Evaluation of surface mount technology reliability of Aerosol-Jet printed landing pads for surface mounted devices

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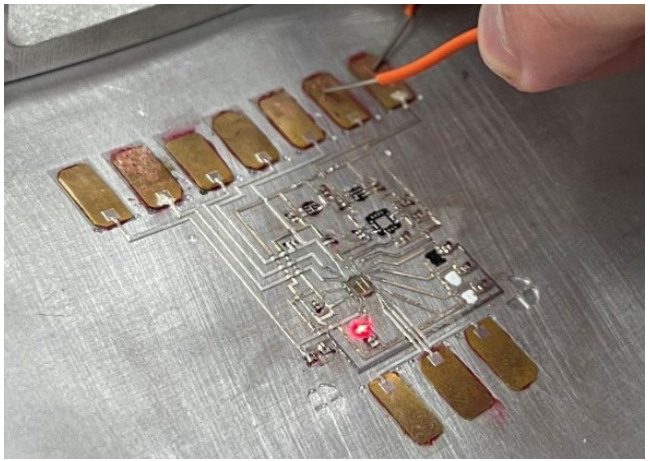
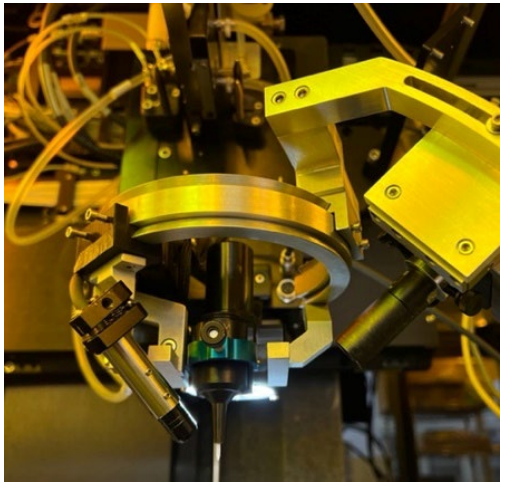
U.S. Department of Defense
31 January 2024





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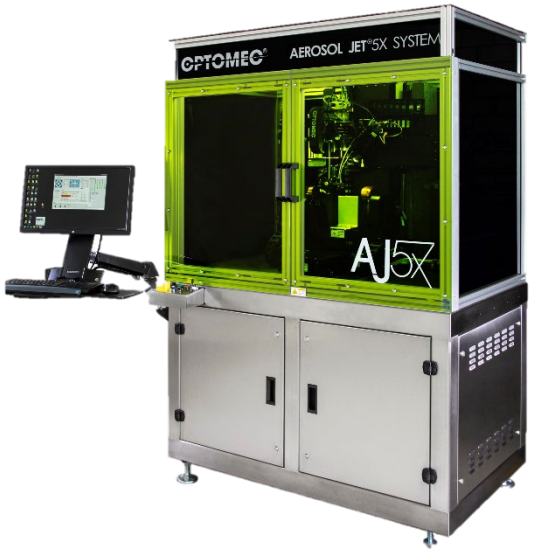
Agenda

- Introduction
- Methods
  - Manufacturing
  - Reliability Testing
- Results
- Conclusions
- Q & A



Optomec AJ5x Machine Used for Aerosol-Jet Printing

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Introduction

- Aerosol jet (AJ) printing has the advantages of being adaptable to print on various surface types and can print features as small as 10 microns. [2]
- Lots of research on manufacturing science and methods
- Limited on reliability/durability characterization

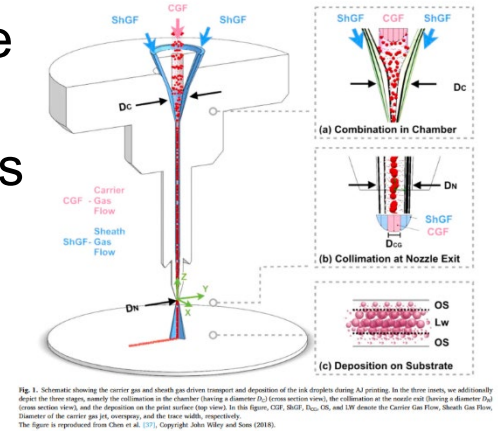
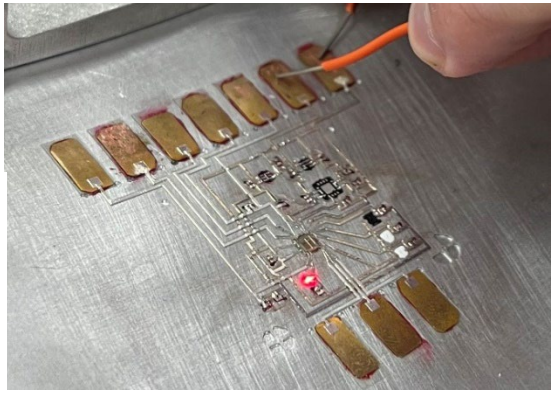
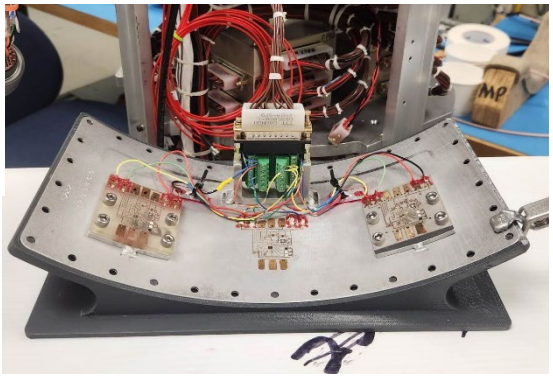


Diagram of aerosol-jet nozzle





Circuit embedded into aluminum door using print-to-lead technique

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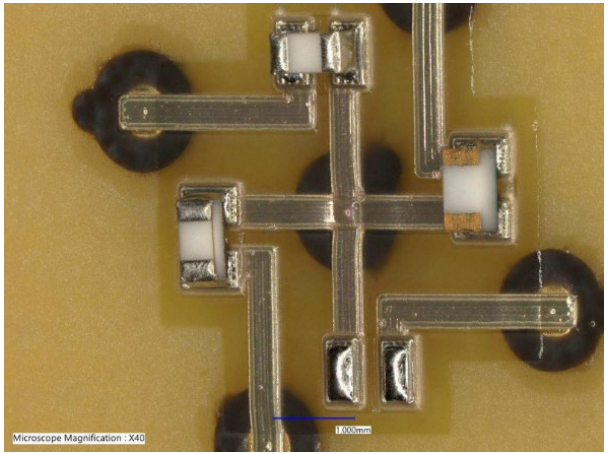
Methods

Feasibility & Manufacturing

- Two solders: SnPb (Sn63Pb37) SAC305
- Manufacturing of the coupon substrates done using parameters as defined in previous publications [9].
- Increased the Ag thickness from 10-15 microns to ~50 microns for the landing pads
  - Allows for a sufficient intermetallic layer to form
- High-temp FR4 base substrate and NEA121 as a polymer base layer



Feasibility assembly of 0402 passive parts placed onto printed Ag pads

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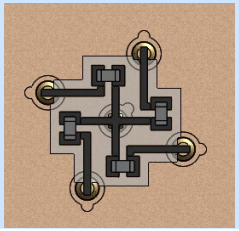
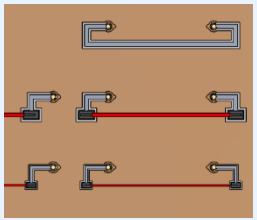
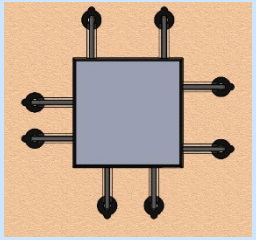
Methods

Test Vehicle Assemblies

	Coupon Name	Purpose	Diagram
Component-Level Test Coupons	BARNACLEBOND	Surface-mounted passives; to test the mechanical strength and performance of SMT mounted parts. Compare to traditional PCB of same design.	
	ROPEWALK	Lead wires to board; to test the mechanical strength of wire solder joints (hand soldered). Also tests pull & shock post temperature cycling.	
	CANNONBALL	Ball Grid Array; tests the full passive performance of a reflowed BGA onto a substrate using a daisy chained part and 64 number of solder ball interconnects.	

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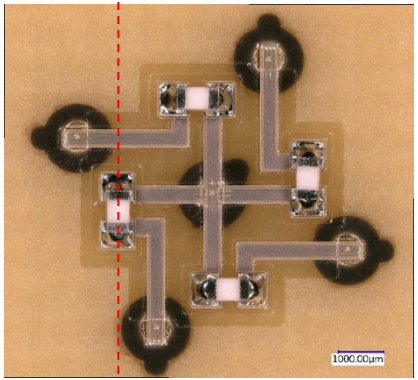
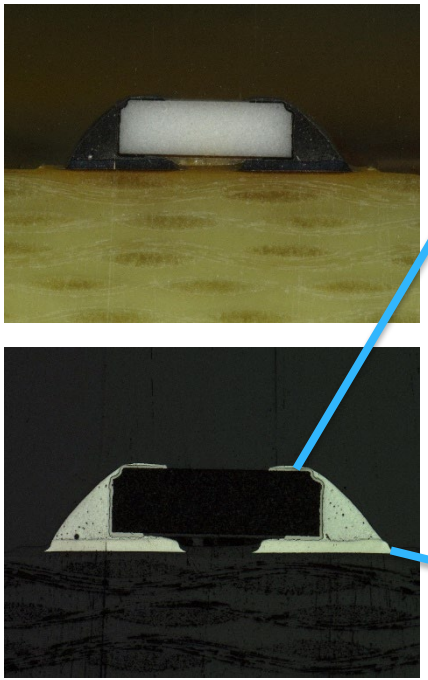
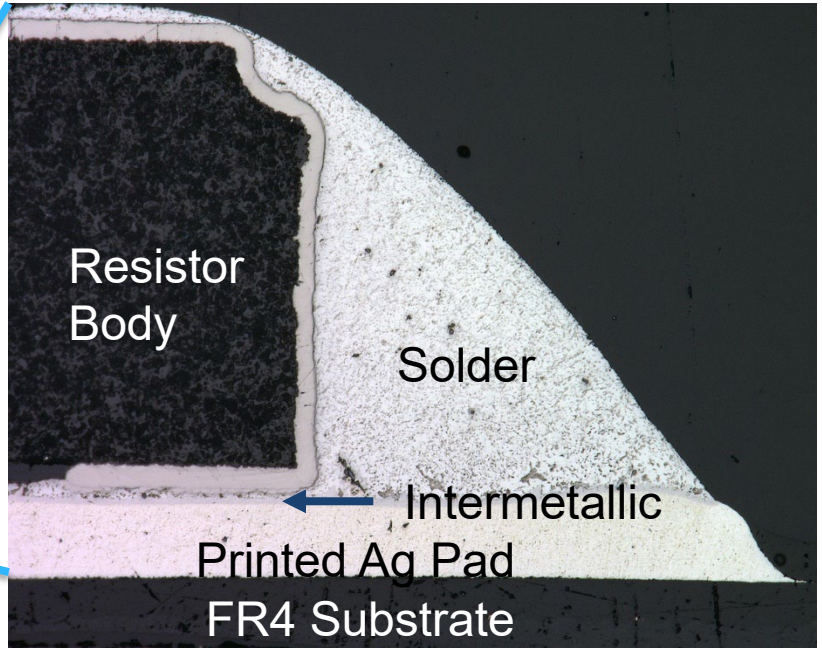
Methods

X-section



BARNACLEBOND Cross Section





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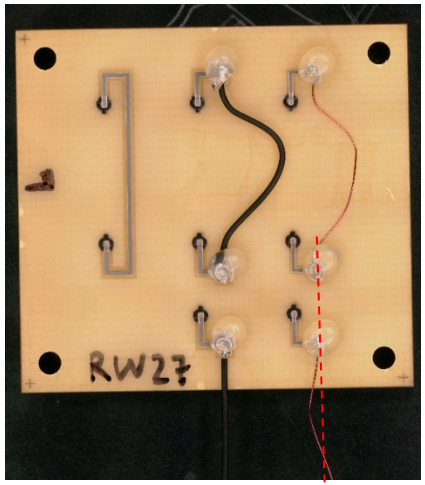
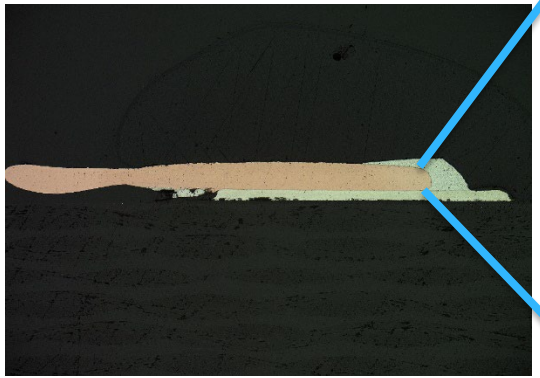
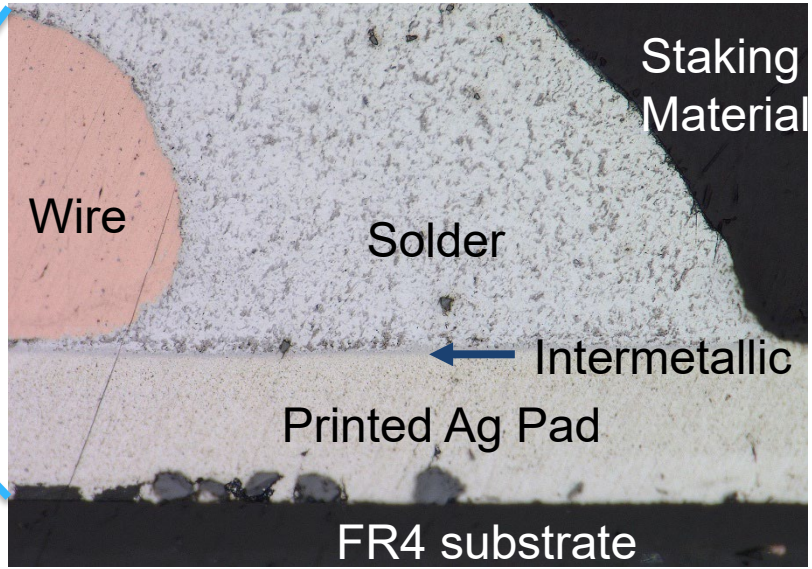
Methods

ROPEWALK Cross Section







*IPC-TM-650, MIL-STD-883 Wire pull specs/standards

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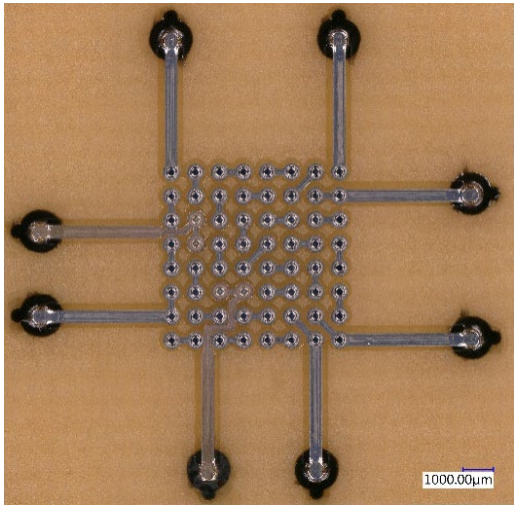
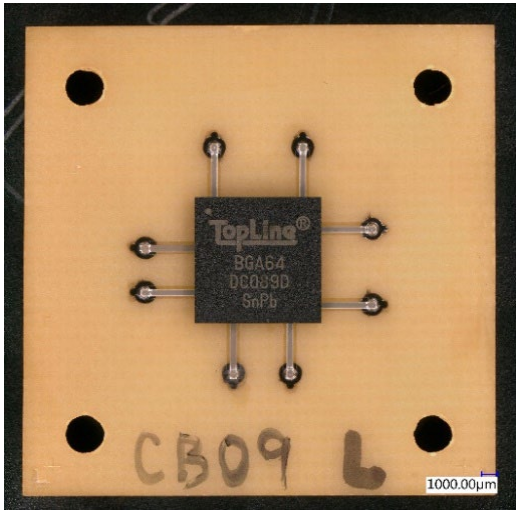
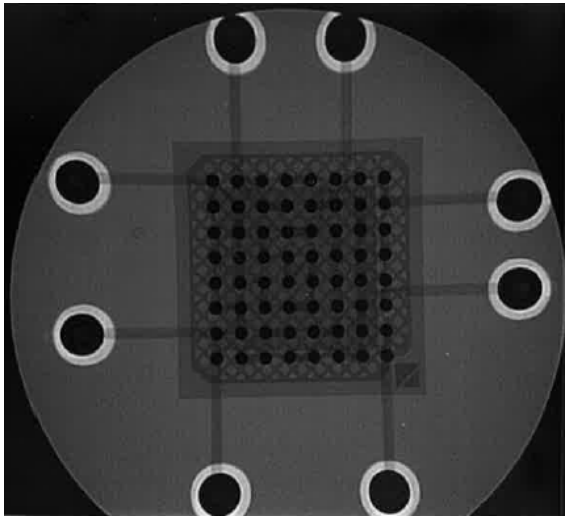
Methods

CANNONBALL Assembly







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Methods

Reliability Tests

Test Conditions	# of Samples
SMT Component Shear **Ref: JESD22-B117 [14]** **MIL-STD-883, Method 5005 [8]**	24 (BARNACLEBOND)
Wire Pull Test **Ref: MIL-STD-883, Method 2011/5005** **IPC-TM-650, 2.4.42.3 [13]**	22 from 4 Devices (ROPEWALK)
Shock **Service condition A, 500 G acceleration peak, 1 ms pulse duration, 30 shocks (5 pulses in each of 6 directions)** **Ref: JEDEC JESD22-B104C [14]**	24 (BARNACLEBOND) 28 (ROPEWALK) 22 (CANNONBALL)

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Methods

Reliability Tests cont.

Test Conditions	# of Samples
Temperature Cycling -40°C to 85°C, 1000 cycles, Preferred ramp rate of 10-14°C/min, 10-minute dwell times Ref: JEDEC JESD22-104F [14]	24 (BARNACLEBOND) 28 (ROPEWALK) 22 (CANNONBALL)
Temperature Humidity 85°C/85% RH, 1000 hours, Unbiased Ref: JEDEC JESD22-A101 [14]	24 (BARNACLEBOND) 22 (CANNONBALL)
Post-TC Shear & Visual Inspection	24 (BARNACLEBOND)
Post-TC Wire Pull & Visual Inspection	22 (ROPEWALK)

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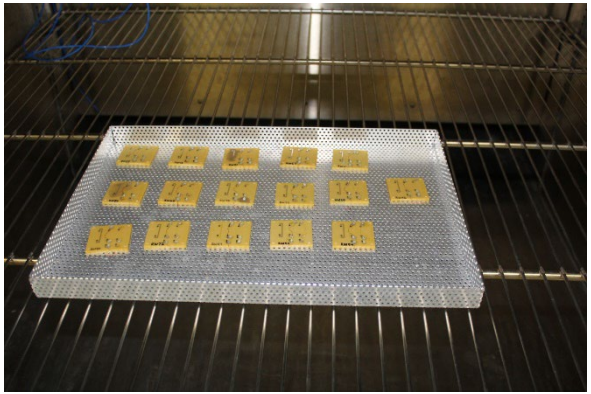
Methods

Temperature Cycling

- Temp cycling was stopped every 100 cycles for testing
- 28 BARNACLEBOND and 74 ROPEWALK assemblies underwent temperature cycling

- Each ROPEWALK contained 3 different wires to be measured: a 42ga wire & 34ga wire connected at two points and a 34ga wire connected at one point.
- A total of 222 unwired ROPEWALK sites

- 50 CANNONBALL samples underwent temperature cycling
- This led to a total of 352 unwired samples and 6 wired samples.



Test Vehicles in Temperature/Humidity Oven

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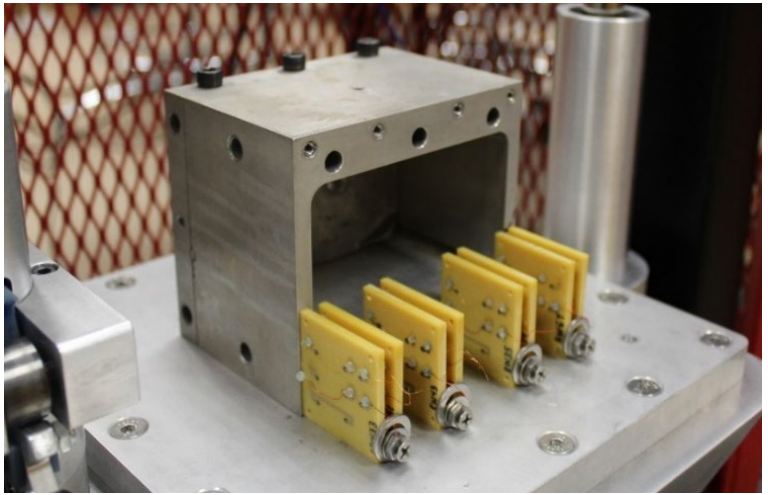
Methods

Shock Testing

- Shock testing was performed to understand mechanical strength
- Each device underwent 5 shocks of 500g with a 1ms pulse duration on each face for a total of 30 shocks per part.
- After testing on both faces of each axis, resistance and continuity checks were performed to assess any damage.



Test Vehicles loaded in shock tester

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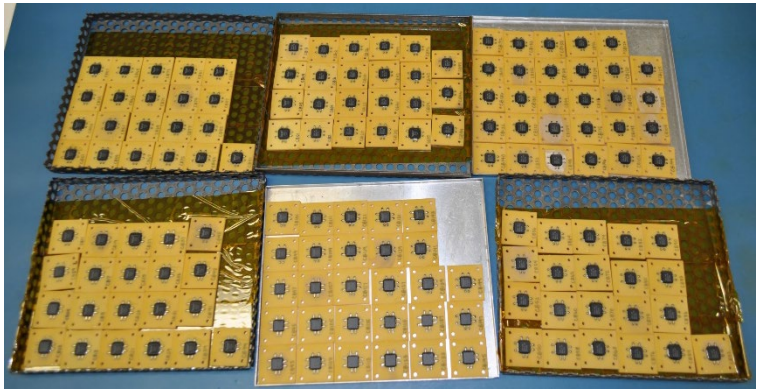
Methods

Failure Criteria

- ROPEWALK and CANNONBALL, a failure is continuity being lost
- BARNACLEBOND, a failure is defined as a 5% change in resistance (or open)
- For wire pull testing on ROPEWALK, a failure is a breakage at a peak below 430/48 grams force for 34ga and 42ga wire.
  - Lowest wire failure values for traditionally soldered, copper pad.



CANNONBALL completed assemblies prior to reliability testing

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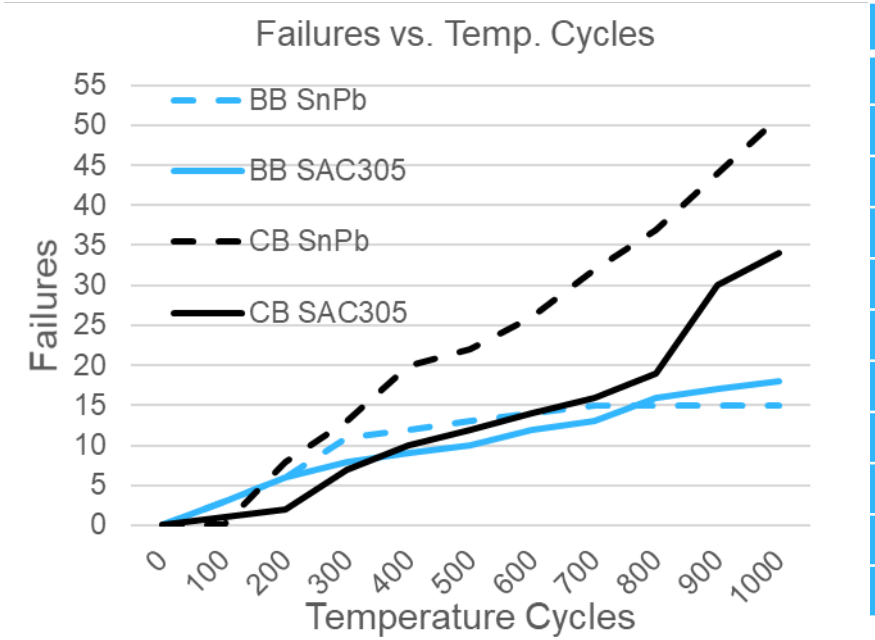
Results

Test Vehicle Temperature Cycling



BARNACLEBOND		
	% Failure	Total Samples
SAC305	49%	57
SnPb	31%	48
ROPEWALK		
	% Failure	Total Samples
SAC305	89%	105
SnPb	51%	105
CANNONBALL		
	% Failure	Total Samples
SAC305	19%	176
SnPb	29%	176

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Results

BARNACLEBOND & CANNONBALL Temperature Humidity Test

BARNACLEBOND		
	% Failure	Total Samples
SAC305	14%	44
SnPb	9%	44
CANNONBALL		
	% Failure	Total Samples
SAC305	2%	176
SnPb	4%	176

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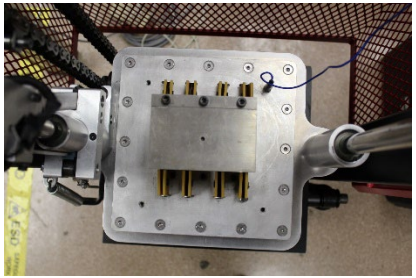
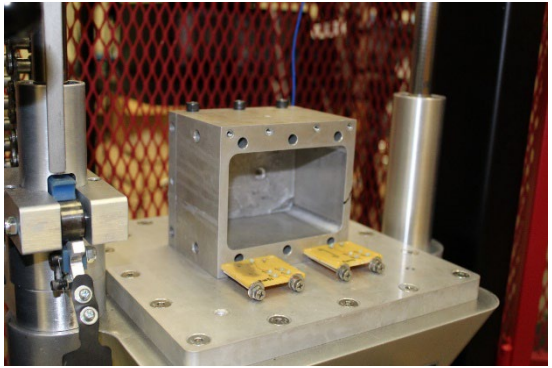
Results

BB & RW Shock

Of the 24 BB coupons (96 sites)

- 11 had previous humidity testing
- 11 had previous temperature cycling
- 2 of them had not experienced any testing.





BARNACLEBOND		
	% Failure	Total Samples
SAC305	0%	44
SnPb	0%	52

ROPEWALK			
	Type	% Failed	Total Samples
SAC305	42ga 2pt	60%	5
	34ga 2pt	29%	14
	34ga 1pt	20%	15
	Type	% Failed	Total Samples
SnPb	42ga 2pt	0%	1
	34ga 2pt	100%	1
	34ga 1pt	57%	7

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Results

ROPEWALK Pull Test

Mechanical pull testing was completed on ROPEWALK to determine equivalent strength to traditional lead wire soldering.

ROPEWALK			
	Wire Type	% Failed	Samples
Pre-TC	42ga, 2 point	0%	3
	42ga off	0%	3
	34ga, 2 point	33%	3
	34ga off	0%	3
Post-TC	42ga, 2 point	66%	3
	42ga 1 point	33%	3
	34ga, 2 point	100%	3
	34ga 1 point	100%	3

ROPEWALK			
	Wire Type	% Failed	Samples
Pre-TC	42ga, 2 point	0%	3
	42ga off	0%	3
	34ga, 2 point	100%	3
	34ga off	0%	3
Post-TC	42ga, 2 point	100%	4
	42ga 1 point	25%	4
	34ga, 2 point	100%	4
	34ga 1 point	25%	4

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Results

BARNACLEBOND Shear Test

SnPb coupons retained an average of **47%** of their shear strength after temperature cycling. SAC305 coupons retained an average of **71%** of their shear strength after temperature cycling.

BARNACLEBOND		
	Solder Material	Force (g)
Pre-TC	SnPb	1687.767
	SAC305	1185.34
Post-TC	SnPb	798.3208
	SAC305	847.52

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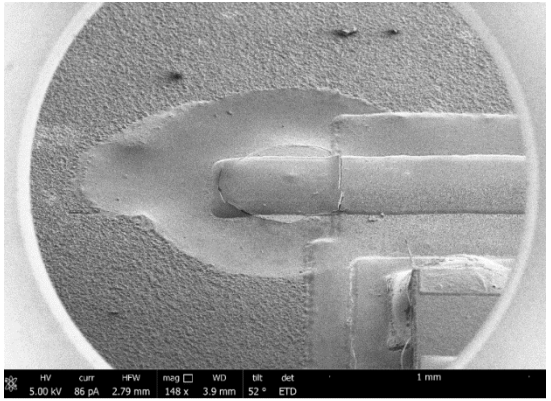
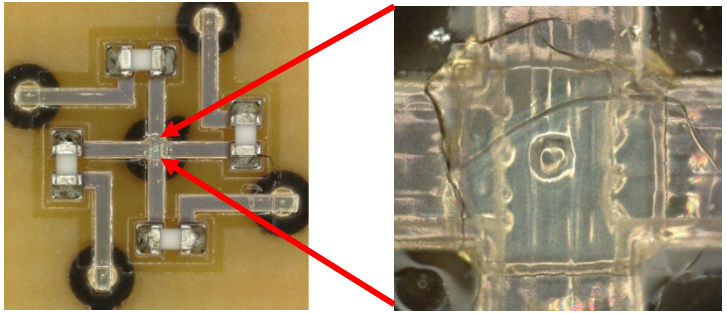
Conclusions

- Temperature cycling testing caused the most significant failures in the test vehicles.
- Most common failure mode across all test vehicles was Ag cracking at the transitions of the test points
- The secondary failure mode appeared to be delamination of Ag from its base NEA121 material as seen in ROPEWALK samples





Cracking shown in BARNACLEBOND as a result of CTE mismatch

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Conclusions

- Across all test vehicles, no solder joint failure could be found.

- Using previously temperature cycled and humidity stressed parts, almost all of the BARNACLEBOND and CANONBALL samples passed shock testing.

- These samples were not affected by Ag cracking like the failed samples, **this data is a testament to the strength of the solder joints themselves, but inconclusive on their reliability.**

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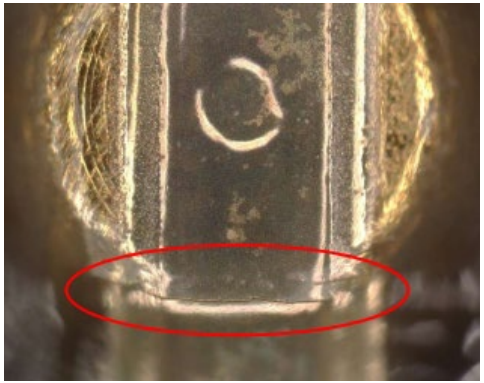
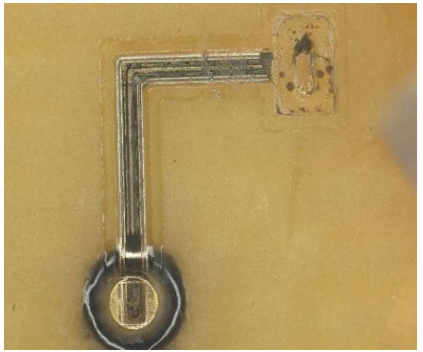
Conclusions

- Study does not confirm 90% confidence that 90% reliability exists
- General durability and weak points characterized
- CTE mismatches and delamination root cause of failures



ROPEWALK cracking near test point due to staking material CTE mismatch



Delamination of printed Ag from base material after pull testing.

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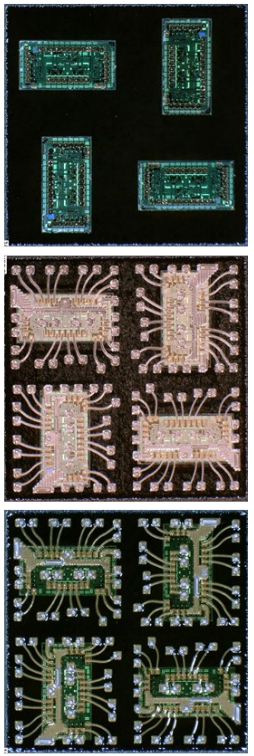
Conclusions

Future Work

- New circuit geometries, materials, configurations and increased circuit density are possibilities

- Advanced packaging techniques such as multichip modules and flip chip packaging could leveraged



Printed electronics multi-chip module

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THANK YOU!

Questions?

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- edwinaquinn@gmail.com
  - Phone Number by Request

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