



Aerosol Jet[®] (AJ) Direct Write Technology

A Manufacturing Tool for Printed Electronics

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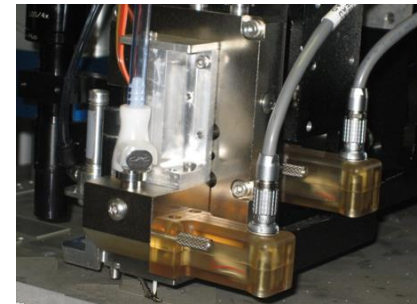
Optomec does not design SAW, RFID, Antennas or Circuits

Optomec Introduction

- » Began Additive Manufacturing Business in 1997 from Sandia Natl Labs CRADA Headquarters in Albuquerque, NM – Development Lab in St. Paul, MN
- » **Business Model: Design, Engineer, Manufacture, & Support Additive Manufacturing Systems**
- » **Inventor / Supplier of Two “Additive” Manufacturing Technologies**
 - **Laser Engineered Net Shaping (LENS):**
Metal deposition for fabrication & repair of metal components.
 - launched from Sandia National Labs LENS CRADA (12 Industrial Members)
 - **Aerosol Jet (AJ):** Direct Write Perinted Electronics
 - launched from \$9M DARPA Project: **M**esosopic **I**ntegrated **C**onformal **E**lectronics
- » **\$30+ Million in Fed Govt Funding for Technology & Product Development**
 - 30 patents issued, 40+ pending...
- » **100+ Aerosol Jet Systems installed worldwide**
- » **Partnerships with Material, Process, and System Integration Companies**
- » **April 2011 Frost & Sullivan Award for Aerosol Jet technology**
“Printed Electronics Enabling Technology of the Year”



AJ Development System



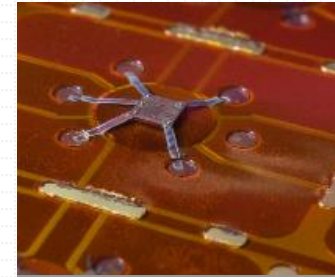
AJ Marathon Print Module



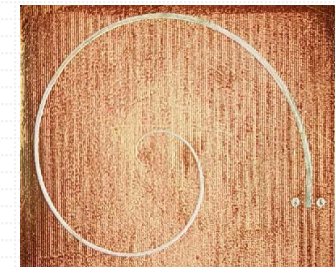
LENS System

Aerosol Jet Introduction

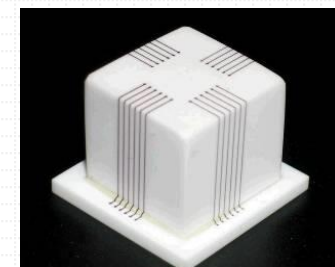
Application Examples



Die Attach



1cm GPS Antenna



3D Interconnects

» Patented Material Deposition Kernel (atomizers, PCMs, print modules)

- Configurable for wide range of Feature Sizes & Multiplexing for volume production

» Development Platforms Successfully Fielded

- for material, process & application development / prototyping

- Configurable Atomizers, Heads, Motion, etc.

» High Throughput Multiplexed Heads for Production

- ie: 40 nozzle head prints 2400 silicon solar wafers / hour

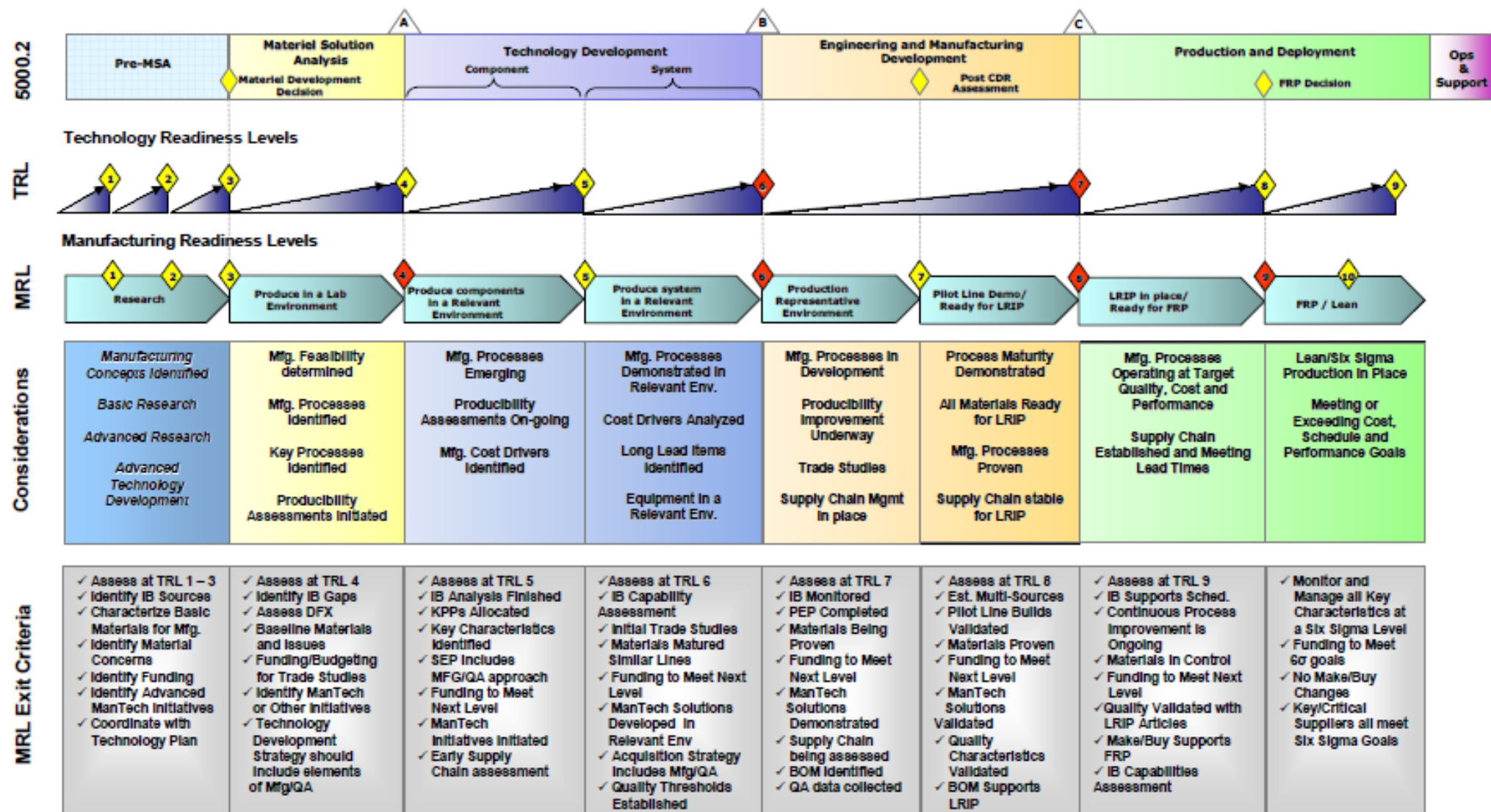
» Platform Independent Modular Print Engines

- for high volume manufacturing

- Standardized communications protocols & interfaces
- Easily integrated with 3rd Party Manufacturing Systems
 - Manz Automation: print 80 solar collector lines on silicon wafers in 2.5 seconds
 - Speedline Technologies: print 20+ die stack interconnects / second



Manufacturing Readiness Levels



A Red Diamond Indicates a Proposed Mandatory Review Point

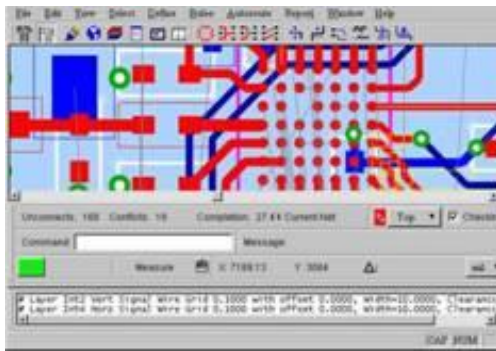
Dated: V7.1 May, 2009

Aerosol Jet[®] Process Overview



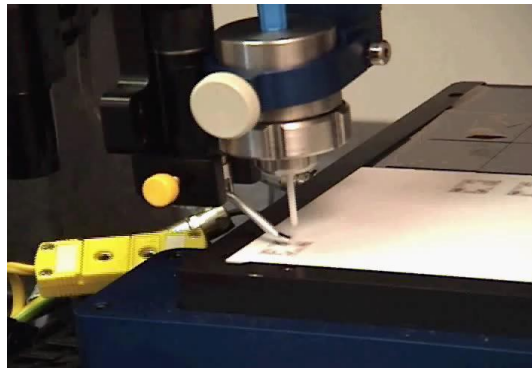
Aerosol Jet Process (Art to Part)

Design



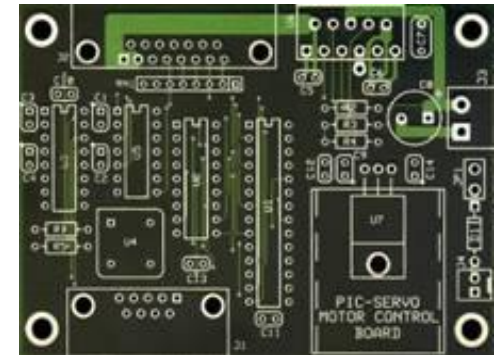
- CAD Model
- Convert to DWG file
- Tool paths generated with Optomec software

Process



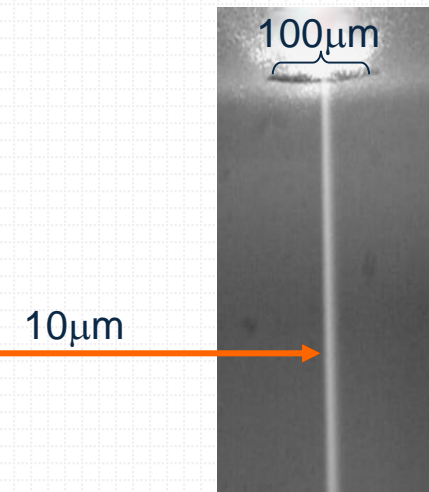
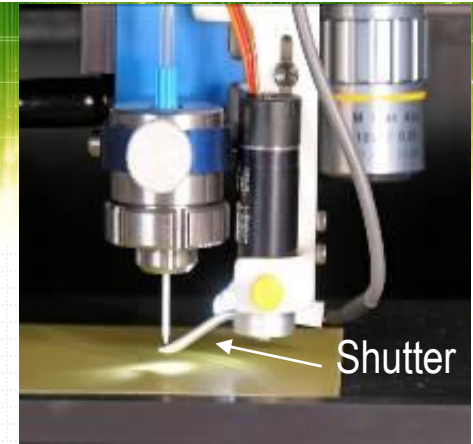
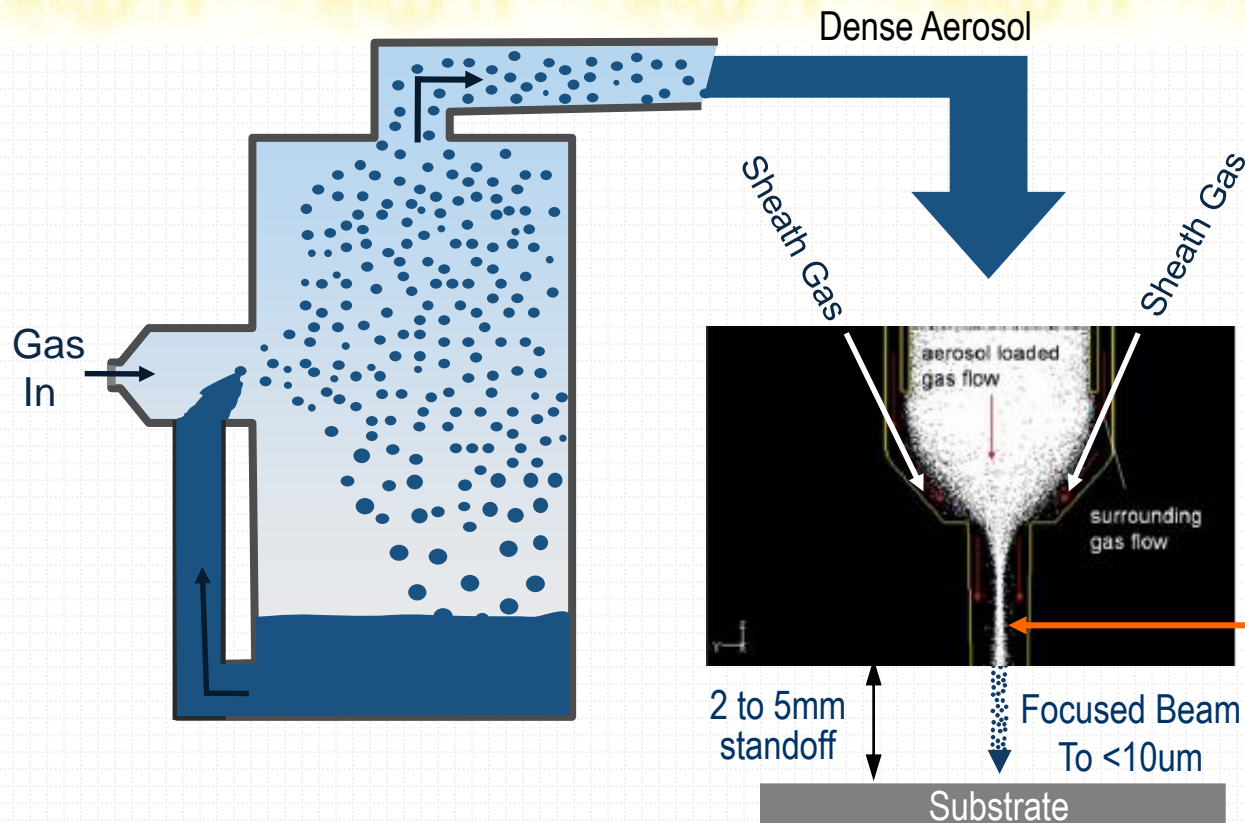
- Liquid raw material
- Create fine (femto Litre) aerosol
- Focus to tight beam (<10µm)
- Post-process (dry, cure, sinter...)

Part



- Fine line traces
- Conformal printing
- Embedded passives
- Interconnects
- Coatings

Aerosol Jet Process Basics



STEP 1: MIST GENERATION

- Ultrasonic & Pneumatic Atomizers
- 0.7-5000cP ink handling viscosity
- Small Aerosol Droplets ~ 1-5μm
- High material loading (vs. InkJet)

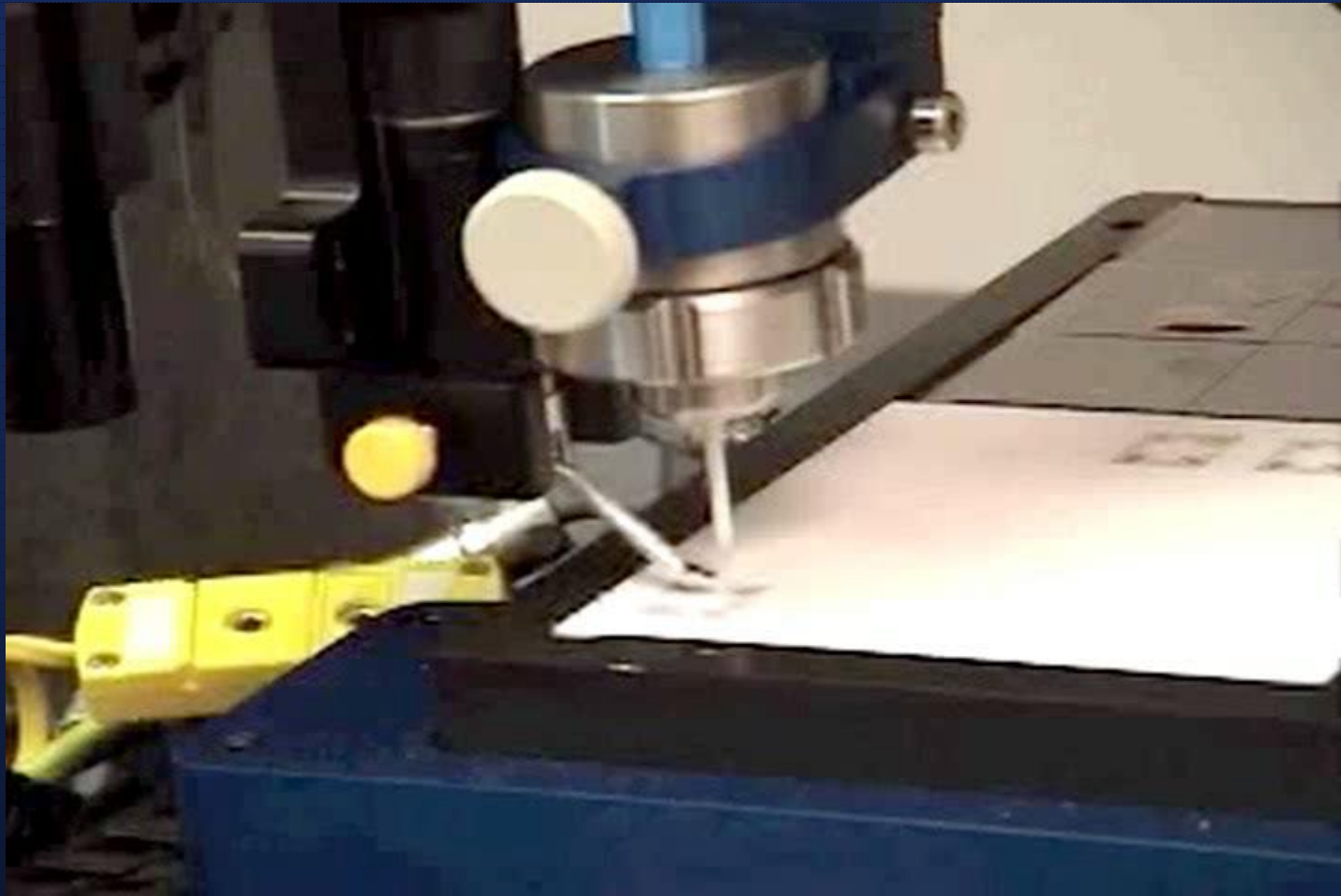
STEP 2: AERODYNAMIC FOCUSING

- Introduction of Sheath Gas, surrounding aerosol droplets with annular, co-axial flow.
- Collimates and Accelerates Droplets to near speed of sound (80 > 100 meters / second)
- Up to 0.25 microliter/sec dispensing speed
- Non contact with tip protects from clogging

STEP 3: DEPOSITION

- Tightly focused, high density stream
- 5mm standoff / working distance
- 10μm to 5cm line widths
- up to 200mm / second burst speed
- Excellent edge definition

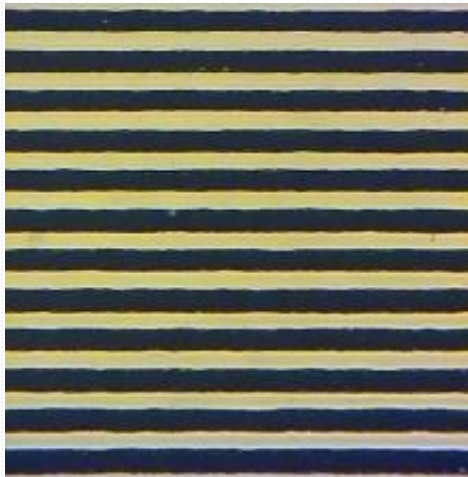
Aerosol Jet[®] Process Video



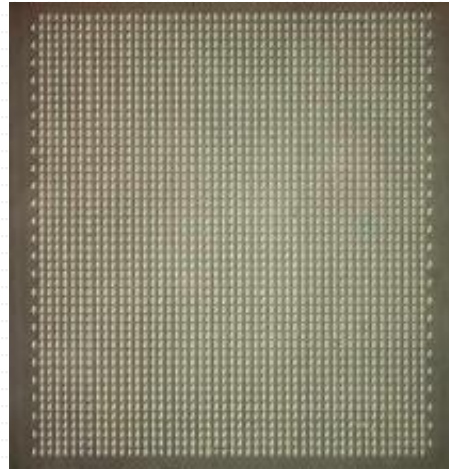
Aerosol Jet Direct Write Examples

Fine Feature Geometries & Conformal Printing

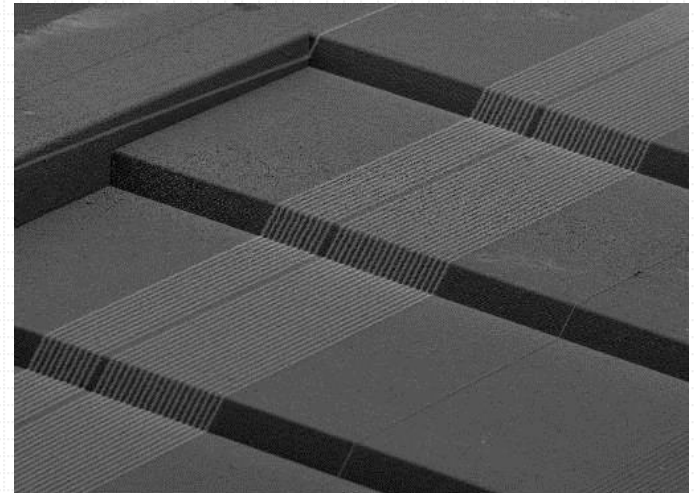
Oligonucleotide Microarray



- » 10 μm line width
- » 20 μm pitch



- » 2 ms shutter speed
- » Enables clean starts and stops
- » 36,000 spots per hour



- » Conformal deposition over varying topologies with no change in Z height
- » 20 μm Ag lines over stepped injection molded LCP
- » 500 micron trenches

Aerosol Jet[®] Materials Overview

Conductive Nanoparticle Inks

Polymers

Insulators

Adhesives

Dopants

Etchants

Biological Material



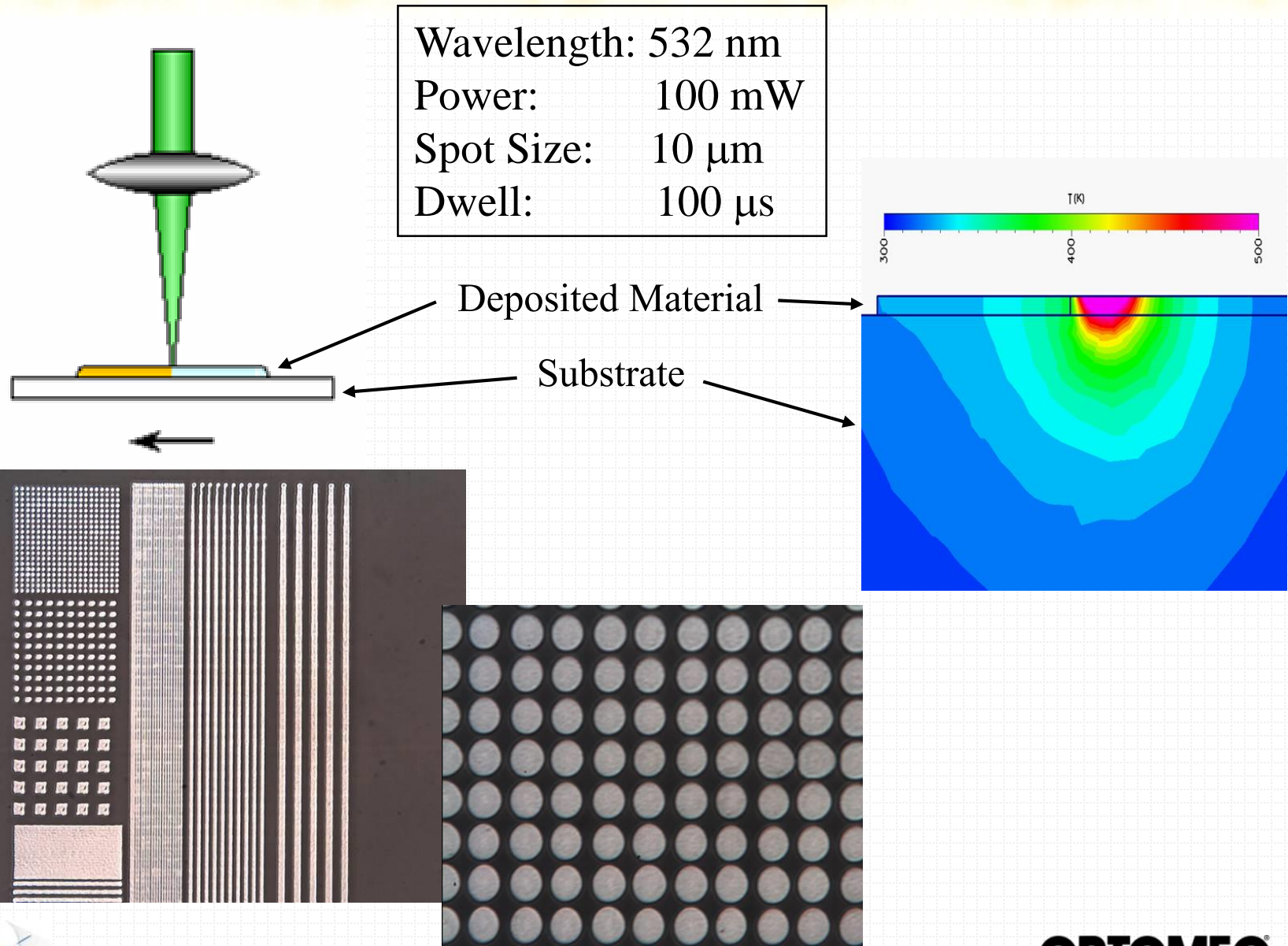
AJ Materials List (as of May / 2010)

MATERIALS MATRIX								LCP Teslin Polyamide
Conductor	Polyester	Polyimide	Glass	ITO	Circuit Board	Metals	Ceramic	
	UT Dots Ag	UT Dots Au		UT Dots Ag	UT Dots Ag	UT Dots Ag	Dupont Au	UT Dots Ag
	UT Dots Au	CIMA Nanotech		UT Dots Au	Cabot Ag	UT Dots Au	Nickel Oxide	UT Dots Au
	Nanomas Ag,Au	Nanosize Ag	Cabot Ag	Cabot Ag		Nanosize Ag		
	Cabot CSD-66	Cabot Ag	Nanosize Ag	Nanosize Ag				
Resistor	Method	Applied Nanotech Cu	Applied Nanotech Cu					
	Brew er Science CNTRENE	Brew er Science CNTRENE	Brew er Science CNTRENE		Brew er Science CNTRENE	Brew er Science CNTRENE		Brew er Science CNTRENE
	H.C. Stark PEDOT:PSS	H.C. Stark PEDOT:PSS	H.C. Stark PEDOT:PSS	H.C. Stark PEDOT:PSS	H.C. Stark PEDOT:PSS	H.C. Stark PEDOT:PSS		
		Baylnk TPS HS	Baylnk TPS HS	Baylnk TPS HS	Baylnk TPS HS			
Dielectric Adhesive	Asahi FTU series	Asahi TU series	Asahi TU series		Asahi TU series	Asahi TU series	Dupont Ruthenate	
	Bayer Baytubes	Brew er Science SWCNT	Brew er Science SWCNT		Acheson M-2031-pol			
		Acheson M-2031-pol	Acheson M-2031-pol		Lord Metech PC11223			
		Lord Metech PC11223	Lord Metech PC11223		Bayer Baytubes			
Biological	Loctite 3492	Loctite 3492	Norland 65 (various others)	Norland 65 (various others)		Norland 65 (various others)	YSZ	Norland 65 (various others)
	Norland 65 (various others)	Norland 65 (various others)	SU-8 GM1010	Summers		Loctite 3492		
	SU-8 GM1010		Summers Optical		SU-8 GM1010	SU-8 GM1010		
	Aldrich Polyimide (various)		Asahi CX-16		Asahi CX-16			
	Dupont Teflon AF	Dupont Teflon AF	Dupont Teflon dispersion			Dupont Teflon AF		
Etch Resists Catalysts Etch Chemicals Masking Semiconductor	BASF Luvitec PVP	BASF Luvitec PVP	BASF Luvitec PVP	BASF Luvitec PVP		BASF Luvitec PVP		
	CA1000	CA1000	CA1000	CA1000		CA1000		
	Sunchem 97B							
	PVDF							
	PMMA							
Etch Resists Catalysts Etch Chemicals Masking Semiconductor	Ion Gel							
			water based			water based		
			solvent based			solvent based		
			PLGA 5%			PLGA 5%		
Etch Resists Catalysts Etch Chemicals Masking Semiconductor	CA1000	CA1000	CA1000		SU-8 GM1010	SU-8 GM1010	Nickel Oxide	
			Polyacrylic Acid		Macdermid Microcat		LSM	Macdermid Microcat
	Sodium Hypochlorite		Ammonium Fluoride			Acids (various)		
			Nazdar RS10-26	Nazdar RS10-26				
Etch Resists Catalysts Etch Chemicals Masking Semiconductor	Merck P3HT	Merck P3HT	Merck P3HT					
	Brew er Science SWCNT	Brew er Science SWCNT	Brew er Science SWCNT					
	NanoIntegris SWCNT	NanoIntegris SWCNT	NanoIntegris SWCNT					

AJ Ink Recipes(as of May / 2010)

Material Recipes (May 23, 2010)						
	Material	Solvent	Cosolvent Added	Atomization	Substrates	PostProcess
Metals	UT Dots Silver 40-60wt%	Xylenes	10-20% alpha Terpineol	UA, r.t. or chilled	PET, PEN, Teslin, circuit board	Thermal 150C @ 30 min
	UT Dots Gold 40wt%	Xylenes	10-20% alpha Terpineol	UA, r.t. or chilled	PEN, PI	Thermal 200C @ 1hr
	Cabot CSD-66	Ethylene Glycol	None	PA (~600 sccm)	Plastic and glass	Thermal 180C @30 min
	Bayer TPS HS	Ethylene Glycol/water	None	PA (~600 sccm)	Plastic and glass	Thermal 180C @30 min
	Applied Nanotech CU		None	UA r.t.	PI, glass	Laser 100 mW @ 10 mm/s
Dielectrics	PMMA (Aldrich) (10% solution)	Acetone	50% Cyclohexanone	UA	Various	Thermal 100C 10 mins
	PVDF (Aldrich) (20% solution)	DMF	50% NMP	PA	Various	Thermal 140C 10 mins
	Polyimide (Aldrich and others)	NMP	50% NMP	PA	Various	Thermal 220C 30 mins
	Loctite 3492	None	None	PA	Various	UV fiber 10 sec
	Dupont Teflon AF	Perfluoro	add FC43 to get 2% solids	UA, r.t or heated	Various	Thermal 100C 10 mins
	Sun Chem 97B	None		PA	Various	UV fiber 10 sec
	CA1000		50% Acitonitrile	UA	Various	Thermal 180C 10 mins
	BASF Luvitec PVP		50% water	UA	glass, ceramic	Thermal 100C 10 mins
Conductors	HC Stark PH 500	Water	10-20% Ethylene Glycol	UA, r.t. , use rband	various	Thermal 50C 10 mins
	Brewer Science SWCNTs	Water	none	UA, r.t., use rband	various	Thermal 50C 10 mins
Resistors	Lord 8661		30% Butyl Carbitol	PA, stir	various	Thermal 180C 30 mins
	Acheson-Minico		30% Butyl Carbitol	PA, stir	various	Thermal 180C 30 mins
Etchants	Aldrich Ammonium Fluoride	Water	none	UA, use rband	coated substrate	wash with DI
	Aldrich Sodium Hypochlorite	Water	none	UA, use rband	coated substrate	wash with DI

Laser Sintering Option



Strategic Partnerships



Strategic Partnerships

Partners for a Greener Tomorrow

Process

Solutions

Materials

Packaging

Display

Photovoltaics

Flex Circuits

Life Sciences



Heraeus



ROHM HAAS



Cima NanoTech

Asahi KASEI



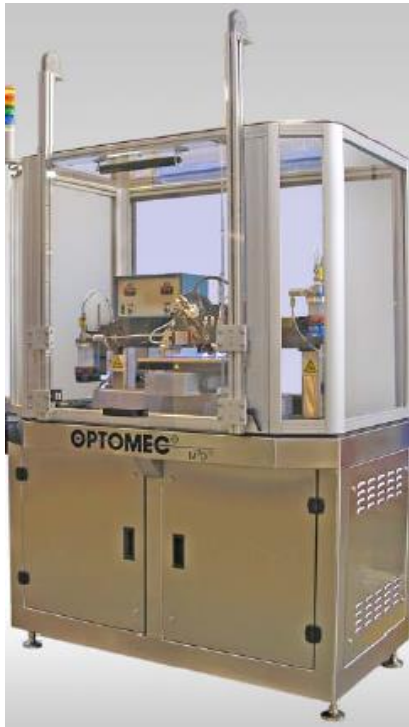
SunChemical



Aerosol Jet[®] System Overview



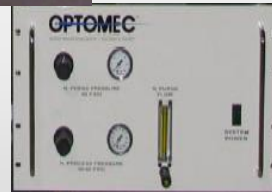
Aerosol Jet & Deposition System Platforms



- » AJ 300CE / P
- » AJ 3DIC Lab
- » AJ Display Lab
- » AJ Solar Lab



Single Nozzle
Deposition Module



Sprint Print Engine



Deposition Module(s)

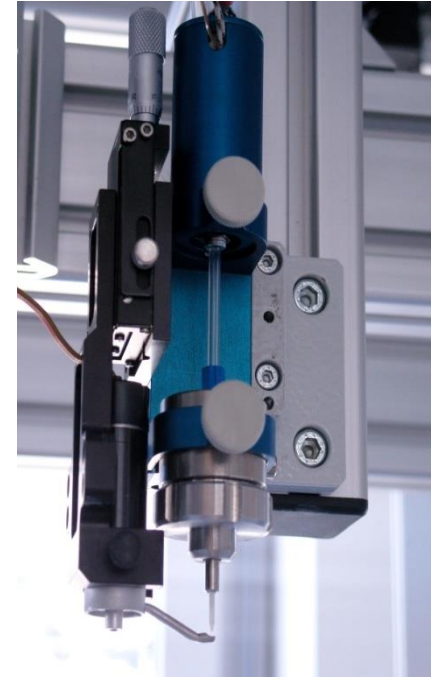
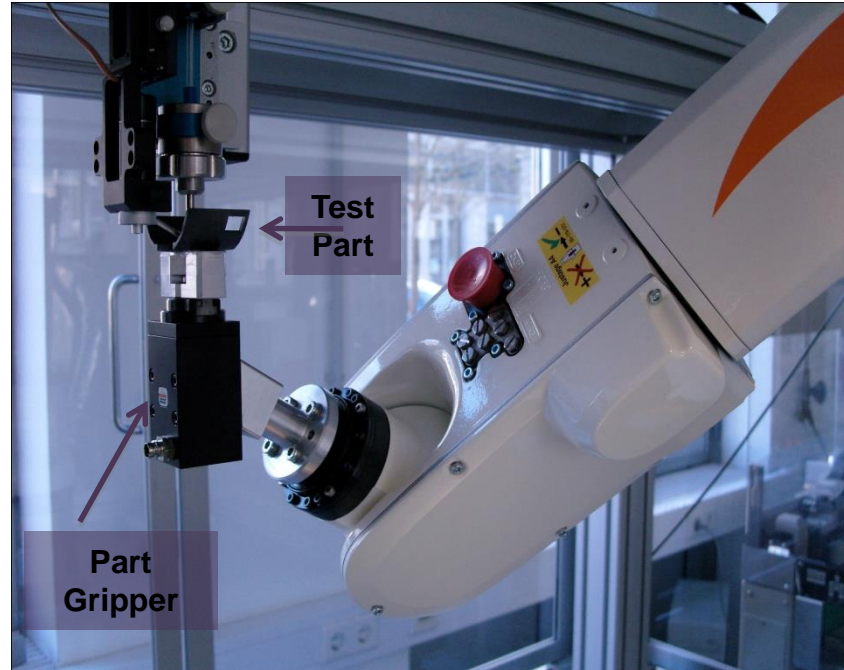


Automation



Marathon Print Engine

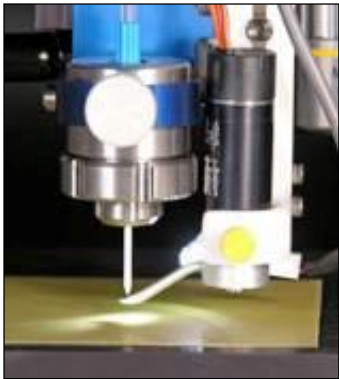
6-Axis Aerosol Jet Printer



Aerosol Jet[®] Robotic Arm Video



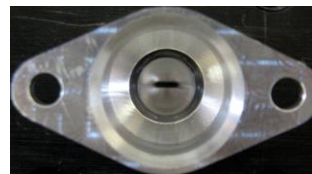
Head Configurations - Scaling for Production



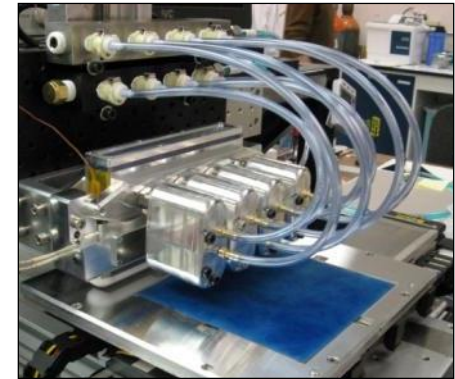
Single Nozzle



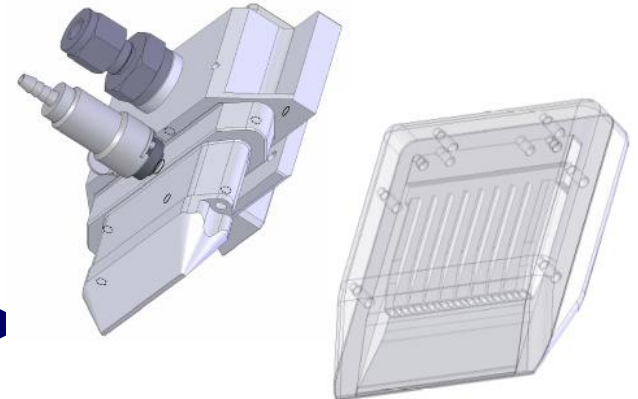
10 Nozzle Head



3mm Slotted Nozzle

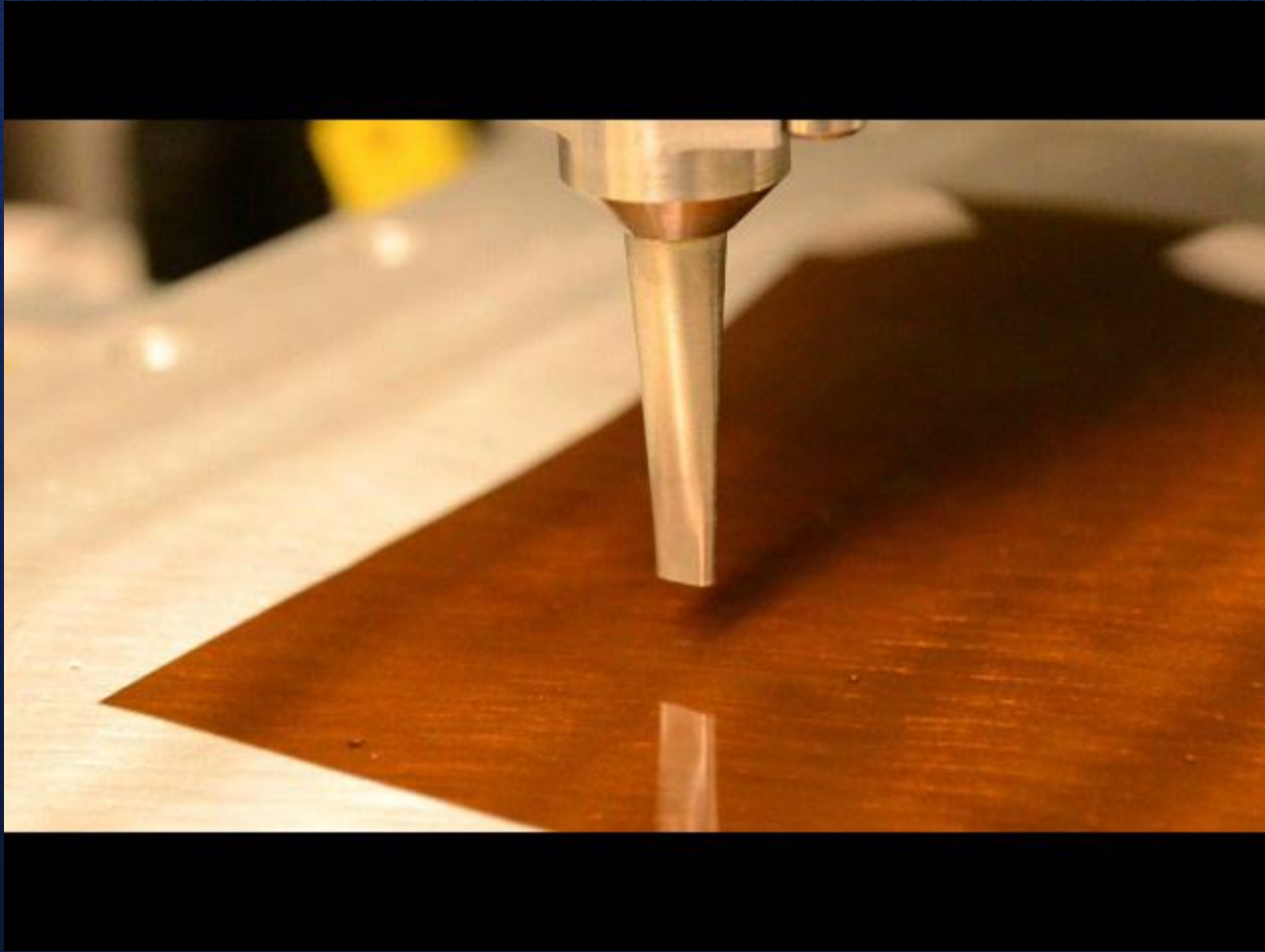


40 Nozzle Head

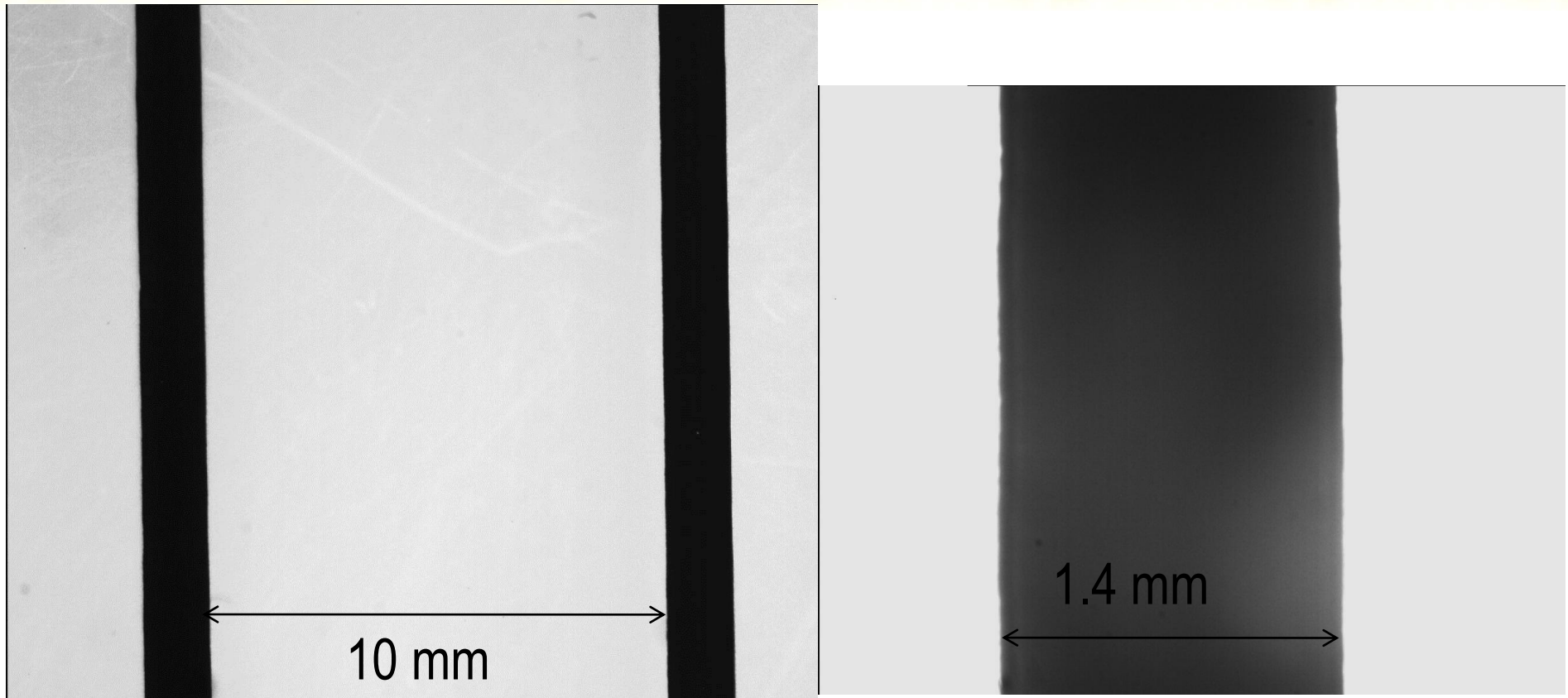


1cm & 5cm Wide Nozzle Heads
(In Development)

Aerosol Jet[®] 3mm Nozzle Video



Printed Traces with 3mm Nozzle



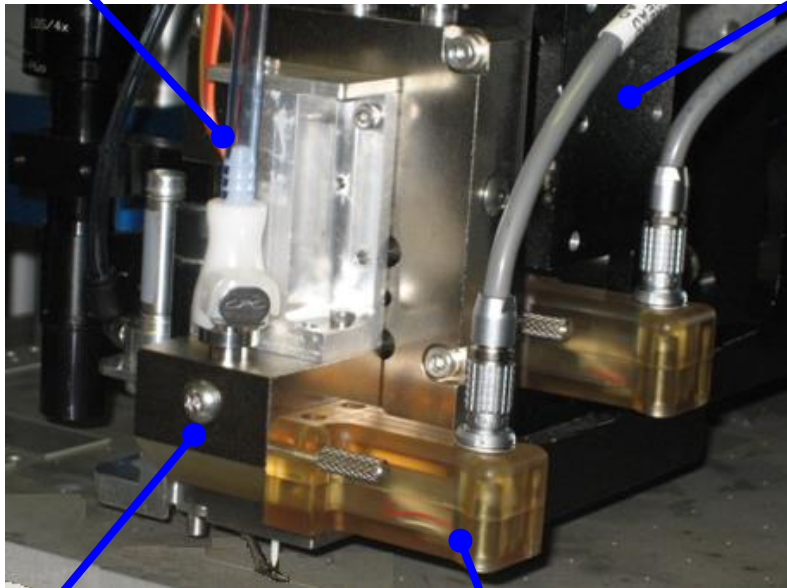
Line width average = 1.38 mm
Standard Deviation = 0.008 mm

Marathon Printhead Assembly Architecture

Sheath Gas Port

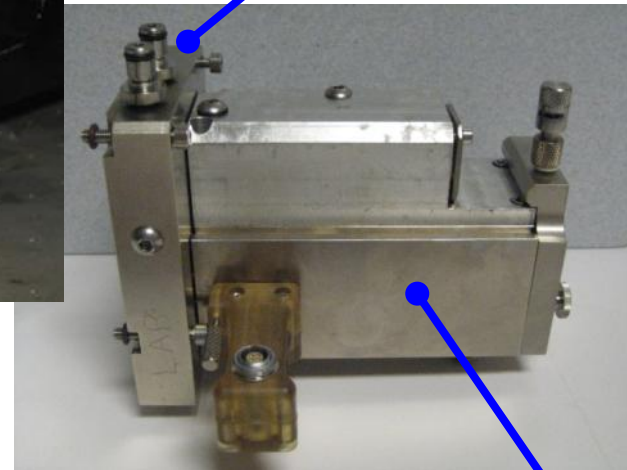
Pneumatic Atomizer

Head/Atomizer
Interface Plate
Assembly



Single Nozzle Printhead
With integrated Shutter
(Scalable Printheads from
3 to 10 or more nozzles)

Integrated Temp Control



Pneumatic Atomizer Cartridge

Aerosol Jet[®] Manz Automation Video



Aerosol Jet[®]

APPLICATIONS



Applications

Packaging and Assembly

High Density Interconnects – 3DIC

Flip-Chip / Direct Die Attach

Embedded / Integrated Passives

Flex Circuits

Meso-Dispensing

Electronic Components

Resistors, Capacitors and Inductors

Micro-Antennae

Micro-Batteries

Electronic Devices

Flat Panel Displays

Fuel Cells

Micro-Sensors

MEMS & RFID

Solar Cells

Hybrid Manufacture

Smart Structures

BioTech

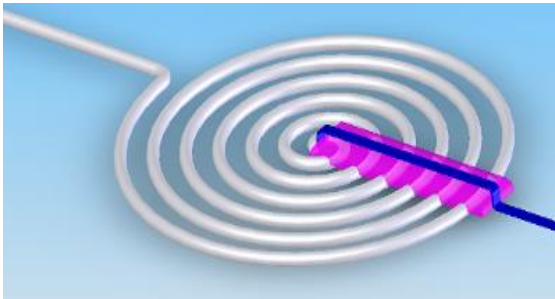
Bio-Sensors

Implantable Devices

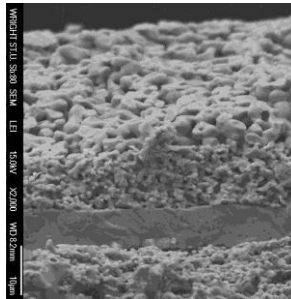
Micro-Arrays

Markets – Emerging via R&D Incubators

Driver: Enable Rapid Development of Novel Devices



Antennas



SOC Fuel Cells



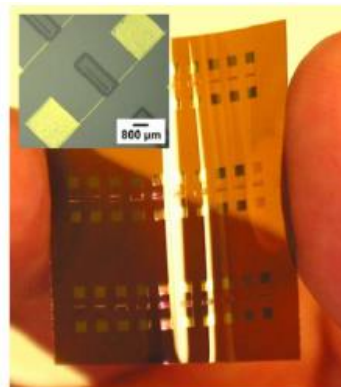
Strain Gauges



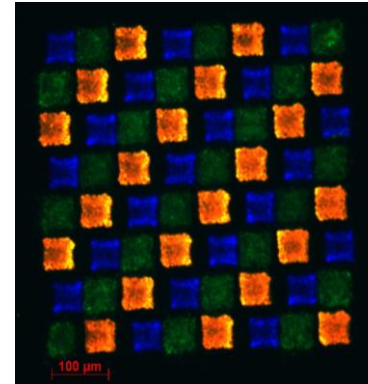
EMI Shielding



Embedded Components



Printed Transistors



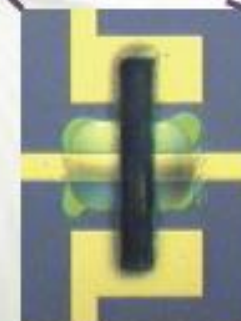
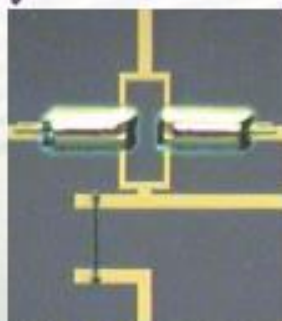
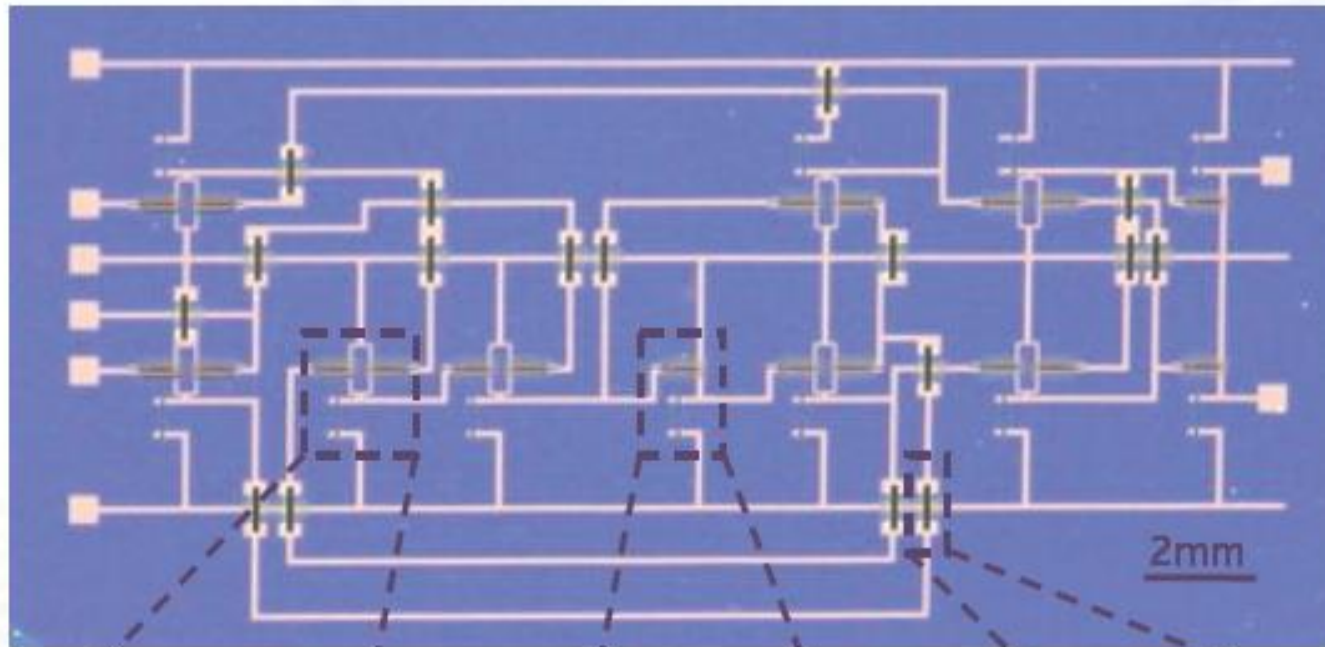
Bio Fabrication



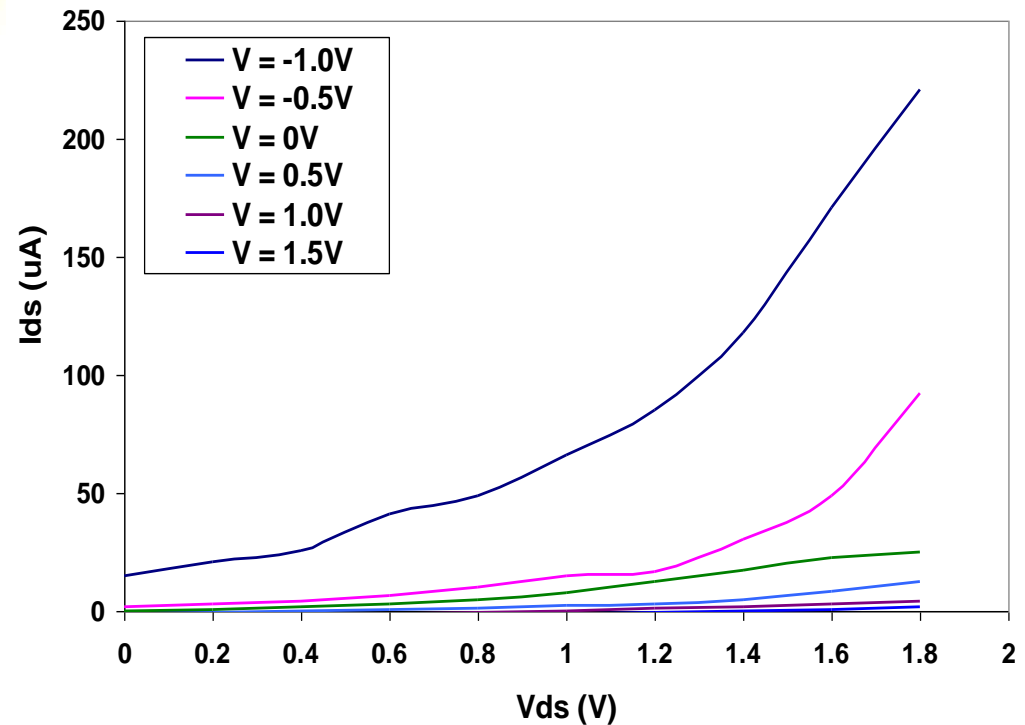
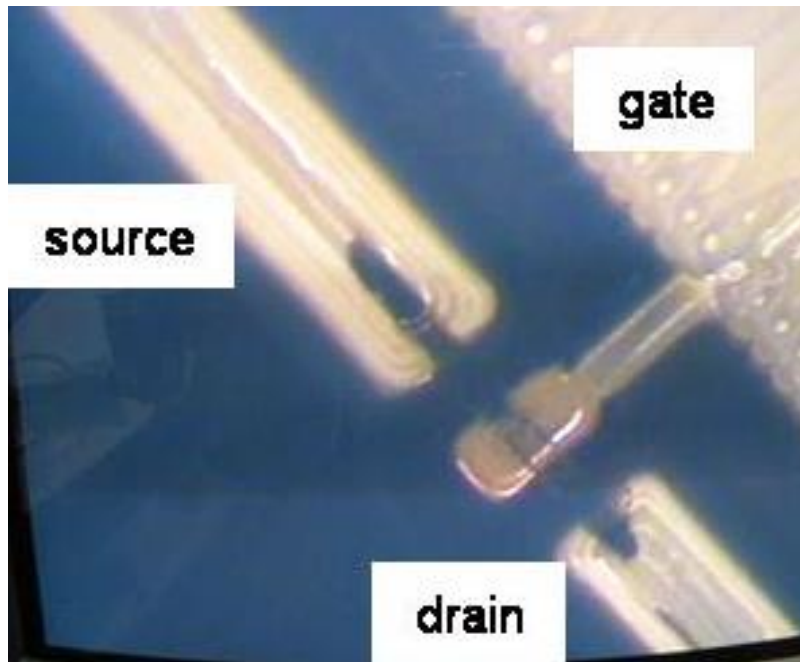
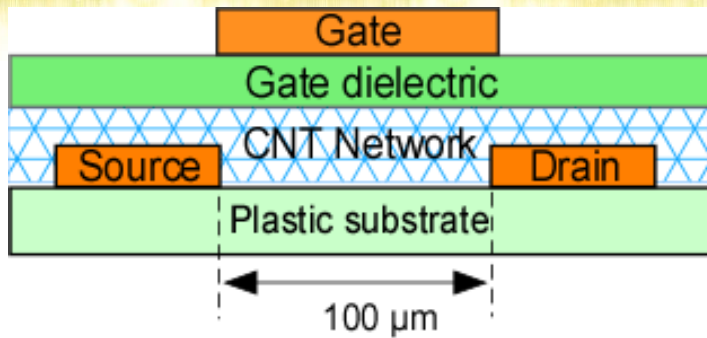
Molded Interconnect Devices

All-Printed OE Circuit

8 NAND Gates - 3 Inverters



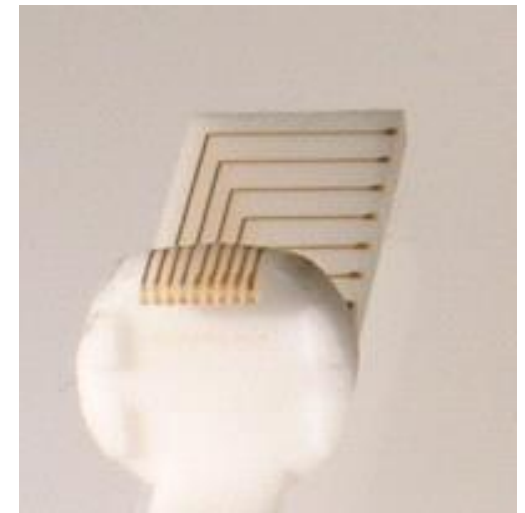
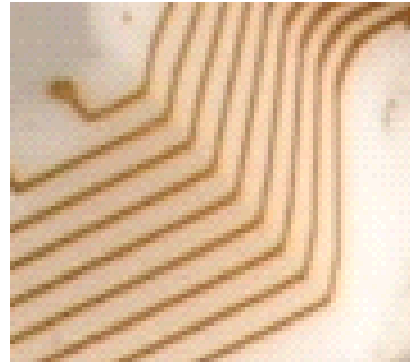
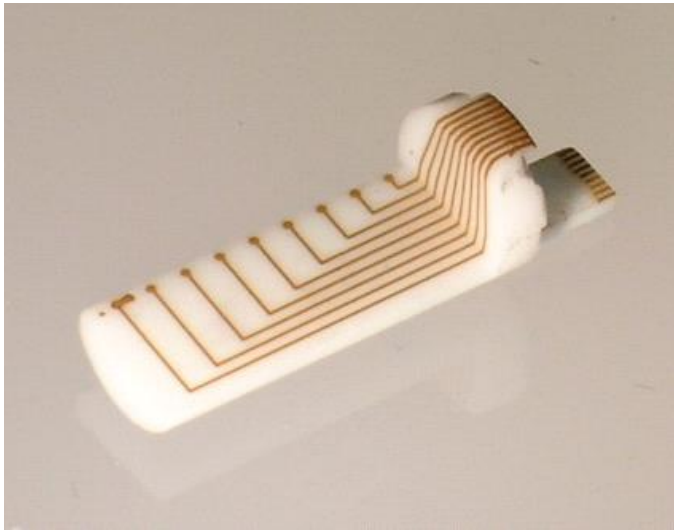
Printed CNT Transistor- Path to Higher Frequency*



I-V curve of a printed flexible FET

- ON/OFF ratio >100
- Frequency >5 GHz

Non-Planar Deposition



Aerosol Jet[®]

APPLICATION

**Display Backplane Bridge Jumpers
Edge Connections**



Display Market

Driver: Increase Functionality and Decrease Cost



Multi-Touch



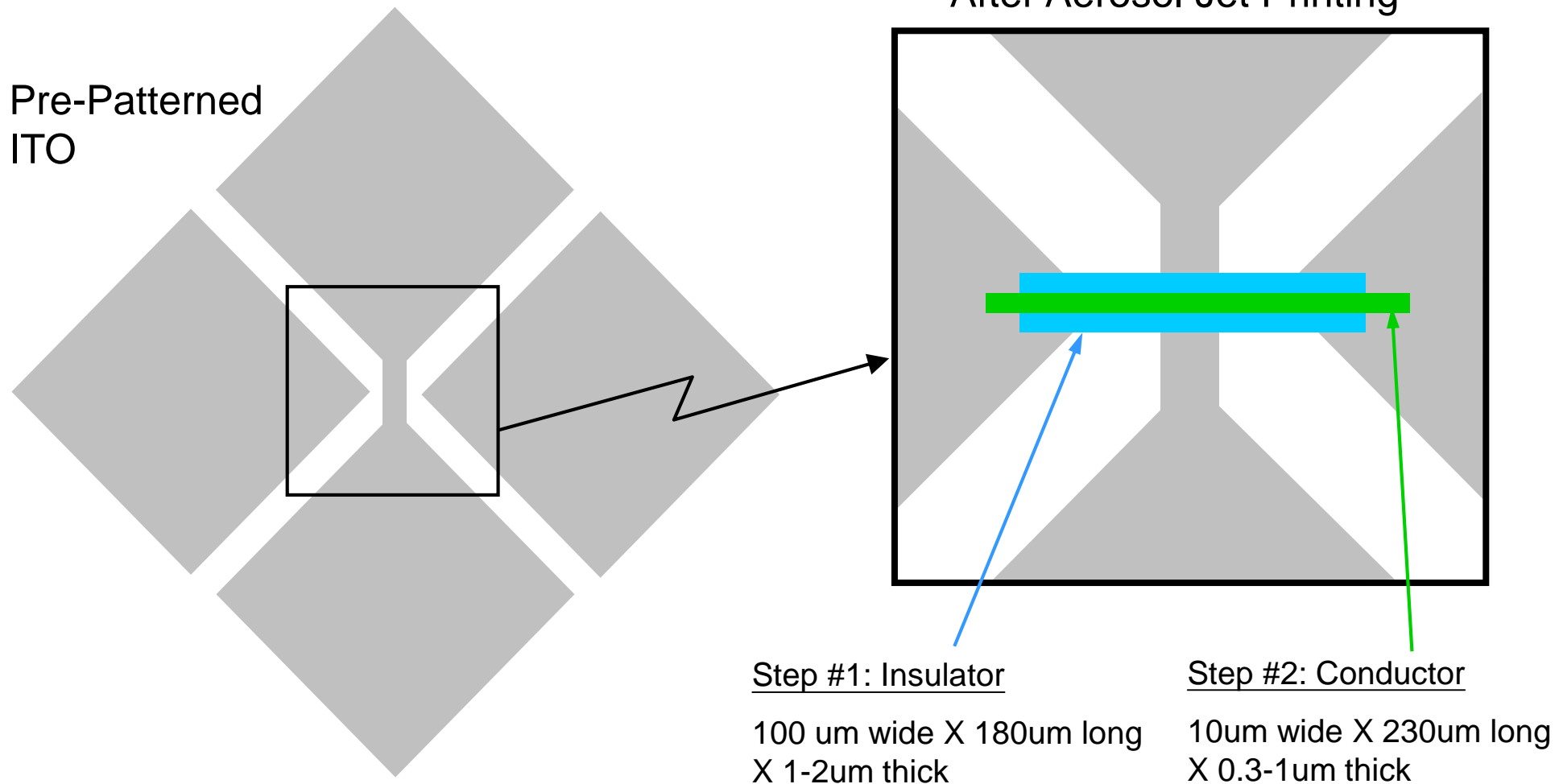
2 → 4 → 10

Illustrations courtesy of Engadget, Do Device
and Good Times & Happy Days



Applications in Display

Touch Screen: Bridge/Jumper Circuit



Applications in Display

Touch Screen: Edge Circuits

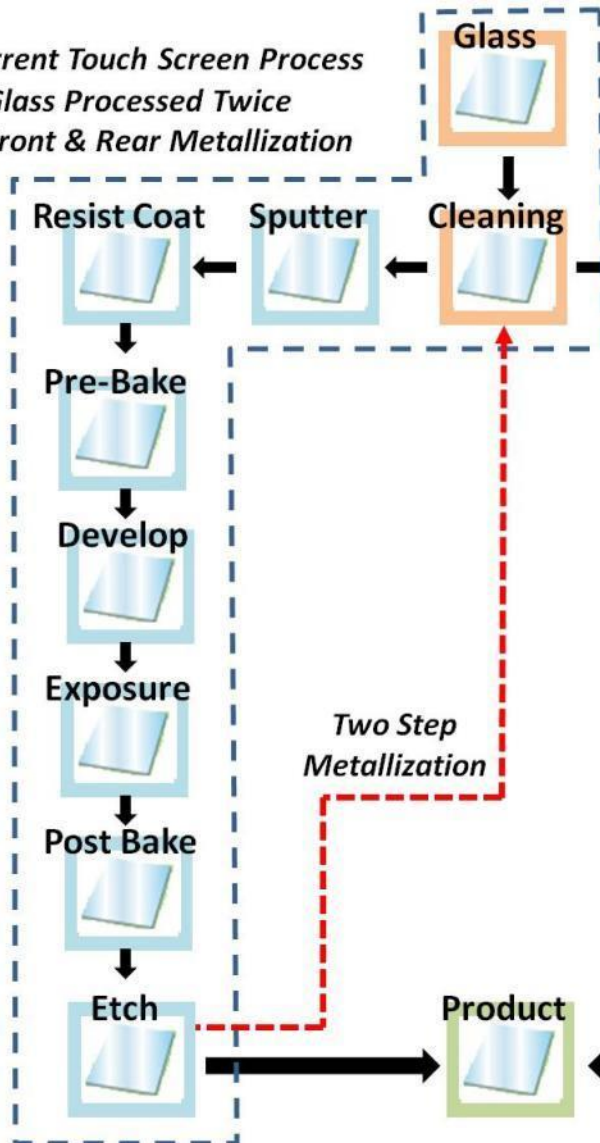
- » Reduce conductor line width <30um
- » Increase usable screen surface area
- » Improved design/usability



AJ Advantages for Touch Screen Apps

Current Touch Screen Process

- Glass Processed Twice
- Front & Rear Metallization



Optomec Touch Screen Process

- One Continuous Process
- Aerosol Jet Dielectric & Interconnect

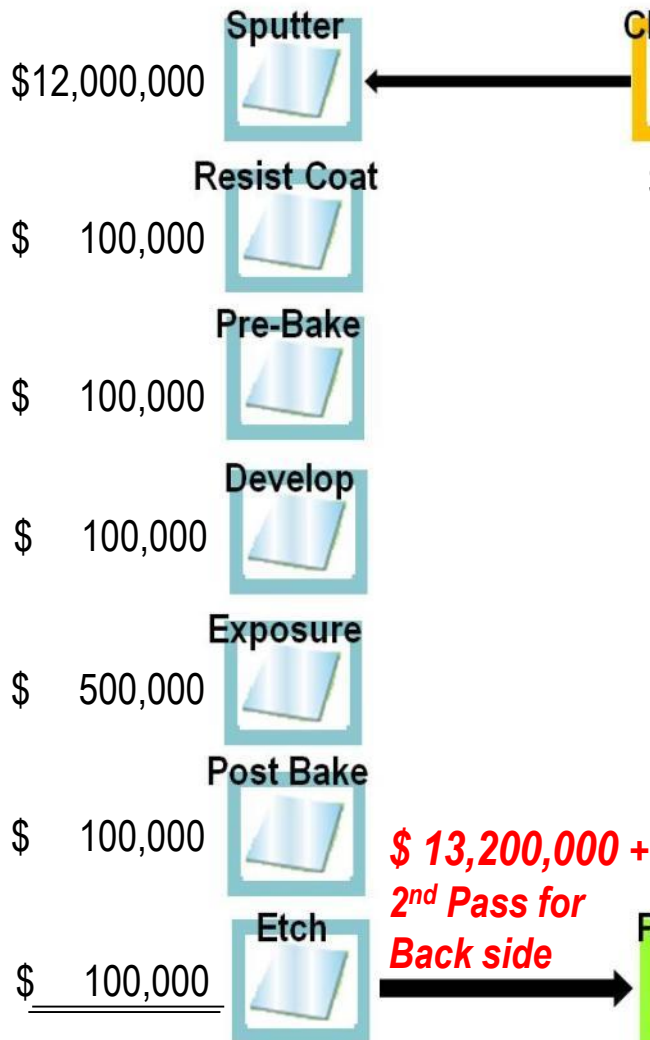


Aerosol Jet Advantages

- ✓ Less contamination
- ✓ Fewer process steps
- ✓ Less floor space
- ✓ Enabling Lower Cost
- ✓ Glass and plastic substrates
- ✓ Rigid & Flex
- ✓ Flat & R2R automation

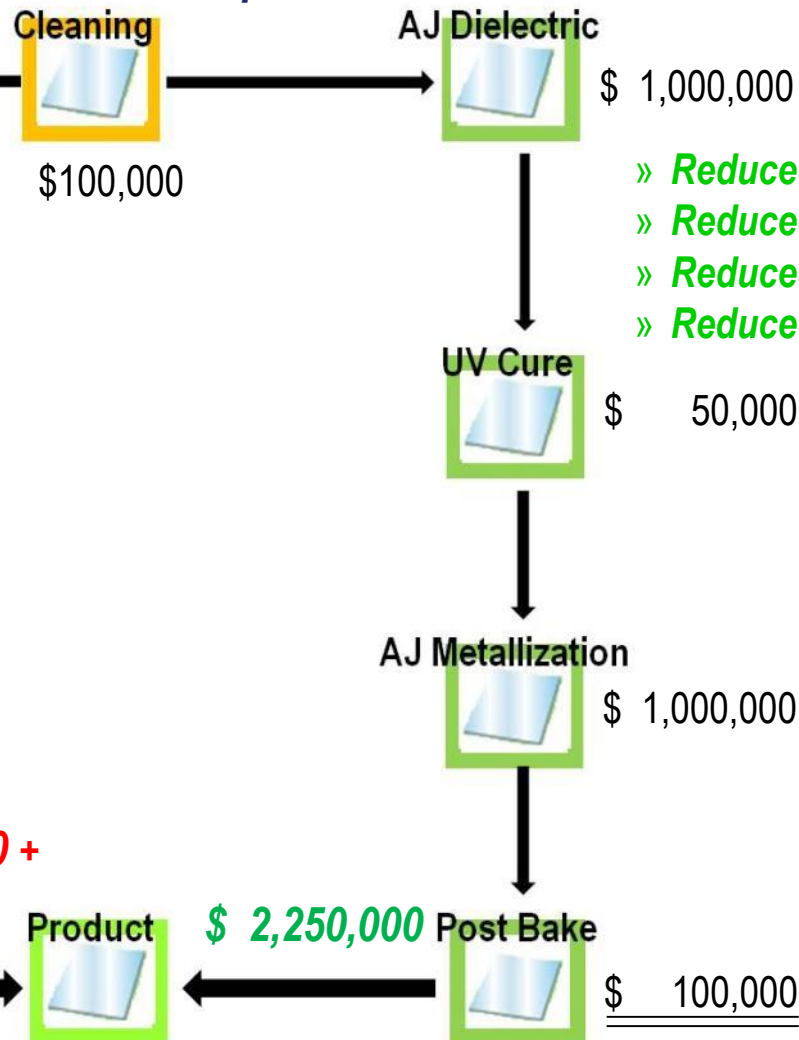
Display – Touch Screen Cost Based ROI

Current Touch Screen Process



**\$ 13,200,000 +
2nd Pass for
Back side**

Optomec Touch Screen Process



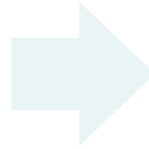
\$ 2,250,000

- » **Reduced floor space**
- » **Reduced material usage**
- » **Reduced utilities**
- » **Reduce Process by 11 Steps**

Based on Gen3 Substrate X 400K substrates / month

Aerosol Jet Print Solutions for Display

Print Platforms



R&D – Display Lab
Production – AJ Print
Engine

Automation Partners



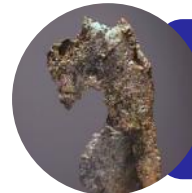
MJC & TPK

Process Partners



KETI / MJC / TPK

Material Partners



Cabot, DuPont,
NanoMas,
Sun Chemical, Others

Aerosol Jet[®]

APPLICATION

3DIC



3DIC: Markets

» Hand Held Devices – Functionality & Size

- SmartPhone
- Portable gaming
- GPS

» PC – desktop & notebook

» Game Stations

» DRAM – Performance and density

» NAND Flash – Density and size

- SmartPhone
- MP3 / PMP
- Digital Camera

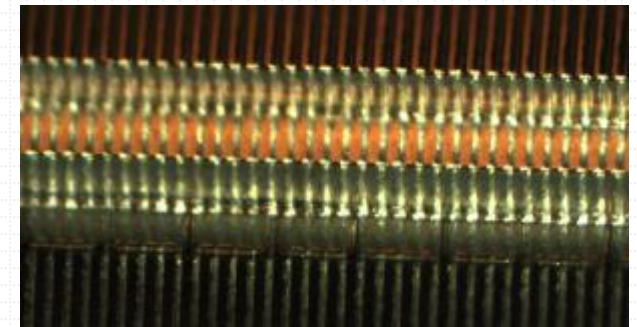
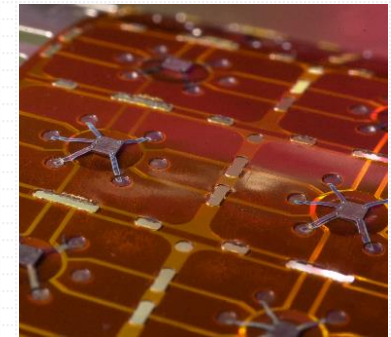
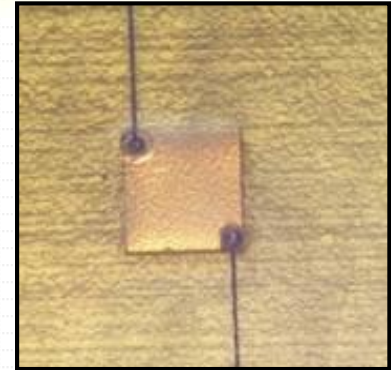
» Specialty & MEMS - Integration & size

- Image & Motion sensors

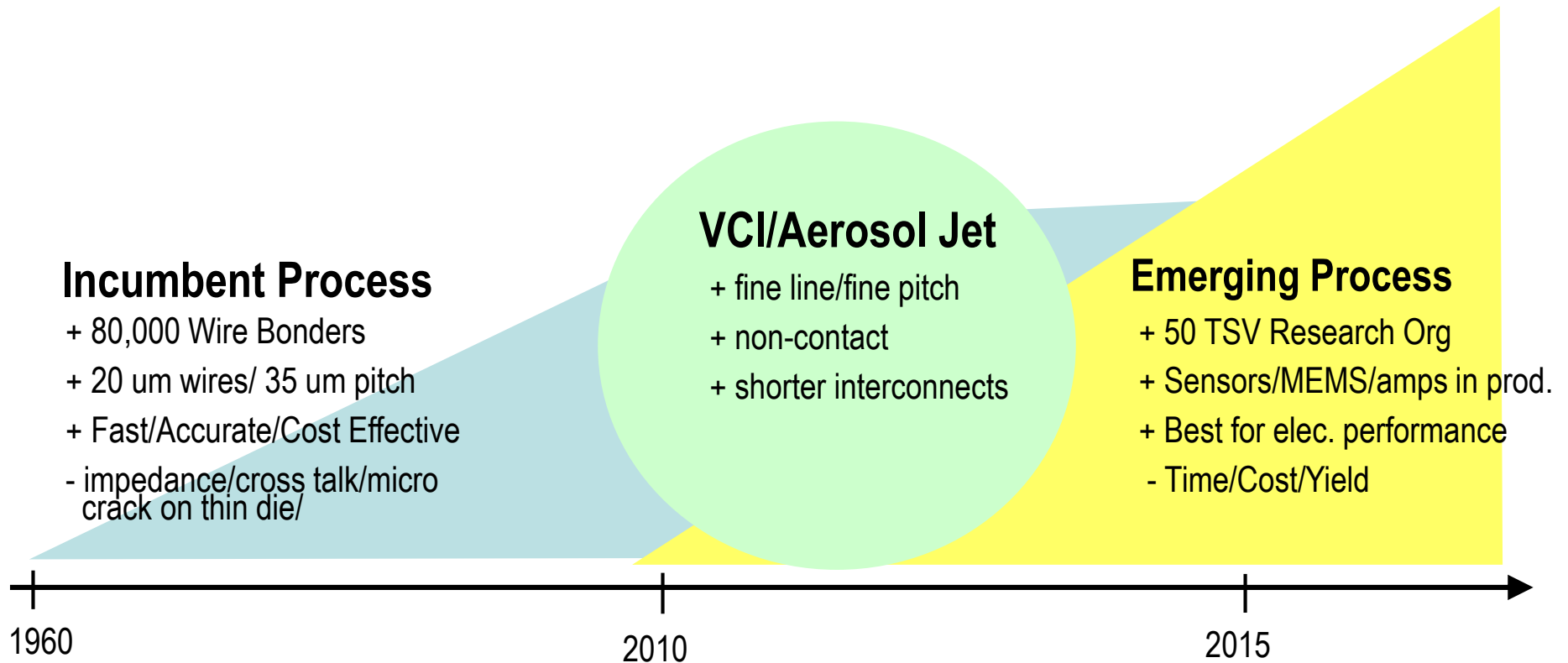


Applications in 2D and 3D Interconnect

- » Aerosol Jet is a leapfrog solution capable of <25um lines @ <50um pitch over stairs.
- » Enables Direct Die Attach
- » Cost & Performance Better than Wire Bond
- » Enables Vertical Chip Stacking with 3D Interconnects
- » Engaged with Leading SmartPhone Player for Multi-Chip Pkgs (Processor/Memory)
- » Cost & Time-to-Market Advantages versus TSV (Through Silicon Via)



Aerosol Jet Fit within the 3DIC Value Chain



Bottom Line:

- Device manufacturers may need fast track path to market
- Device manufacturers may need flexible methods to introduce new technology
- AJ can fill the gap between WB and TSV to meet high performance time to market requirements

Difference In Approach Yield, Cross Talk, and \$\$\$

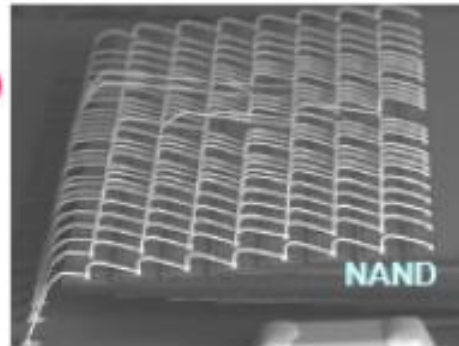
16GByte



- 17 dies stacked (8Gb NAND x16 + Cont.)
- Die thickness : 20um



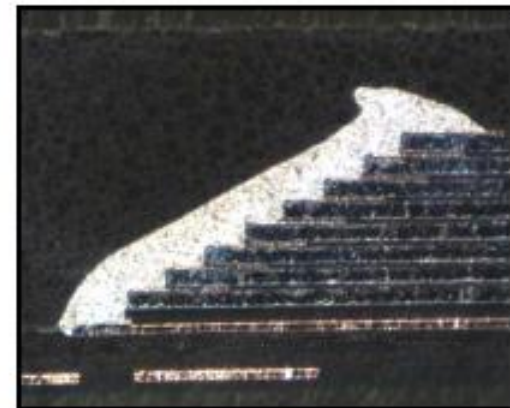
Wirebond Solution



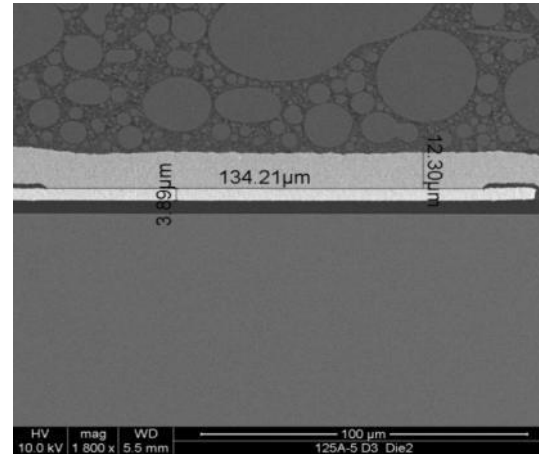
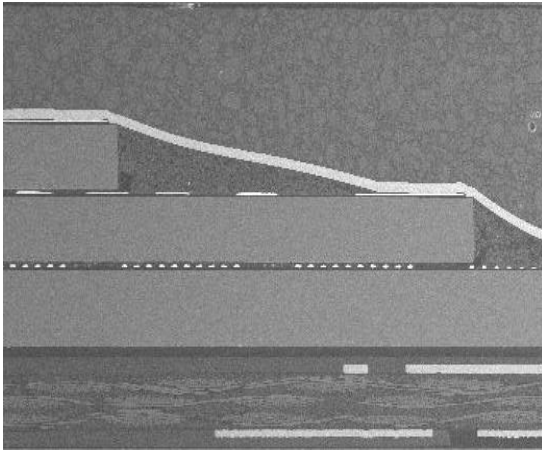
16GByte



- 8 dies stacked (16Gb NAND x8 + cont)
- Die Thickness: 40um



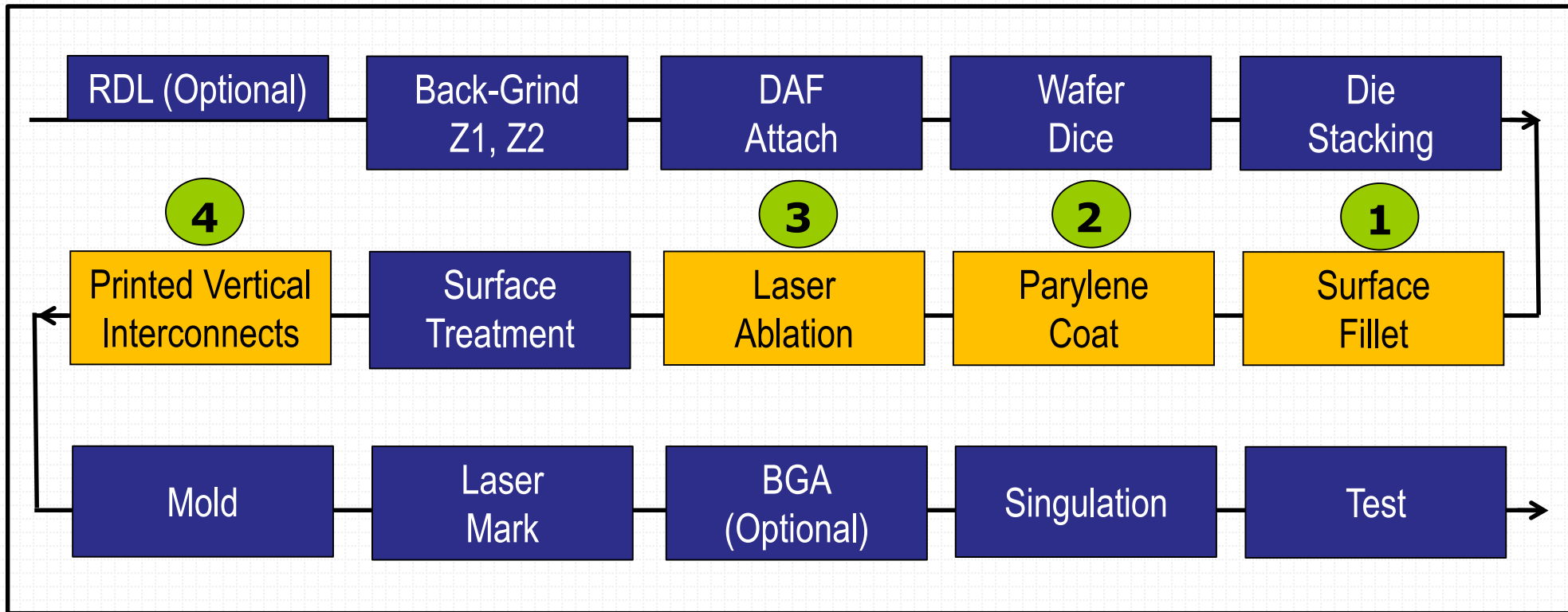
3D Interconnect Printing



Courtesy: Vertical Circuits, Inc.

- » 150 μm Nozzle – Producing ~ 30 μm wide traces x ~6 μm tall
 - Two print passes required to build up print height
- » Staggered interconnect package with interconnect pitch of <60 μm
- » Package heights of <4mm require no Z-axis (typical package height <1mm).
- » Current print speeds of 5 to 10mm/s

Process Flow – ViP for 3DIC



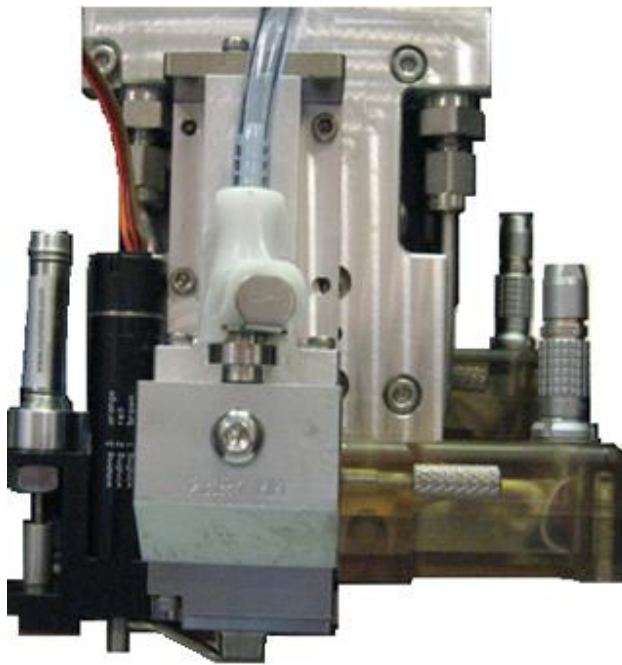
Std. Step

VCI
Step

VCI[®] = Process


VCI vertical interconnect process steps are executed in a standard DAG flow with minimal disruption.

Scalable Solution



» Optomec Print Engine
• 3 to 5+ Nozzles

VCI[®] = Process

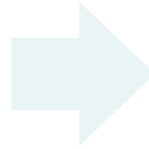
 = Inks
CABOT



 **Speedline** technologies = Automation

Aerosol Jet Print Solutions for 3D Interconnects

Print Platforms



R&D – 300IC
Production – AJ Print
Engine

Automation Partners



Speedline

Process Partners



Vertical Circuits, Inc.

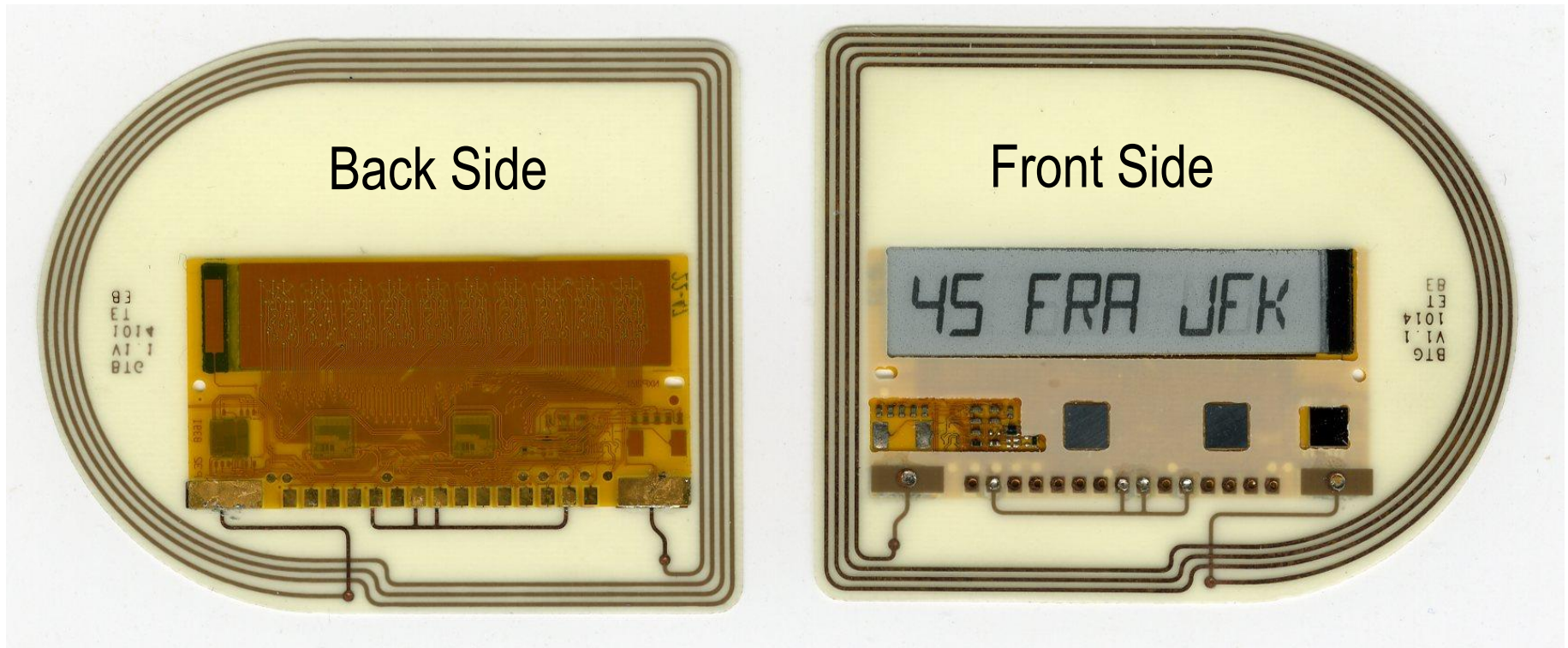
Material Partners



Cabot, NanoMas,
UTDots

Tocreo Labs Smart Display Card / Tag Project

Flip Chip Replacement using Aerosol Jet for Interconnect



Driver: Reduce Cost - 47% of cost is due to design with flip chip

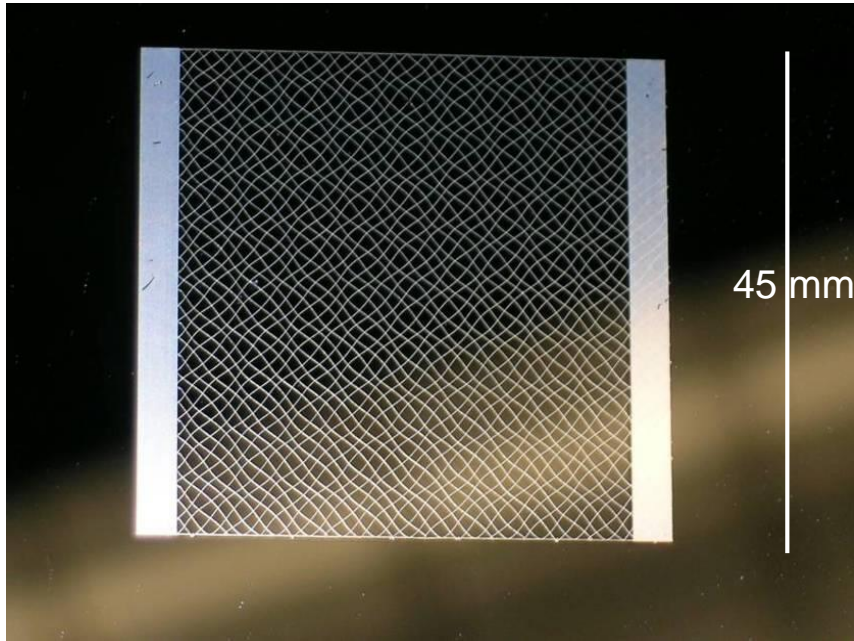
Aerosol Jet[®]

APPLICATION

EMI – Sensors - Antennas



Silver Mesh Printing on Glass



Line Width $\sim 20 \mu\text{m}$

Resistance $\sim 8 \text{ Ohms/sq.}$

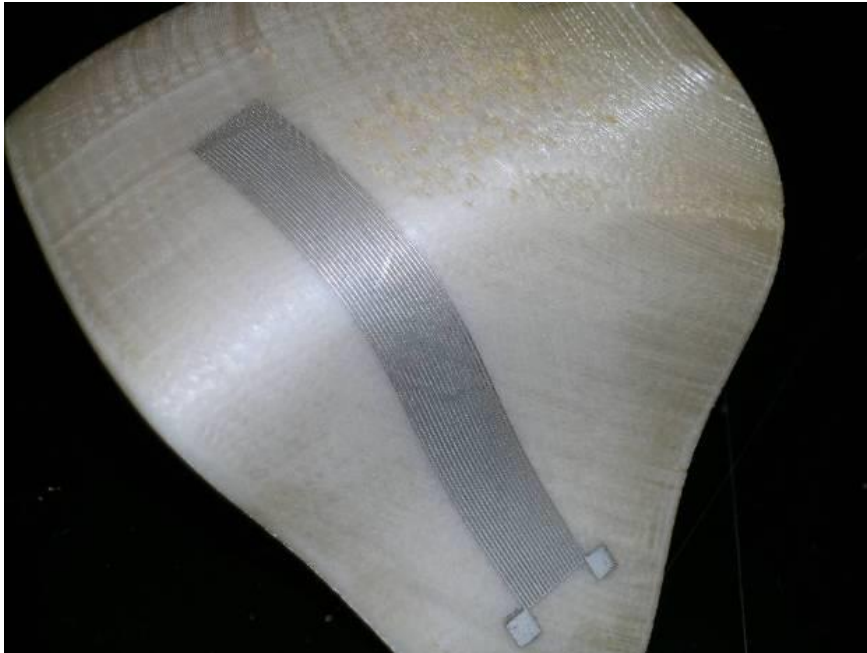
Oven Fired at 250°C



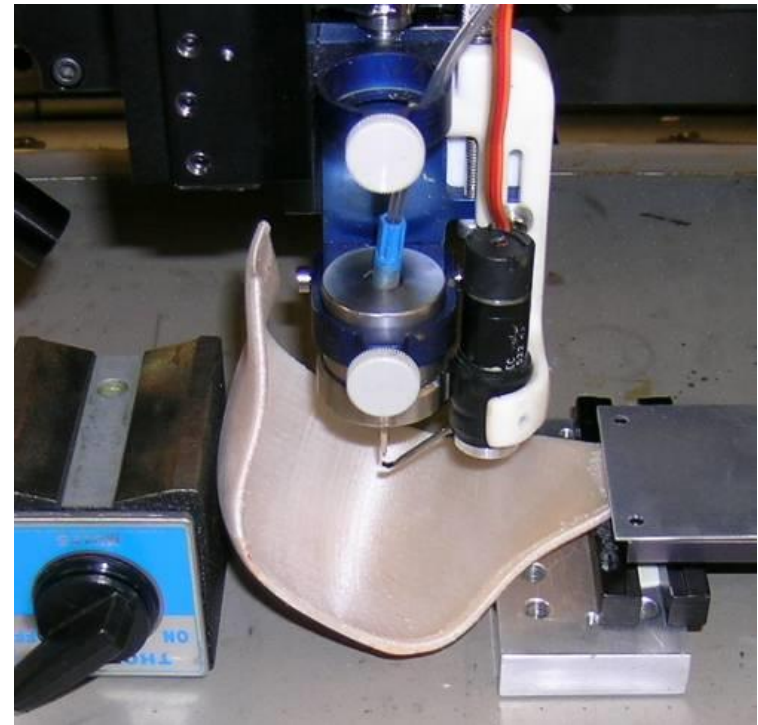
50x magnification

Strain Gage Printing

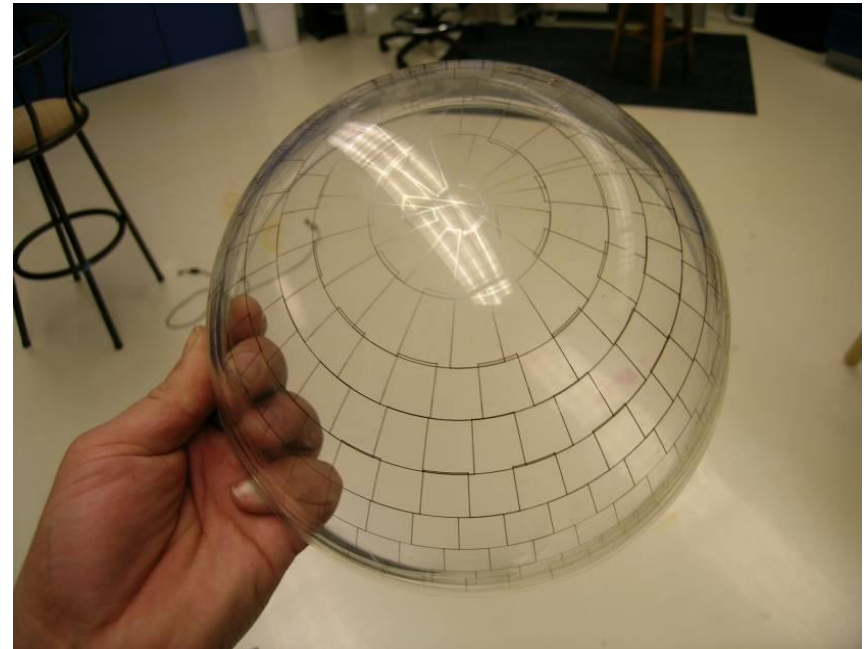
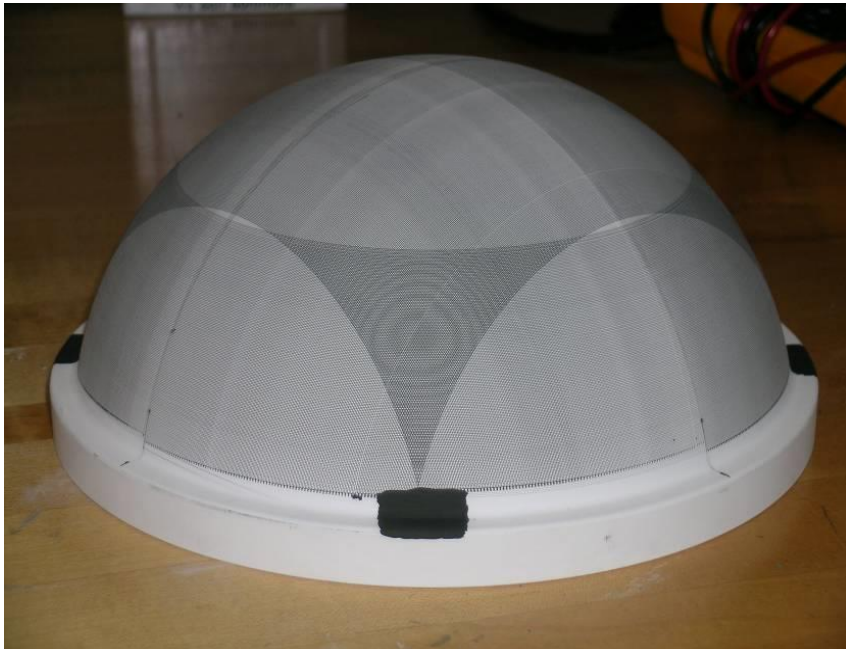
**Strain Gage on
Outer Surface**



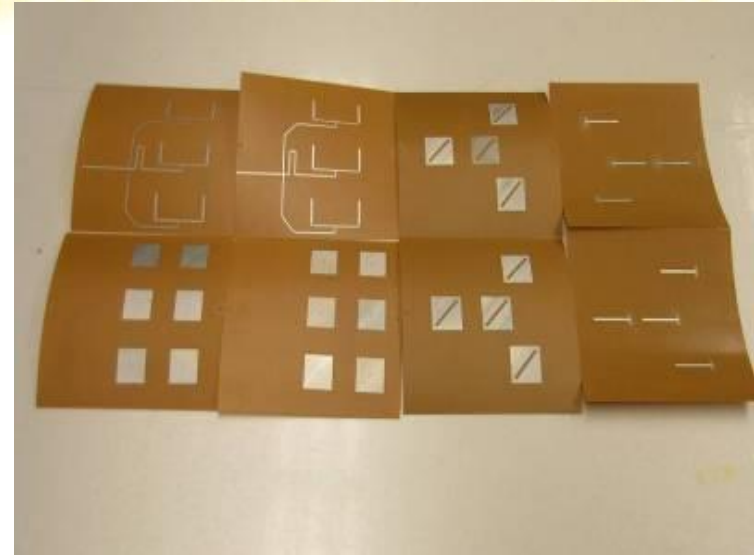
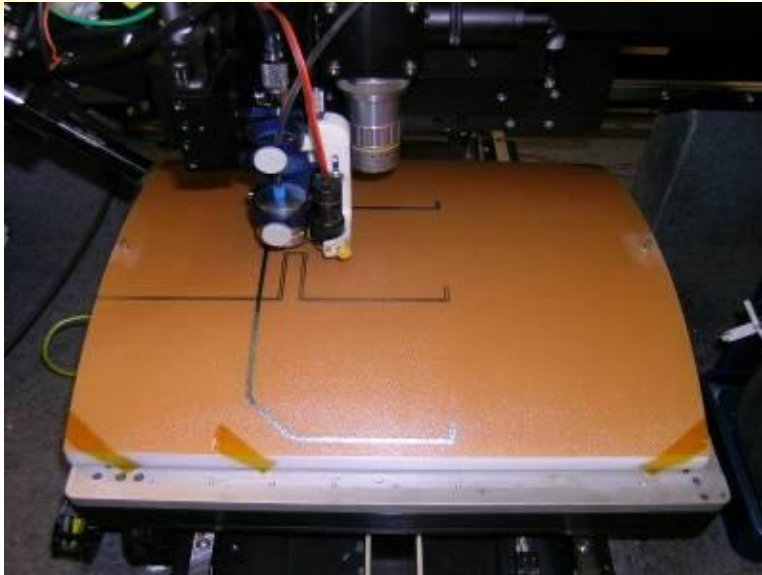
**FDM part orientated
for printing on inner
sidewall**



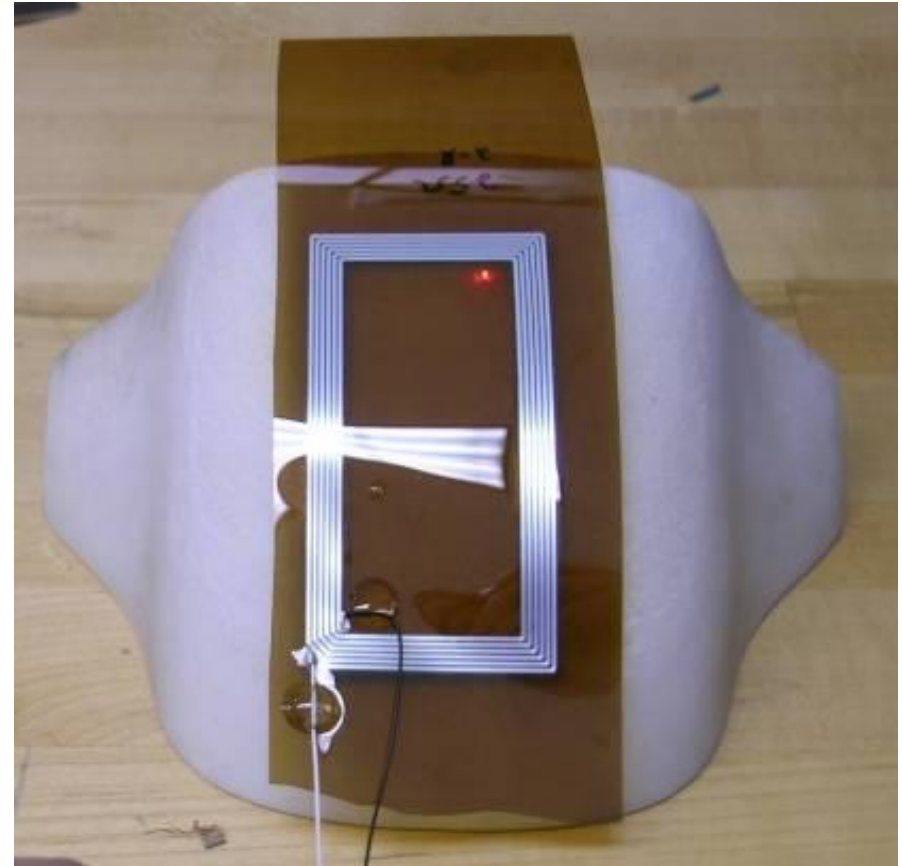
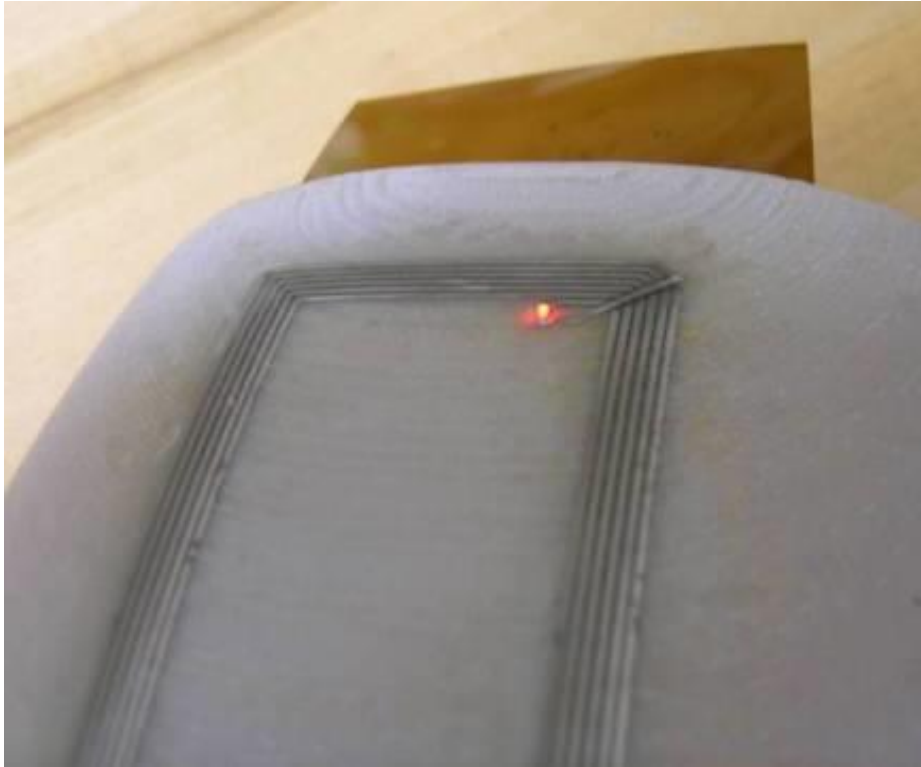
Five-axis Printing for EMI Shielding



Conformal Antenna



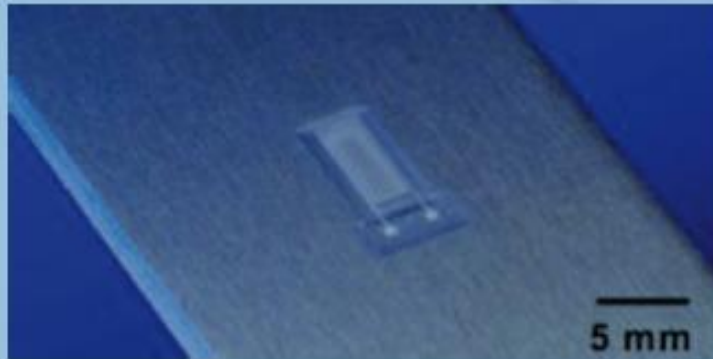
Printed Antenna on SLS RP Part



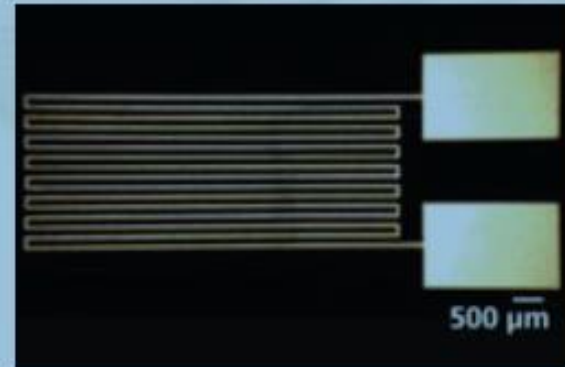
The matching antenna on Kapton was energized with a 5.5 MHz, 5 V_{pp} AC signal from a function generator. The antenna was laid over the printed antenna in one case and held under the printed antenna in a second case. In both cases, the LED was shown to illuminate which indicates sufficient excitation current and voltage was inductively coupled into the printed antenna.

Shown above on the left is the first case of the excitation antenna laying over the tooling part. The right picture shows the excitation antenna held underneath the part.

Sensors for Structural Health Monitoring



Ag Strain Gauge on Al



CuNi Strain Gauge



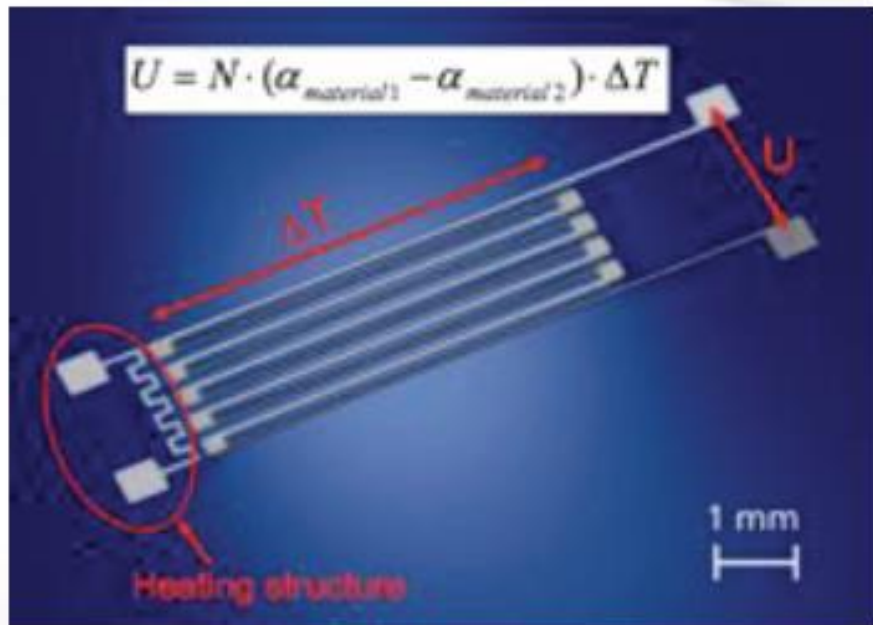
Ag Strain Gauge on CFC

COURTESY:

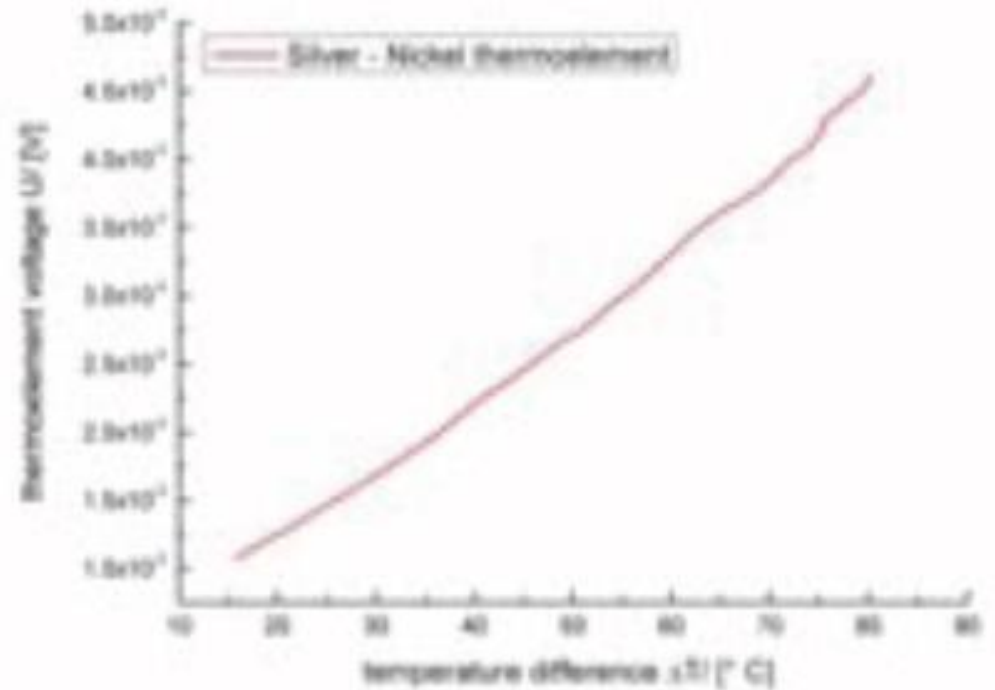


20.01.2010

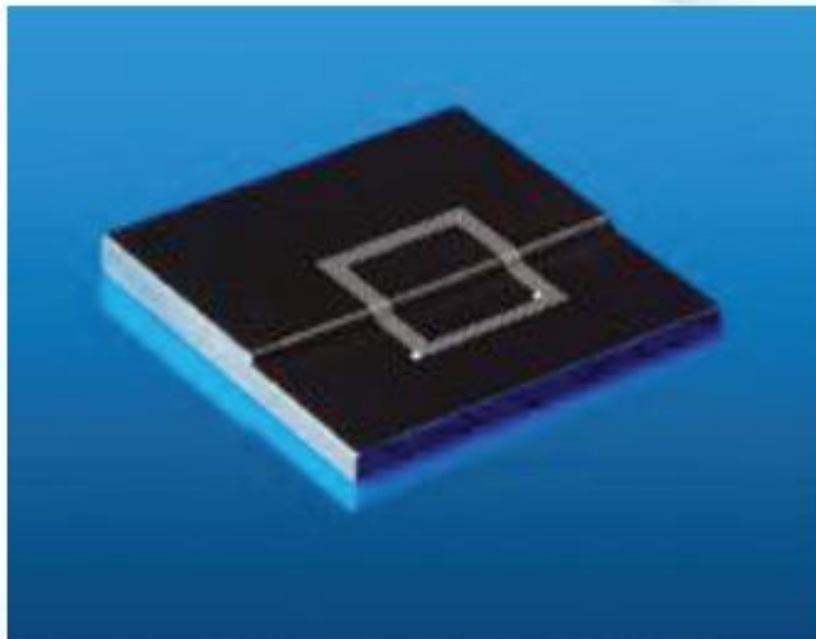
Printed Temperature Sensor



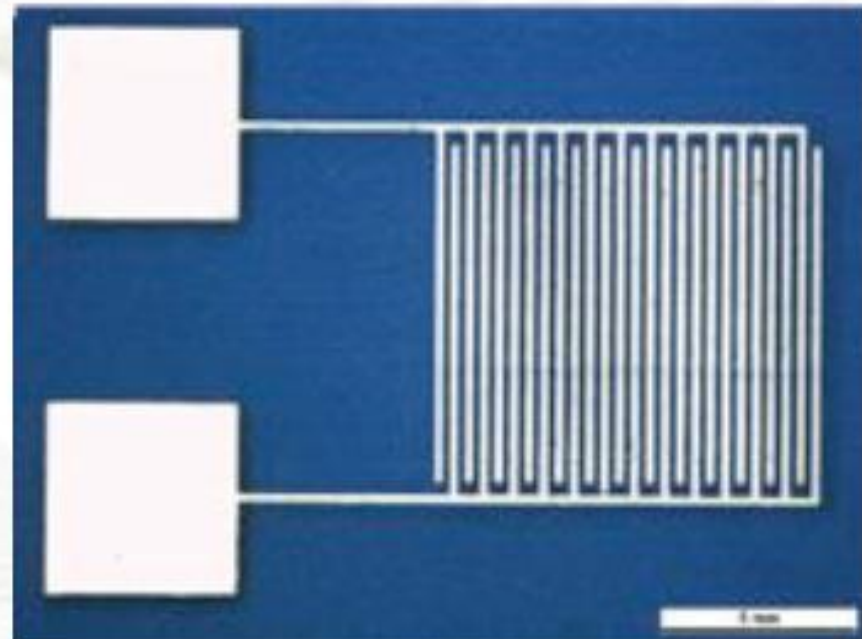
Ag and Ni sensor structure



Printed Sensor Structures



Antenna Coil printed over a 3D Step.
Ag on CFC



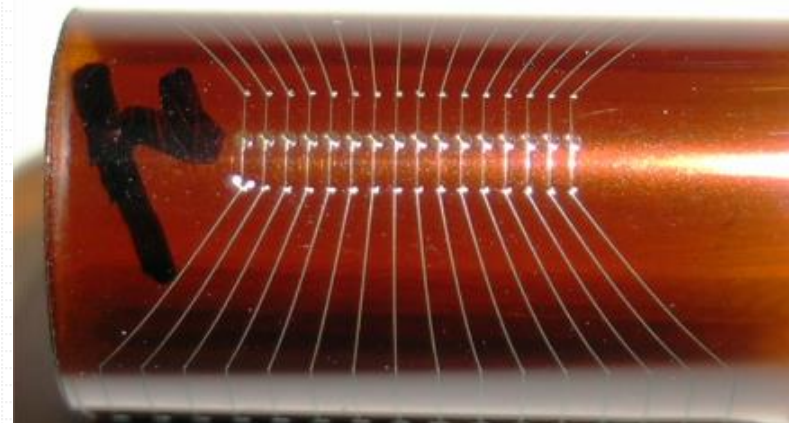
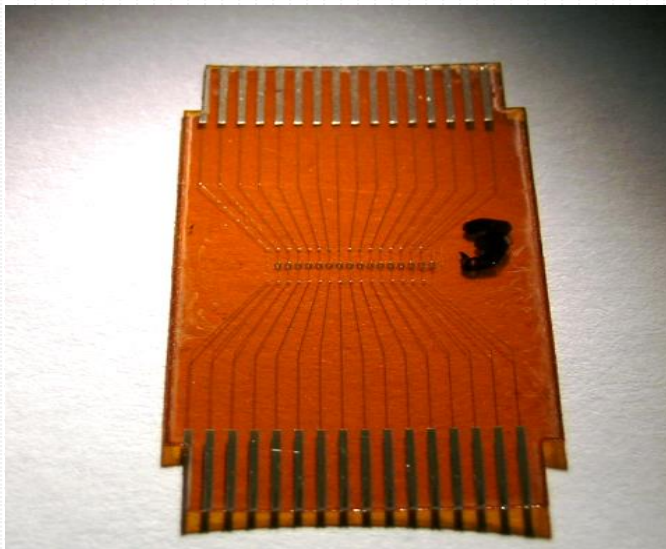
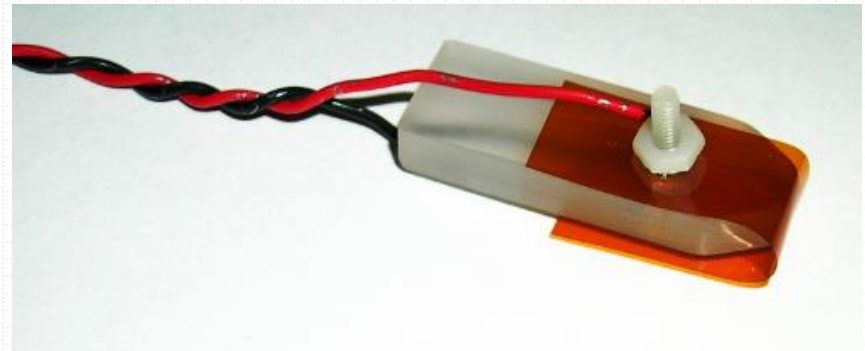
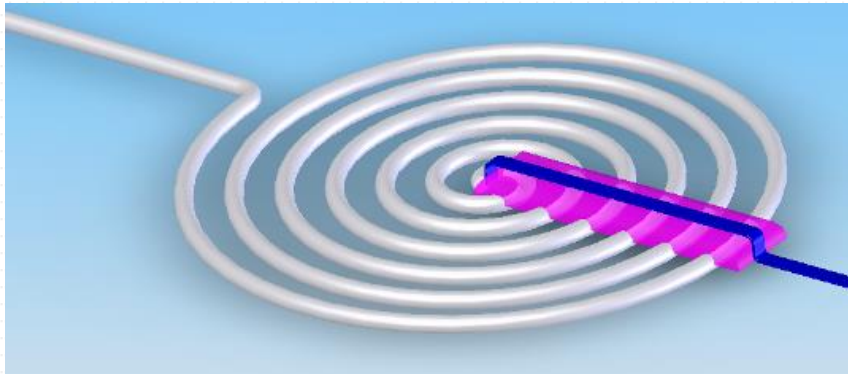
Gas sensor Structure

COURTESY:



20.01.2010

Eddy Current Sensor Array



APPLICATION

AFRL UAV Solid Oxide Fuel Cell

SBIR Phase II - AF2006-174

Advanced Manufacturing Techniques for High-Efficiency Functional Gradient Solid Oxide Fuel Cells



Fuel Cell Goals



USAF Fuel Cell Applications



- Enable Long Endurance Aerospace Power Systems Through Development of Power Dense Fuel Cells
- Explore Fundamental Technology to Ensure Future USAF Air Superiority

Battlefield Airman



**>30 Lbs Batteries for
72 Hour Mission**

**50% Reduction in
Power System Weight**

Small UAV



**< 60 Min SUAV Flight
@ ~\$100/Flight**

**10X Increase in Flight
Endurance, Reduced Flight Cost,
Tailored Sensor Packages**

Area Dominator



10 hr Persistence

**4X+hr Increase
in Persistence,
Strike Capability**

**Current
Capability**
**Program
Objective**

SOFC Challenge

SOFC performance could be improved by depositing material using a combustion spray process.

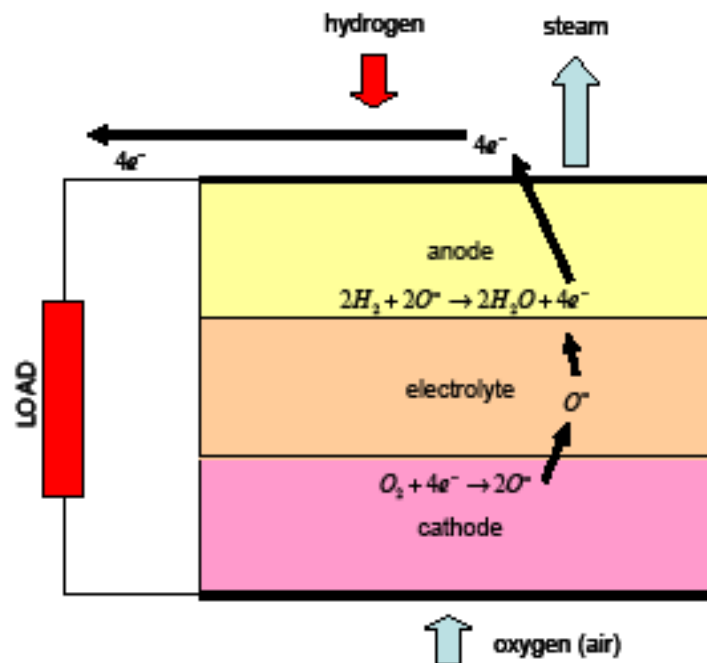
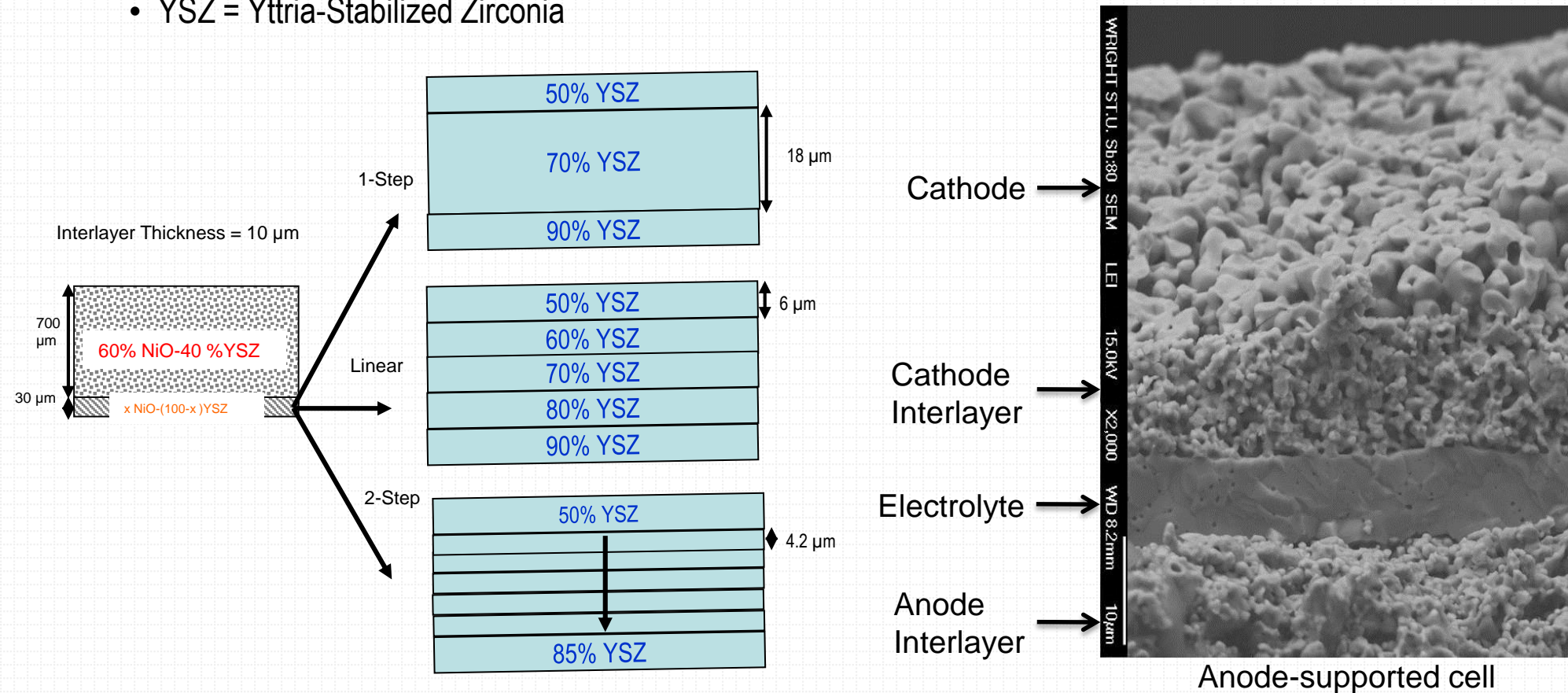


Figure 1. Basic operation of a solid oxide fuel cell (SOFC) utilizing hydrogen as a fuel. Carbon monoxide may also be used as a fuel in which case carbon dioxide gas is produced.

Aerosol Jet Gradient Layers

» Anode Interlayer Profiles

- YSZ = Yttria-Stabilized Zirconia



Aerosol Jet Gradient Process

AFRL Extension Proposal Multi-Layer Wide Nozzle Head

Draft Proposal Headlines:

Concept: Produce Graded Structure in a Single Pass (ie: Multiple "layers"). Develop Internal Mist Tube Matrix to control both Mist Distribution and Layer Uniformity.

Deliverables:

- Multi-Layer Deposition Head (Prototype)
- Plumbing to allow 2 Atomizers to produce 3 (or more) Mix Ratios
- Potential Atomizer and PCM upgrades
- Rudimentary Control Capability
- Report on Scaling to 3+ Atomizers with 5+ Mix Ratios

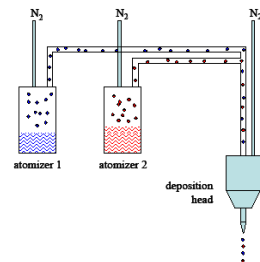
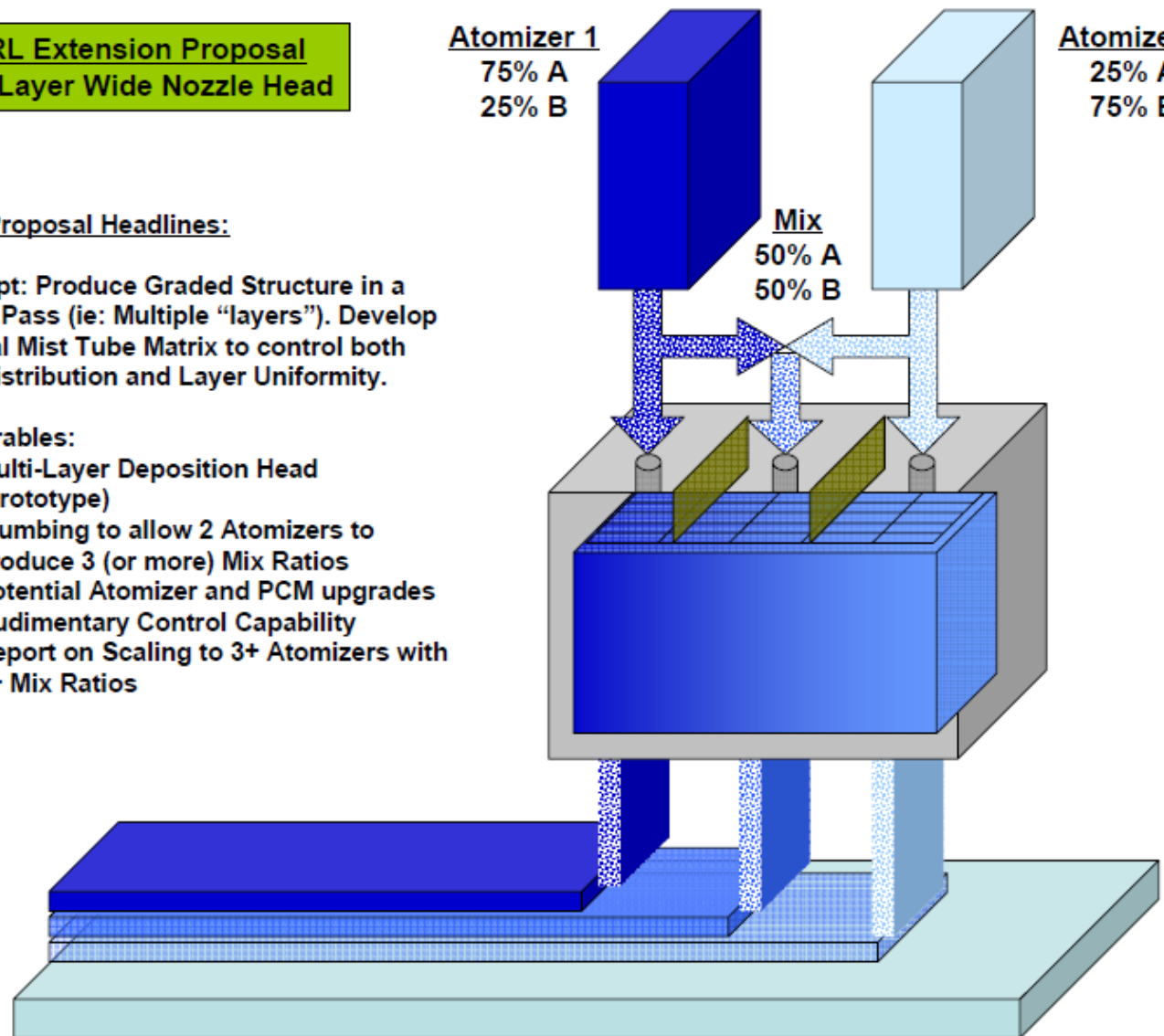


Figure 7. Basic dual-atomizer arrangement developed under Phase I.

Atomizer 1
75% A
25% B

Atomizer 2
25% A
75% B

Mix
50% A
50% B



Optomec Customer Engagement Steps

1. Build generic samples and evaluate properties.
(Optomec Lab with Customer)

2. Develop functional prototypes, evaluate performance & reliability.
(Customer Lab or Optomec)

3. Develop and validate volume processing strategies & production
recipes to optimize throughput & quality.
(Customer, Optomec, Partners)

4. Plan, train and deploy full production system.
(Customer, Optomec, Partners)

1. Feasibility

2. Validation

3. Optimization

4. Production

CONTRACT MANUFACTURING



**QUEST
INTEGRATED INC.**

Jonathan Kniss
Director, Business Development
Quest Integrated Inc.
19823 58th Place South
Suite 200
Kent, WA 98032
(253)872-9500 1209
JonathanK@QI2.com
<http://www.qi2.com>

SUMMARY

Optomec's Aerosol Jet Technology Delivering on Value

- » Strong material vendor relationships
- » Widest range of fluids and inks available for printed electronics
- » Chemically inert deposition print module construction
- » Small droplet sizes producing fine features as small as 10 microns
- » Wide area coating with uniform thickness down to 100nm
- » Family of scalable, customizable print solutions
- » Tailored for R&D and Production needs
- » Complete solutions offerings for selected markets
- » Industry standard communications interface to ease third part automation integration

Thank You.

www.optomec.com

