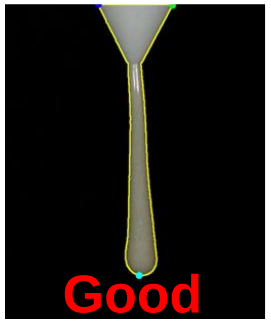
3D Printed Electronics 6U Cubesat

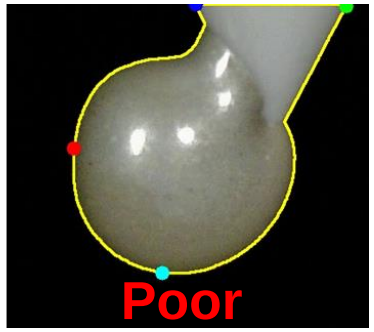
0474

Printed Electronics : Integrating Multi-Sensors

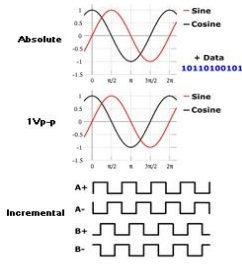
In Situ Metrology

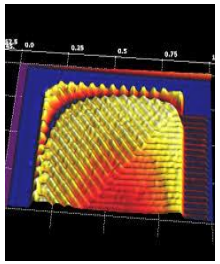
- **Automate**
  - Intelligent planning
  - On system probing
  - Machine tool metrology
- **Integrate**
  - Fusion of sensors both system and lab
  - Machine and full lab networking
- **Communicate**
  - Intelligent machine network
  - Tool condition monitoring
  - Lab environmental monitoring
  - Product health monitoring
- **Digital Twin**
  - Machines
  - Materials
  - Processes
  - Products





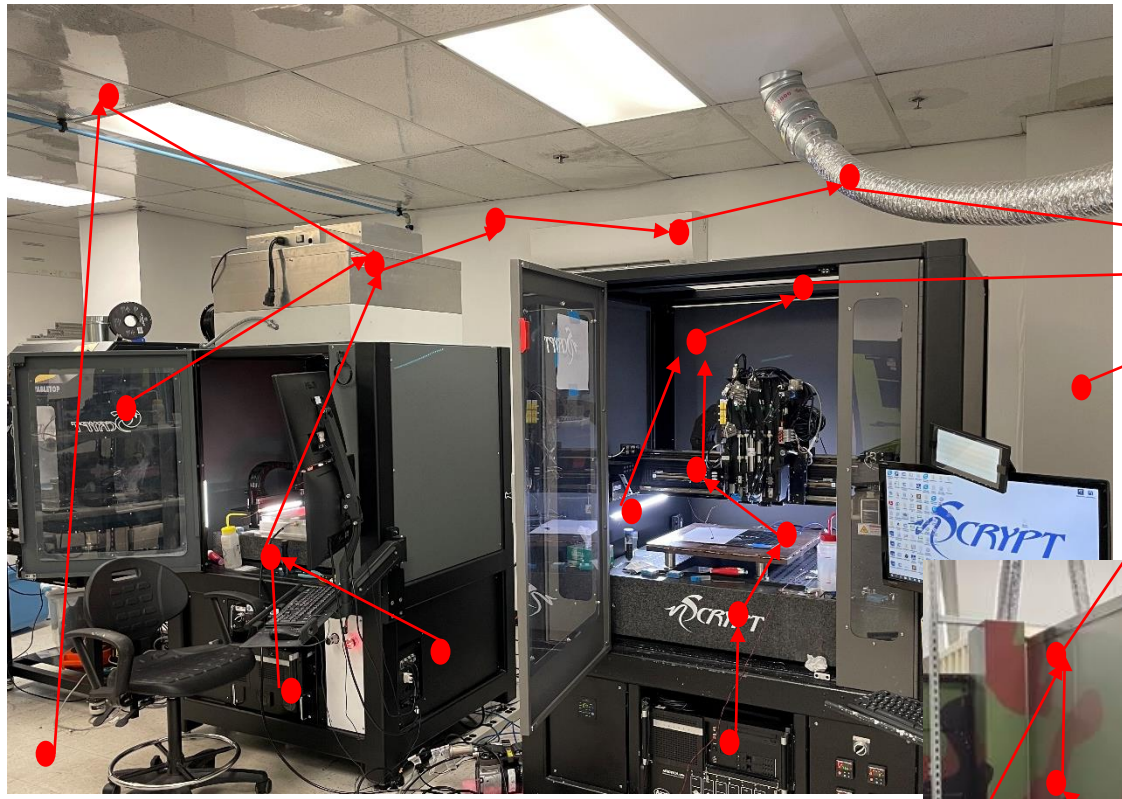
- Sensor feedback during prints
- Sensor feedback during processing
- Real time in situ adjustments





Industrial IoT

SMART 3D Manufacturing



Local Cloud

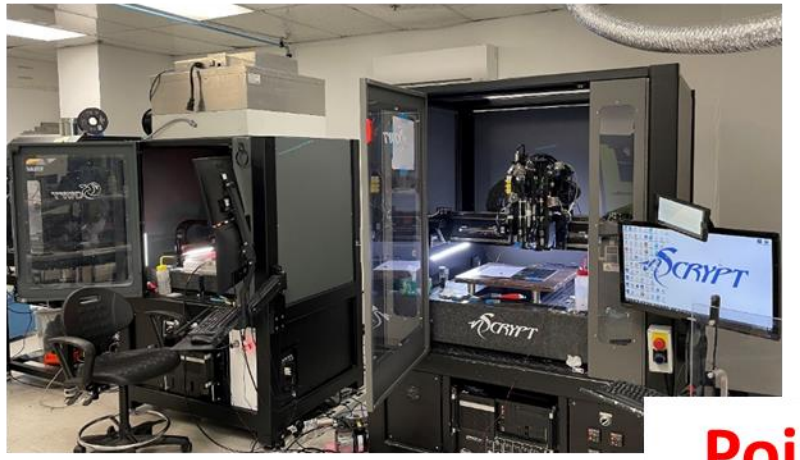
- Integrate
- Automate
- Communicate
- Fabricate
- Digital Twin

- Sensorize the equipment
- Sensorize the lab
- Sensorize the box
- Mesh the sensors (wireless or hardwired)
- Sensor Fusion
- Machine Learning

Factory in a Lab
Or
Factory in a Box, that can be forward deployed.

Printed Electronics : Integrating Multi-Location

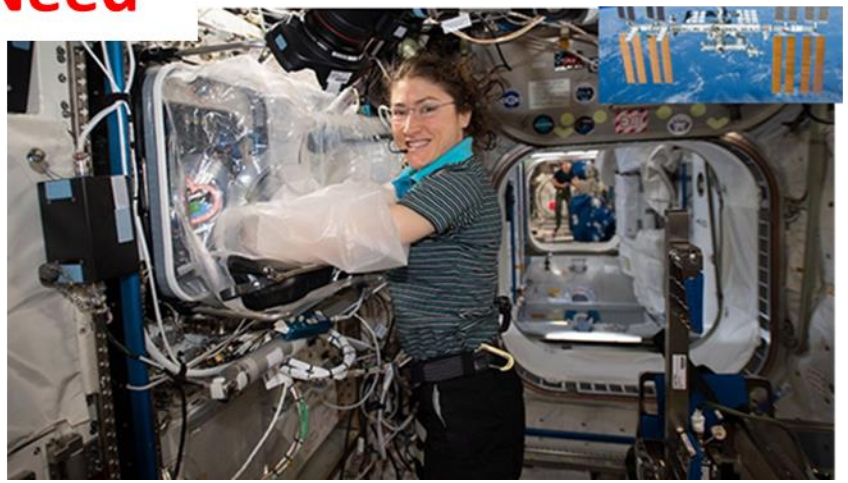
Brick & Mortar



Austere

Point of Need

Mobile



* Space

Distributed Manufacturing

*** 3DPE System Launch to ISS in**

Austere Manufacturing

The International Microelectronics, Assembly and Packaging Society

Florida Chapter

Advanced Technical Workshop & Tabletops

Heterogenous Integration - System in Package

Research, Manufacturing & Digital Workflow

https://imaps.org/page/IMAPS-Florida

SAVE THE DATE

Expanded 2 Day Event!

Date: August 28th and 29th 2024

Skywater/BRIDG/imec - 200 NeoCity Way, NeoCity, FL 34744

Workshop Focus:

The focus is on manufacturing low volume, highly customized chips which have little or no broad-based demand by the average consumer, but are **highly sought after by the aerospace, defense, and medical industries because those industries operate in extreme environments that often require microchips with specific functions in very low volumes. Large scale, commercial fabs do not make these types of chips because they either do not meet aerospace, defense, and extreme environment requirements or the way they are produced does not meet the system developer's security needs.*

This workshop will bring together the scientists, engineers, manufacturing, academia, business and people from around the world who work in the area of smart sensors, systems and advanced packaging technology. This workshop and tabletop exhibits enable discussion and presentations on the latest semiconductor-based design, process and materials for smart sensor and photonic technologies.

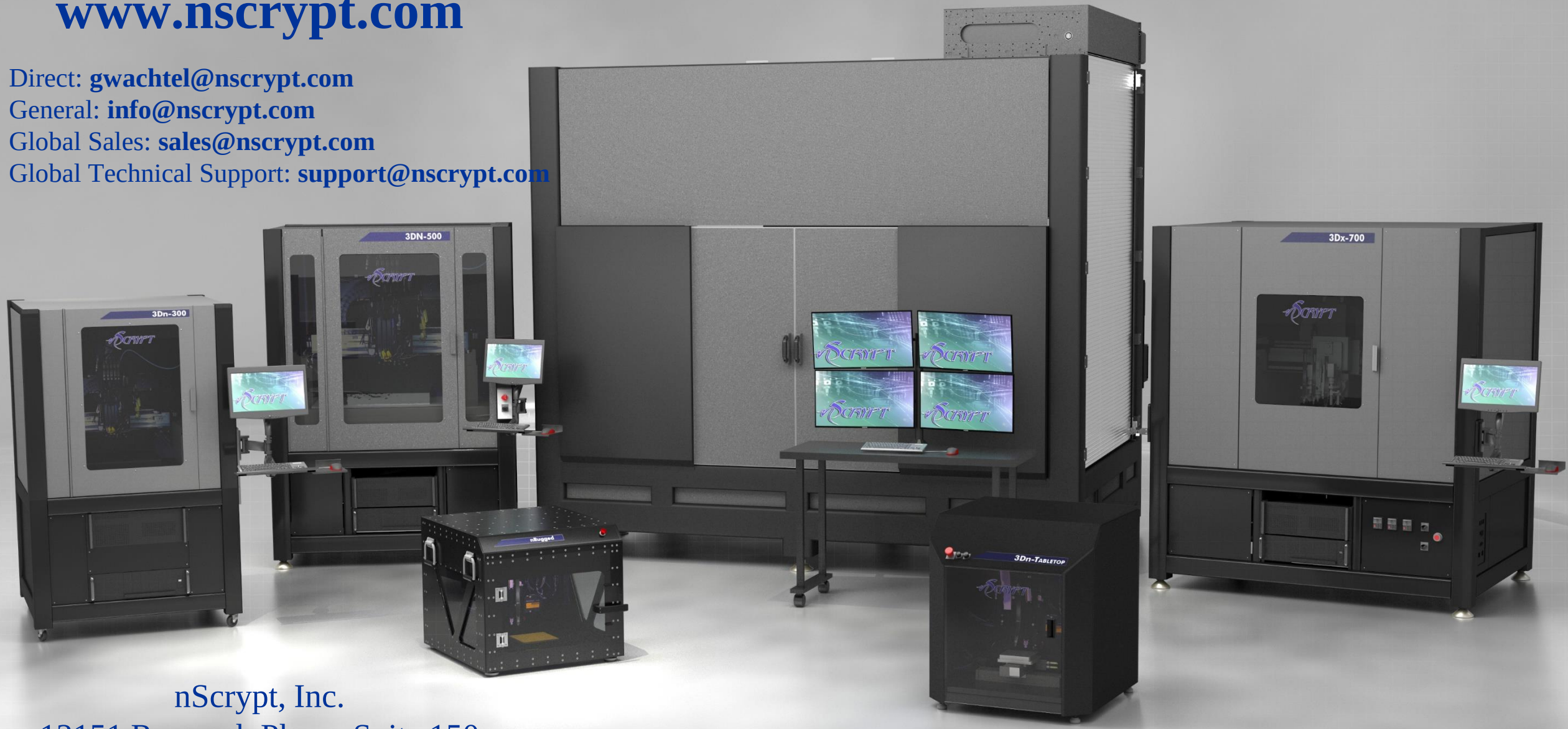
- Fan-Out Wafer-Level Packaging (FOWLP)
- Silicon and Glass Substrates/Interposers
- Hybrid Bonding
- Chiplet Technology
- Additive Manufactured Electronics (AME)
- Interconnect Materials
- Novel Die Interconnect
- Digital workflow & Cybersecurity
- Design, Simulation and Modeling
- In Situ Metrology & Machine Learning
- Digital Twin,
- CHIPS and SHIPS
- On Shoring
- TSV's & TGV's

On Shoring of the semiconductor supply chain is driving the need for new advanced packaging and


U.S.ARMY
DARPA
U.S. AIR FORCE
NORTH CENTRAL STATE COLLEGE
1969
ROCHESTER INSTITUTE OF TECHNOLOGY
R·I·T
1829
UNIVERSITY OF DELAWARE
UNITED STATES SPACE FORCE
DEPARTMENT OF THE AIR FORCE
MMXIX
UNITED STATES NAVY
UTEP
UMASS LOWELL
FLORIDA A&M UNIVERSITY
NJIT
New Jersey Institute of Technology
UNIVERSITY OF LOUISVILLE
NASA
FLORIDA INSTITUTE OF TECHNOLOGY
AD ASTRA PER SCIENTIAM
1958
FLORIDA INTERNATIONAL UNIVERSITY
SPES SCIENTIA FACULTAS
1965
MIAMI
USF UNIVERSITY OF SOUTH FLORIDA
America Makes
TEXAS A&M UNIVERSITY
1876
IN SPACE MANUFACTURING
3D
NASA ISM
ISS MAY 2019
ISS 2024
NEXTFLEX

www.nscrypt.com

Direct: **gwachtel@nscrypt.com**
General: **info@nscrypt.com**
Global Sales: **sales@nscrypt.com**
Global Technical Support: **support@nscrypt.com**



nScrypt, Inc.
12151 Research Pkwy, Suite 150
Orlando, FL 32826
Phone: 407-275-4720

nScrypt will make mass, complicated manufacturing, personalized and simple

Multi-axis Process integration for Wafer scale and Substrate-Like Printed electronics

C. Mike Newton[1], Dr. Rudy Ghosh[2], Grant Wachtel[1], Connor Whitley[1]
[1] nScrypt, Orlando, FL, USA. [2] PulseForge, Austin, TX, USA

Abstract

Organic based HDI packaging technology has been in use for quite a long time in various forms, but line and space limitations are limited to 40 microns. With the interest in chip level disintegration or chiplets there is a need for even higher levels of multichip integration and ever smaller feature sizes for PCB. Additionally wafer scale packaging technologies that incorporate substrates/interposers like silicon and glass take advantage of foundry capabilities that do not require the most process node feature sizes required for chiplet packaging driving wafer costs down. Substrate-like PCBs (SLP) fill a gap between WSP and HDI and push lines and space features size to below 30 microns. The 5G market is a key driver for SLPs. This presentation will discuss a multi-axis and process capability enabling Substrate-Like Printed electronics or SLPe that are traditionally flat or conformal. A modular factory in a tool capability will be outlined that that incorporates processes like aerosol printing of interconnect, photonic curing, micro dispensing of solder dots, chip assembly and in-situ metrology.