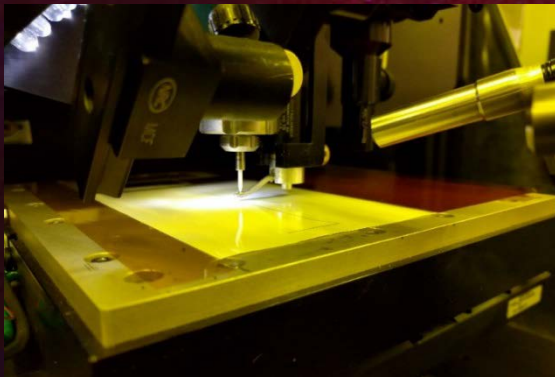




Direct Write Printing on Thin and Flexible Substrates for Space Applications



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Additive Manufacturing for Defense & Aerospace

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Introduction: Direct-Write Printing and Aerosol Jet Printing

- Direct-Write Printing – additive manufacturing technique where electronic components and circuits are fabricated by depositing materials onto a substrate without the use of masking or etching
- Aerosol Jet Printing is a type of direct-write printing that uses aerodynamic focusing to precisely and accurately deposit nanoparticle inks onto substrates¹



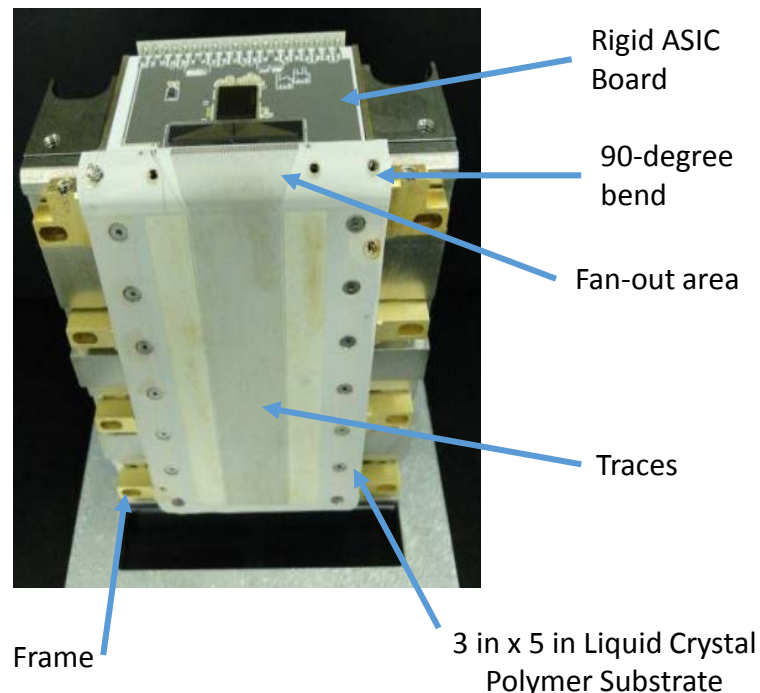
1. Optomec <http://www.optomec.com/printed-electronics/aerosol-jet-technology/>



Why Direct-Write Printing?

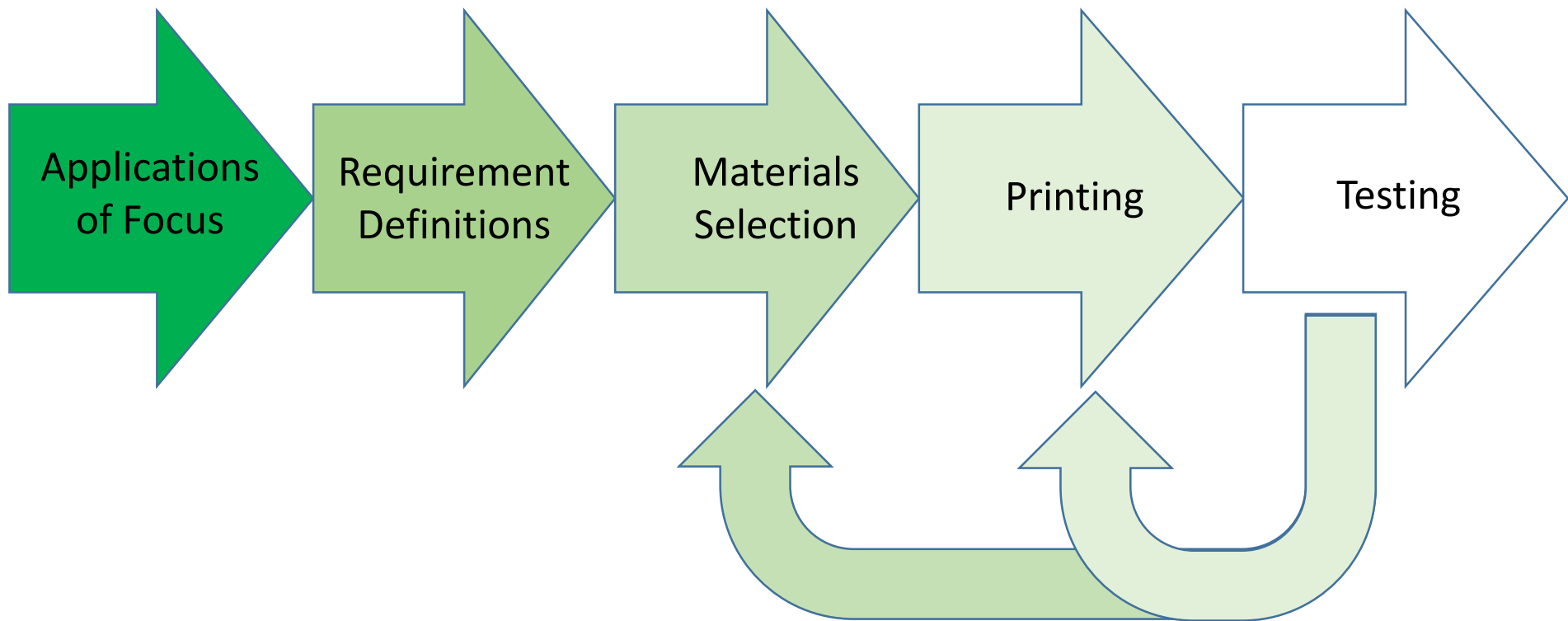
- Next Generation X-Ray Polarimeter
 - Study sources of X-Rays such as black holes, pulsars, supernova remnants
- Photoelectron tracks are imaged using strip detectors in a gas environment
- Original strip design: traces at 121-micron pitch, etched into copper cladding on a liquid crystal polymer substrate
- The minimum pitch of the strips and the area required to fan the strips in to the pitch of the ASIC readout is limited by the accuracy of the etching, and limits the gas choices and pressure, thus restricting the achievable sensitivity
- Reducing the pitch could reduce the Polarimeter design in size, which saves mass, and improves track resolution
- A reduction in strip pitch will enable the detector sensitivity to be increased by more than a factor of three and a mission sensitivity increase by more than a factor of ten

Assembled Strip Detector

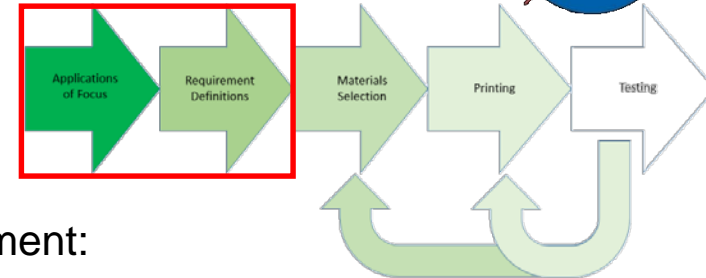




Repeatability Plan – 5 Items

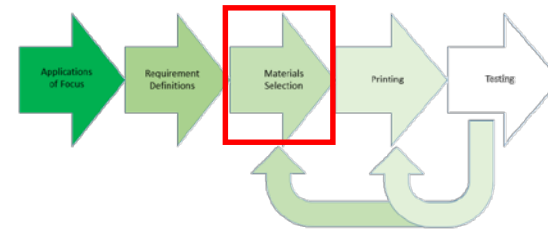


Application and Requirement Identification



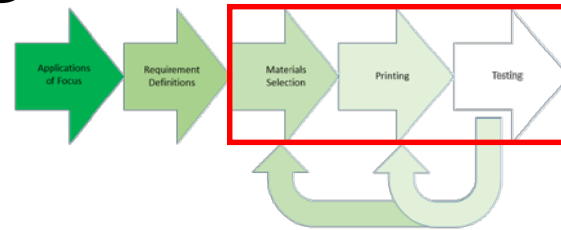
- Application: Strip Detector for Next Generation X-Ray Polarimeter
- Mechanical:
 - Printed traces:
 - At maximum, 60 micron width traces with 121 micron pitch
 - Bend around a 90-degree corner of ¼-inch radius
 - Survive being pulled flat
 - Substrate:
 - Low moisture absorption rates: .04%/24 hours
 - Has a high melting temperature: 250°C minimum
 - Has a high surface resistivity: 10¹² Mega ohms
- Environment:
 - Outgassing:
 - Total mass loss <=1%
 - Collected Volatile Condensable Material <=0.1%
 - Temperatures:
 - 125°C for 10 days
 - +20°C to +30°C operational
 - 10°C to 40°C survival
 - Vibration, shock and acoustics per NASA Goddard's General Environmental Verification Standard GSFC-STD-7000
- Electrical:
 - Low capacitance
 - Carry 1-microamp pulses, 500 pulses per second

Materials Selection

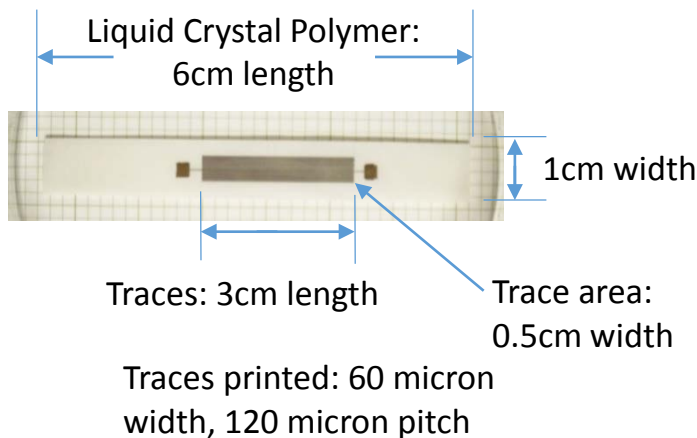


- Selected liquid crystal polymer (LCP) substrate due to cleanliness/outgassing requirements.
- Selected one gold ink and one silver ink.
- Gold ink was selected because it could potentially be cured at temperatures of 200°C or lower – LCP starts to ripple at temperatures higher than this.
- Silver ink selected was based on previous printer user experience – successful prints with it in the past, plus 200°C sintering temperature. Silver is also less expensive.
- Used AJ200 aerosol jet printer.

Printed Test Coupons



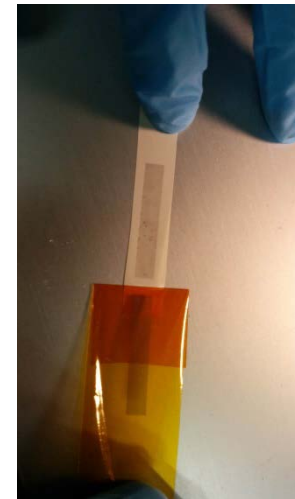
- Initially printed small coupons as a representation of the full assembly.
- Coupons were used for mechanical tests – bending, tensile and adhesion tests as well as wire bonding tests.
- Status: 23 tested so far.



Tensile Test
Setup

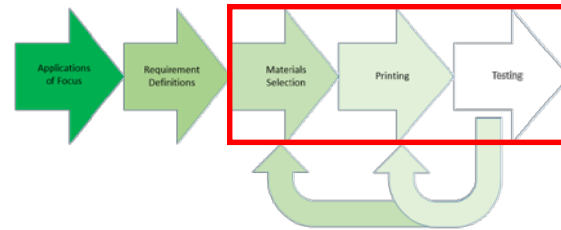


Bend Test Setup

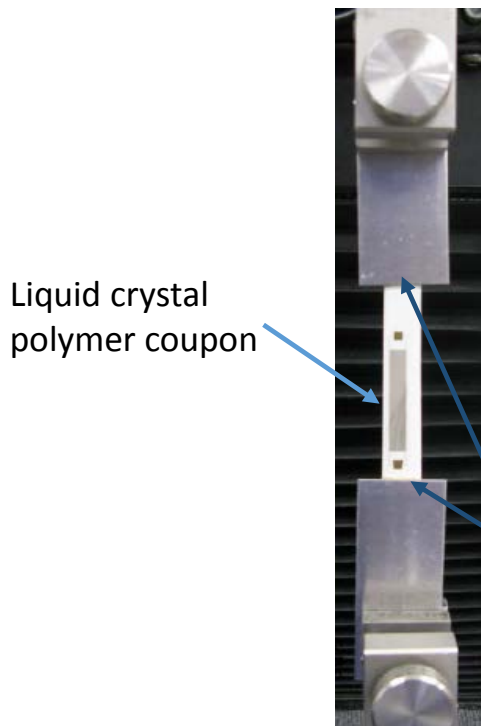


Tape Test

Printed Test Coupons



Tensile Tests:



Pulled at .003 inches per minute until one of the following is observed:

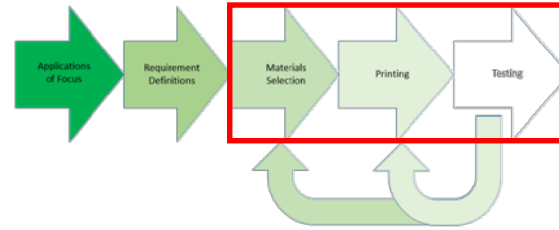
1. LCP tears
2. Bonds holding LCP to metal plates breaks
3. Traces break

Tensile tested:

- 7 coupons with silver traces
- 5 coupons with gold traces
- 4 coupons with no traces (referred to as “blank”)

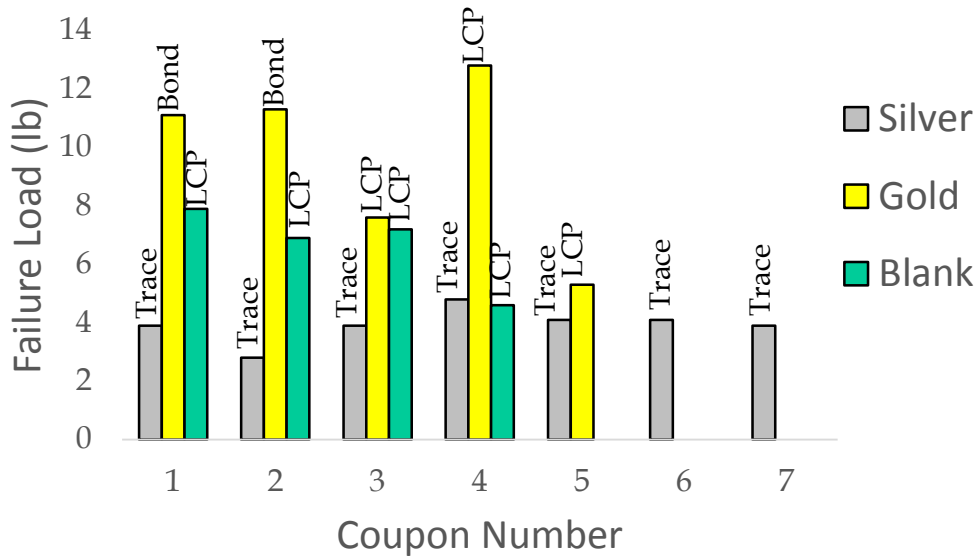
Tensile Test Setup

Printed Test Coupons

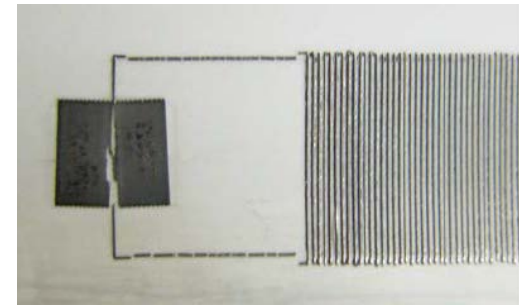


Tensile Tests:

Tensile Tests of Silver and Gold Traces Printed on Liquid Crystal Polymer (LCP)



All silver prints experienced trace fractures

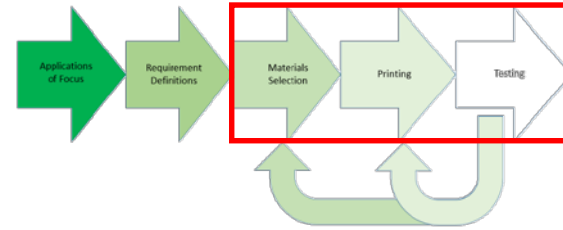


Gold prints experienced breaks at the LCP-to-metal bond or LCP



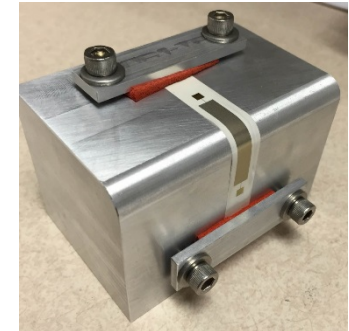
Variations in LCP breaks in blank and gold print coupons may be from micro-tears on edges.

Printed Test Coupons

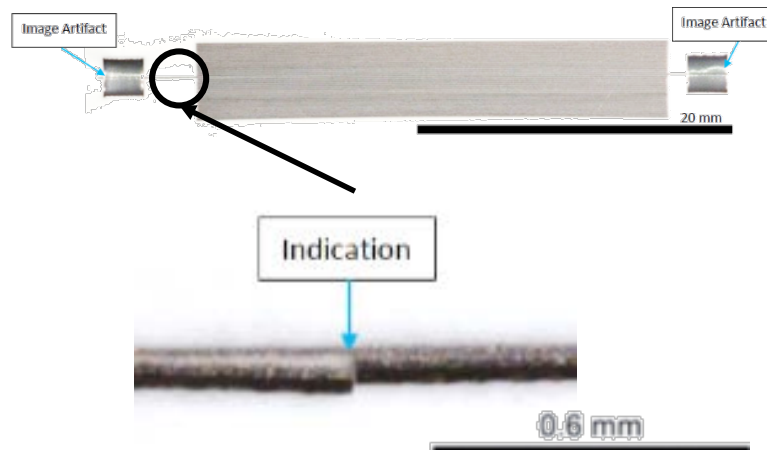


Bend Tests:

- Bend Test coupons were pulled to eliminate slack and bend around a ¼-inch radius for 1-2 hours.
- 3 silver and 4 gold coupons were bent and un-bent 1-2 times each.
- Trace breaks were noted in 1 silver coupon.
- Anomalies noted in 1 gold coupon but not confirmed breaks.

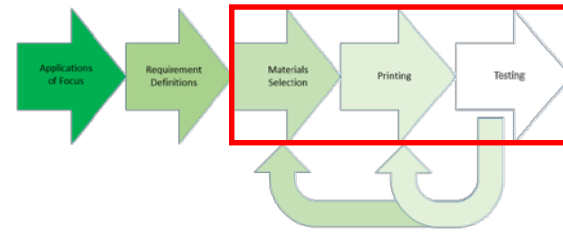


Bend Test Setup



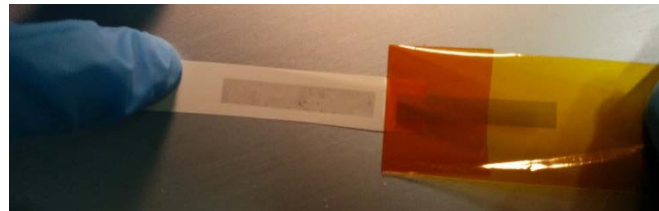


Printed Test Coupons



Adhesion Tape Tests:

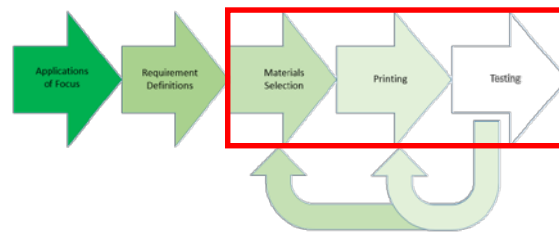
- Kapton tape was placed over the printed traces.
- The tape was then pulled away from the tape.
- The coupon and tape were inspected after the tape pull.



- 2 silver and 2 gold coupons tape tested.
- Preliminary results: Gold adhered to the liquid crystal polymer better than silver.
- A larger sample set still needs to be tested for adhesion.



Printed Test Coupons

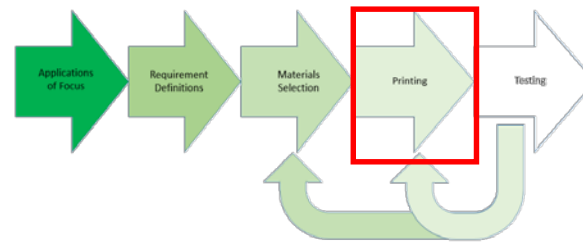


Conclusions from Coupons:

- The gold ink overall adhered better and survived mechanical tests.
- The silver ink showed poor adhesion and did not survive mechanical tests.
- For printing the detector strips, print with gold and find an alternative silver ink that may adhere better.

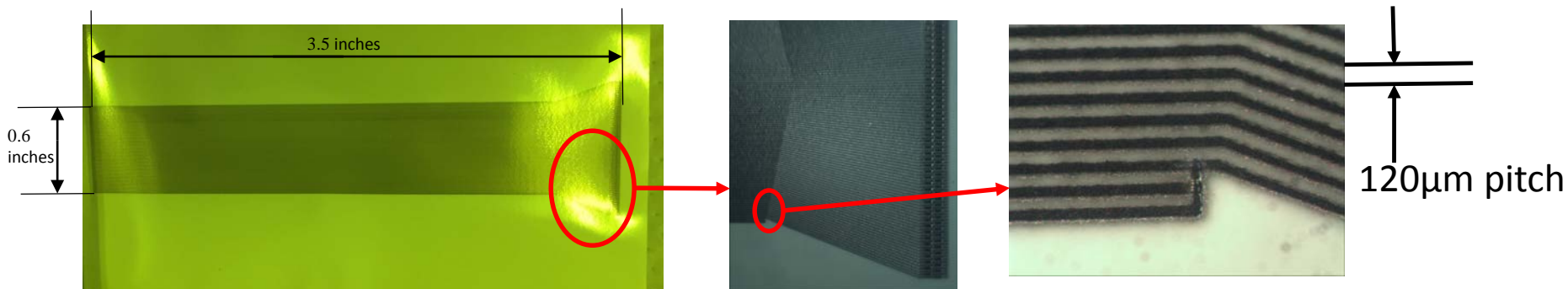


Detector Prints



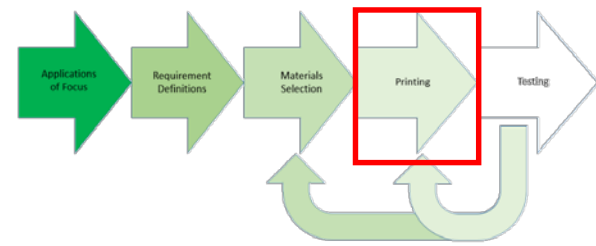
- Printed full strips with gold and silver inks.
 - A different silver ink was used due to the previous coupon tests showing poor adhesion.
- Printed with same equipment, but at a different facility with different operators.
- Printed on Kapton and Liquid Crystal Polymer.
- Printing using AJ200 with pneumatic and ultrasonic atomizer depending on recommendation from ink vendor.
- Status: 1 print of gold on Kapton, 4 prints of silver on Liquid Crystal Polymer.

Detector 1: Silver printed on Liquid Crystal Polymer with pneumatic atomizer. 200 μ m tip used. Traces consistently 60-80 μ m throughout print.

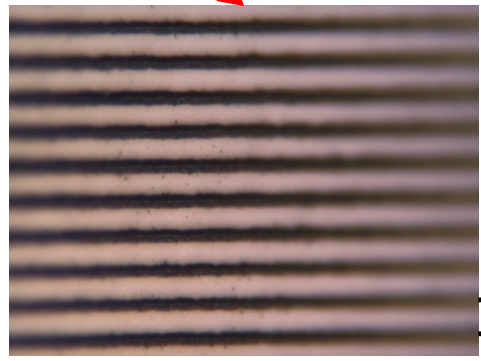
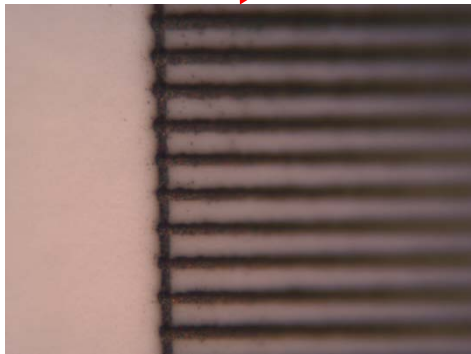
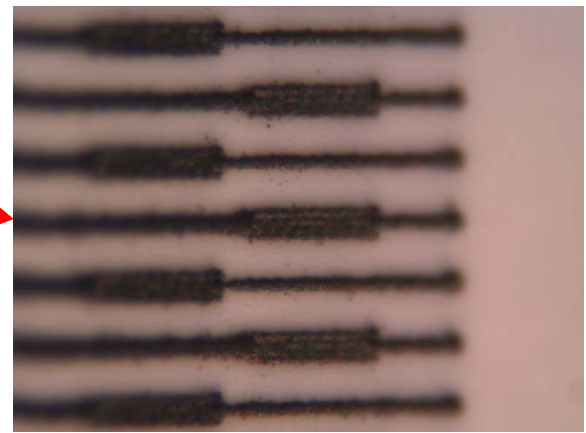
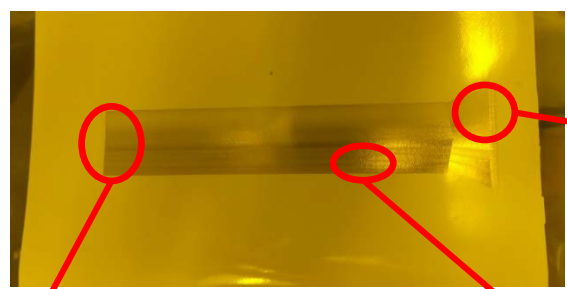




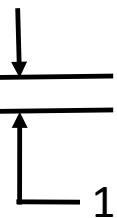
Detector Prints



Detector 2: Silver printed on Liquid Crystal Polymer with pneumatic atomizer. 100 μ m tip used.



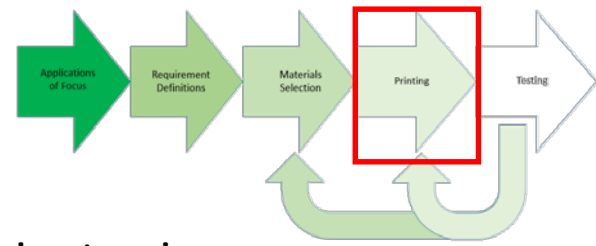
Traces started at 40 μ m width but got wider to about 80 μ m half-way through printing. Settings had to be adjusted to get thinner traces again.



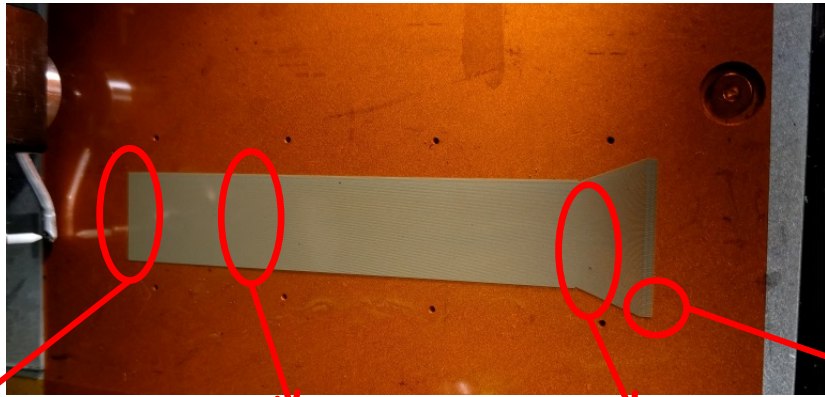
120 μ m pitch



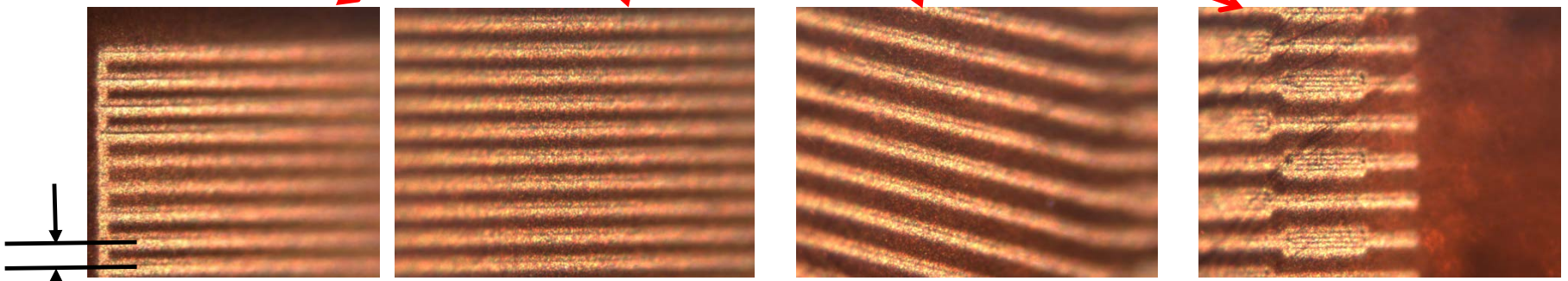
Detector Prints



Detector 3: Gold printed on Kapton with ultrasonic atomizer.
200 μ m tip used.

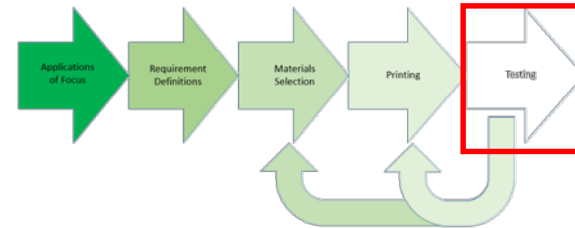


Traces consistently
80 μ m wide.
Overspray observed.

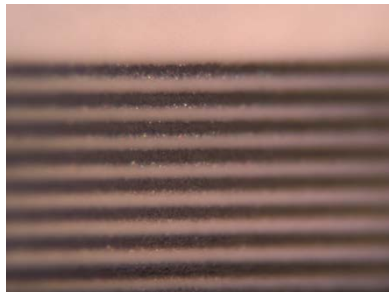


120 μ m pitch

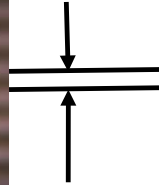
Testing



Verifying dimensions, resistivity, adhesion, and assembly robustness of printed cured strips.



Trace width and height – these are being measured to determine size tolerance.



Electrical measurements will be taken to determine resistivity of the material.



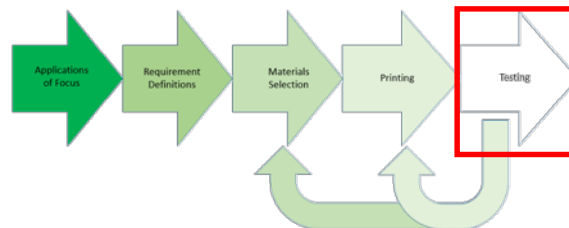
Adhesion tests to continue to determine whether or not the ink can survive the assembly process and the mission.

The detector strips are to be put through the assembly process to determine robustness. This includes IPA cleaning, bake out, stretching, bending, and wire bonding.

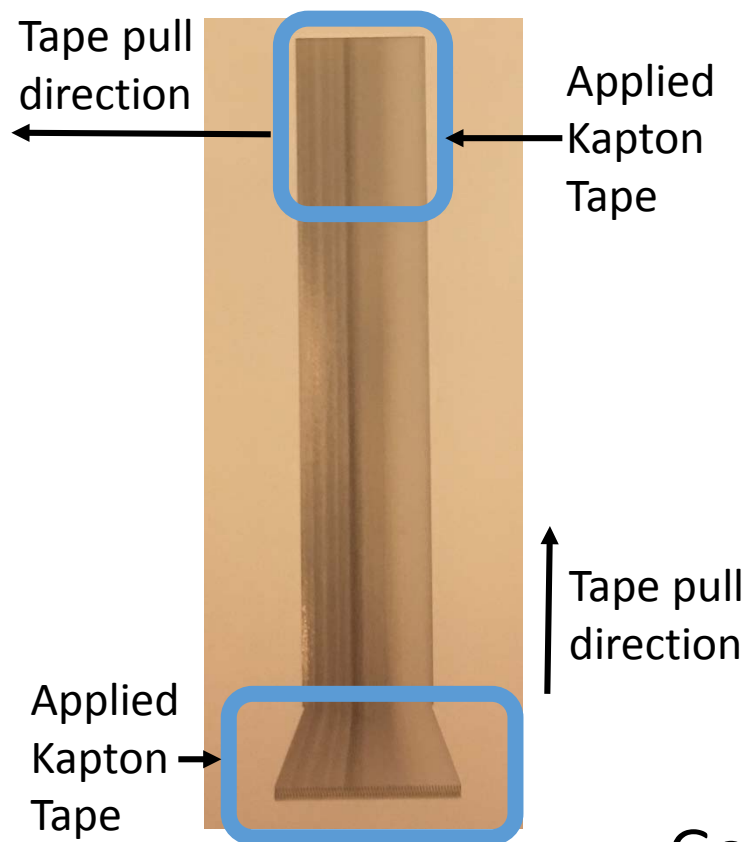
Observations so far: inks seem to behave differently over time and between users.



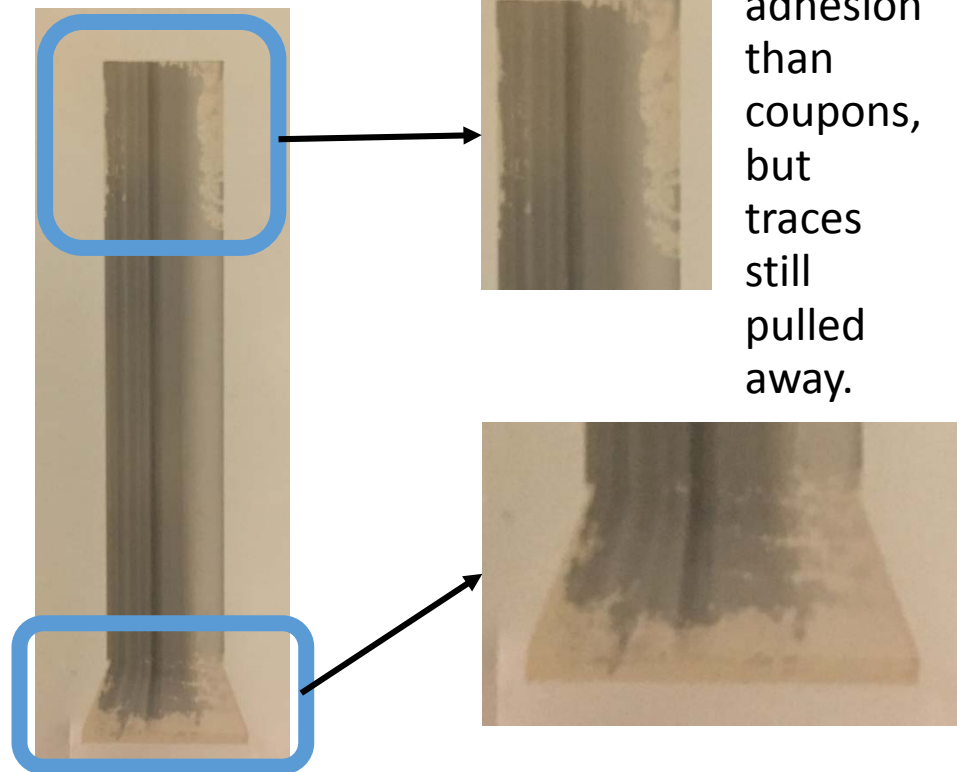
Testing



Adhesion: Preliminary results for silver print



After Pull:



Gold ink to be tested next.



Future Work

- Continue printing and testing detector strips.
 - Print more detector strips with the same silver and gold inks, to better determine repeatability between inks, printers, facilities, and procedures. Recommend 20 samples per set.
 - Take physical and electrical measurements of traces of each print to determine size and electrical tolerances. Modify printing processes to improve tolerances as needed.
 - Put strips through the full assembly process to determine robustness.
- Continue direct-write printing work with different applications:
 - Print on 3D rigid substrates instead of flexible substrate.
 - Print trace-to-die pad connections.



Special Thanks:

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- Stephen Farias, NanoDirect LLC
- Mike Renn, Optomec

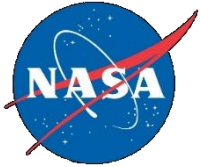


Questions?



Contact:

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Backup

X-Ray Image Example:
Supermassive black hole at the center of the Milky Way
NASA's Chandra X-ray Observatory
<http://chandra.si.edu/photo/2014/sgra/>



Low-energy X-rays - red

Sagittarius A*

High-energy X-rays - blue