

Printing for and in Space:

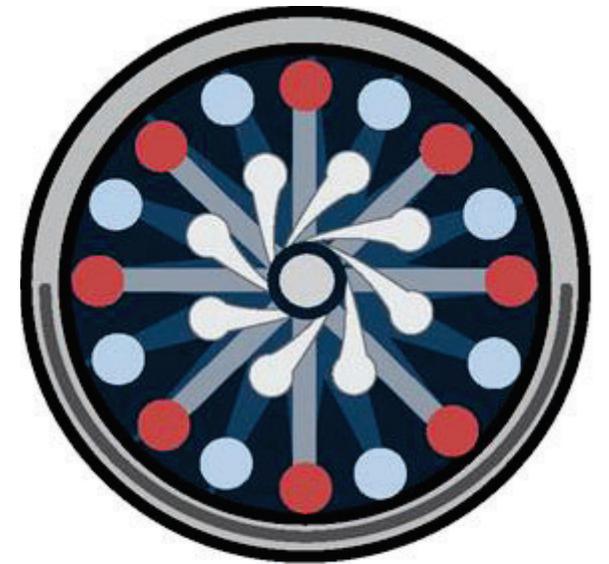
Novel Applications and Opportunities for Printing Technology on the Frontier

Sean Garnsey
Sr. Engineer
Enova Concepts

In Partnership with:

NASA Jet Propulsion Laboratory

*Multifunctional Electronic Materials & Devices Research Laboratory
at UT San Antonio*



ENOVA
CONCEPTS

Outline

- Introduction
 - About Enova Concepts
 - “What is a Printer?”
 - Alignment between Printing and Electronics Industries
 - Challenges in Civil Space Industry
 - Addressing these Challenges with Printing
- Research: Cold Survivable Printed Electronics
 - Experimental Methods
 - Results
- Conclusion
 - Findings & Discussion
 - Future Work & Opportunities
 - Acknowledgements

Presenter Bio

Sean Garnsey

*Sr. Engineer, Additively Manufactured Electronics
Enova Concepts, LLC*

Prior Experience:

- *Keynote Speaker for EDSF Dinner at PRINT14, Chicago "Printed Electronics: A Disruptive Force You Must Not Ignore"*
- *Cal Poly TAGA Student Chapter (2012-2014)*
- *Inkjet Applications Development Engineer, FUJIFILM Dimatix*

Education:

- *Master of Nanoengineering, North Carolina State University*
- *B.S., Graphic Communication, Cal Poly SLO*

Other Affiliations:

- *Doctoral Candidate, University of Texas at San Antonio*



Questions? Let's chat!
Contact Sean Garnsey:

sgarnsey@enovaconcepts.com

Introduction

About Enova Concepts

Veteran-owned engineering startup in San Antonio, TX

Technology developed in collaboration with UT San Antonio's Multifunctional Electronic Materials & Devices Research Laboratory

Operationalized after receiving NASA Small Business Technology Transfer Research Grant (STTR) in 2024

Committed to advancing development of printed electronics for space applications



Matt Trippy | Founder, CEO
M.S., Electrical Engineering; B.S., Physics; B.S. Electrical Engineering

Physics & Material Modeling
RF Engineering SME
30+ yrs spanning DoD Space, NASA rapid prototyping, space qualified parts



Paul Flynn | Principal Investigator
M.S., Advanced Materials Engineering; B.S., Physics

Commercialization of Emerging Technology

- Computer Vision - Industrial NDE
- Composite construction material
- Medical Device - Biosensor array

Small business ownership experience



Sean Garnsey | Sr. Engineer
M. Nanoengineering; B.S. Graphic Communication

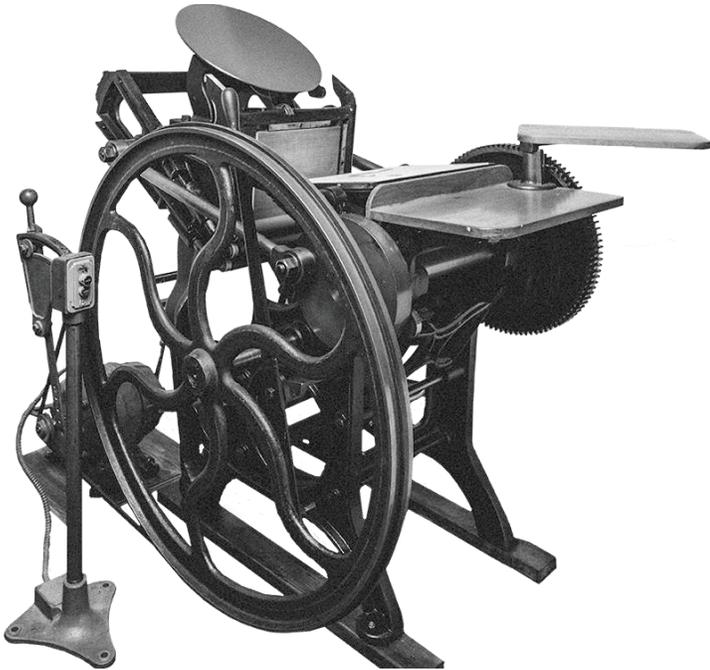
AME / Printing Technology

- FUJIFILM Dimatix
- Fraunhofer IOF
- InnovationLab GmbH

What is a printer?

A Conventional Definition:

Machine designed to repeatably pattern colorant agent onto substrate to convey information.



<https://hobancards.com/blogs/thoughts-and-curiosities/meet-our-letterpresses>



<https://www.vastex.com/Screen-Printing-Equipment/Screen-Printing-Presses/>



<https://kmbs.konicaminolta.us/products/predecessor-products/bizhub-press-c71cf/>

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What is a printer?

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<https://cst.princeton.edu/studiolab/equipment/3d-printing>

What is a printer?

An Expanded Definition:

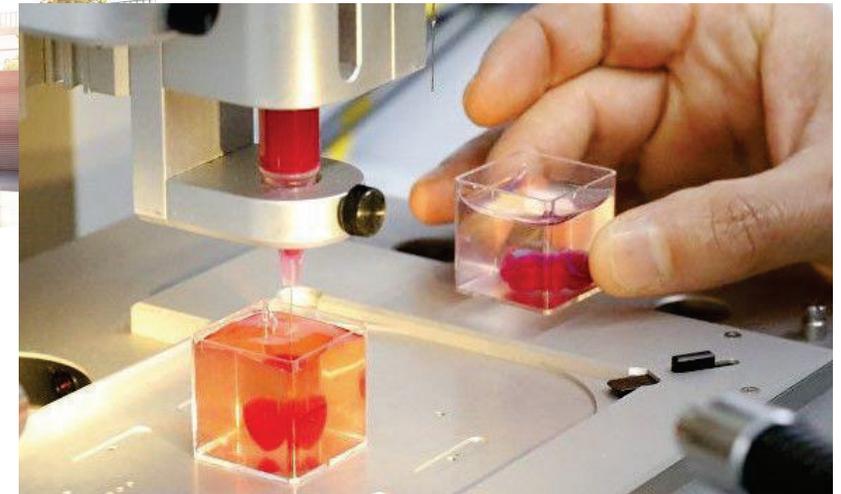
Machine designed to repeatably pattern **material** ~~colorant agent onto substrate to convey information.~~



<https://cst.princeton.edu/studiolab/equipment/3d-printing>



<https://knowhow.distrelec.com/3d-printing/the-rise-of-3d-printed-houses-changing-the-future-of-housing/>



<https://sites.nd.edu/biomechanics-in-the-wild/2021/04/06/this-toner-might-be-more-expensive-3-d-printing-artificial-organs/>

Alignment between Printing and Electronics Industries

TAGA is No Stranger to “NextGen” Printing Applications

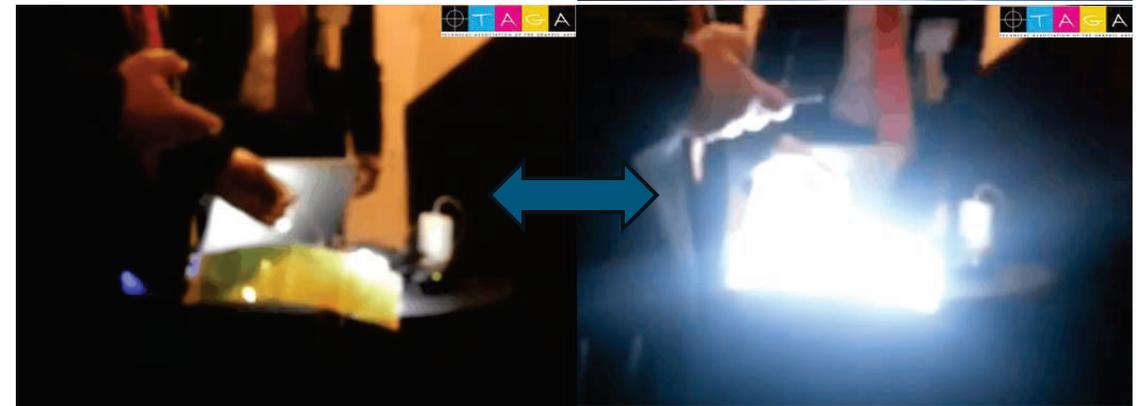
- Bill Ray of Nth Degree Technologies, 2012
 - Flexographically Printed Light Emitting Diode Films
 - Early promoter of the “expanded” definition of printing

What the print & graphics industry has “figured out”:

- High Throughput, Distributed Manufacturing
- Repeatability across complex processes
- Integration of cutting-edge technologies to improve quality

The needs of the electronics Industry

- Higher throughput processing, supply chain independence, sustainability
- New form factors (large area, flexible, biocompatible)
- Pristine quality of electronic (insulating, conducting, semiconducting) films to ensure device functionality



Alignment between Printing and Electronics Industries



Additive, Printed, Hybrid and Sustainable Electronics Innovations Day 2025
DEC 2025 TechBlick's Virtual Event Platform



[Short Sample](#)

[Full Presentations *](#)

[Agenda](#)



Perovskite Innovation Day 2025
DEC 2025 TechBlick's Virtual Event Platform



[Short Sample](#)

[Full Presentations *](#)

[Agenda](#)



Additive, Sustainable or 3D Electronics Innovations Day 2025
April 2025 TechBlick's Virtual Event Platform



[Short Sample](#)

[Full Presentations *](#)

[Agenda](#)

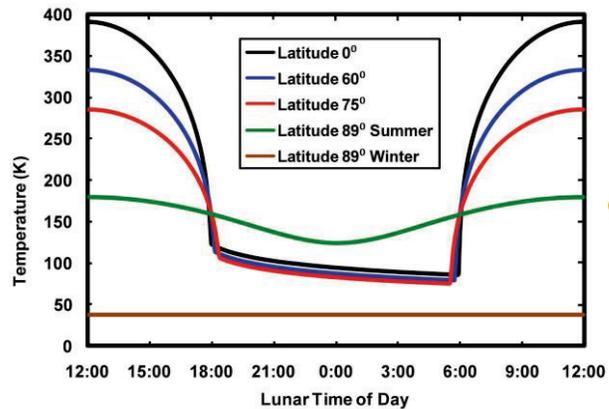
Challenges in Civil Space Industry



Image generated using OpenAI Chat GPT 5.3

Challenges in Civil Space Industry

Equatorial temperatures swing from around 127 C during the lunar day to around -179 C during the lunar night. (Williams et al 2017)



Values collected from the Lunar Reconnaissance Orbiter (LRO)

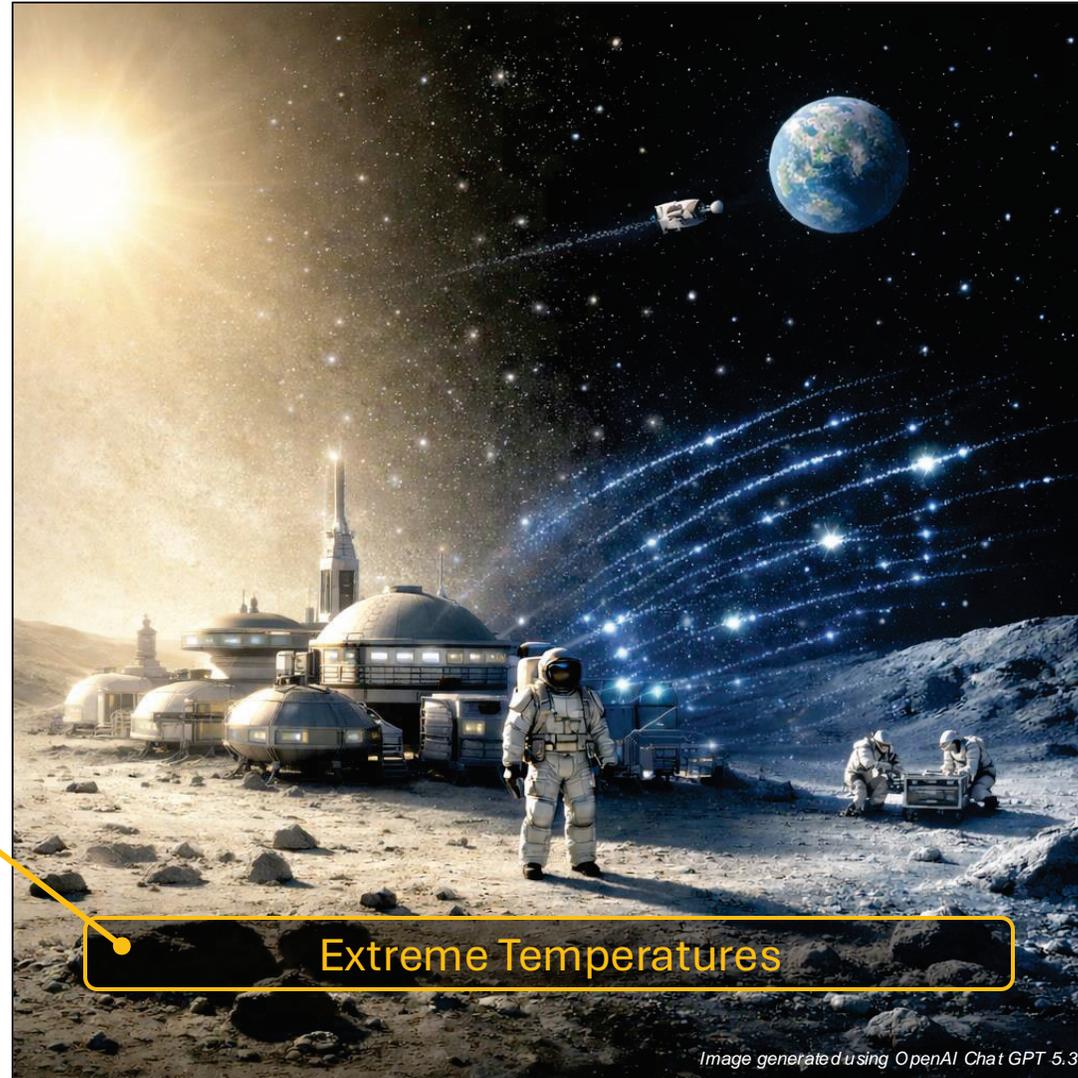
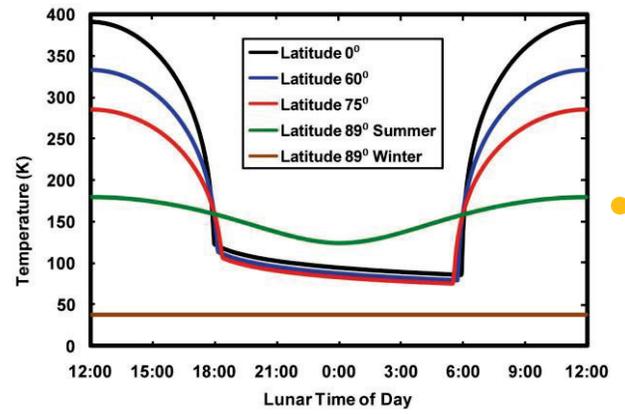


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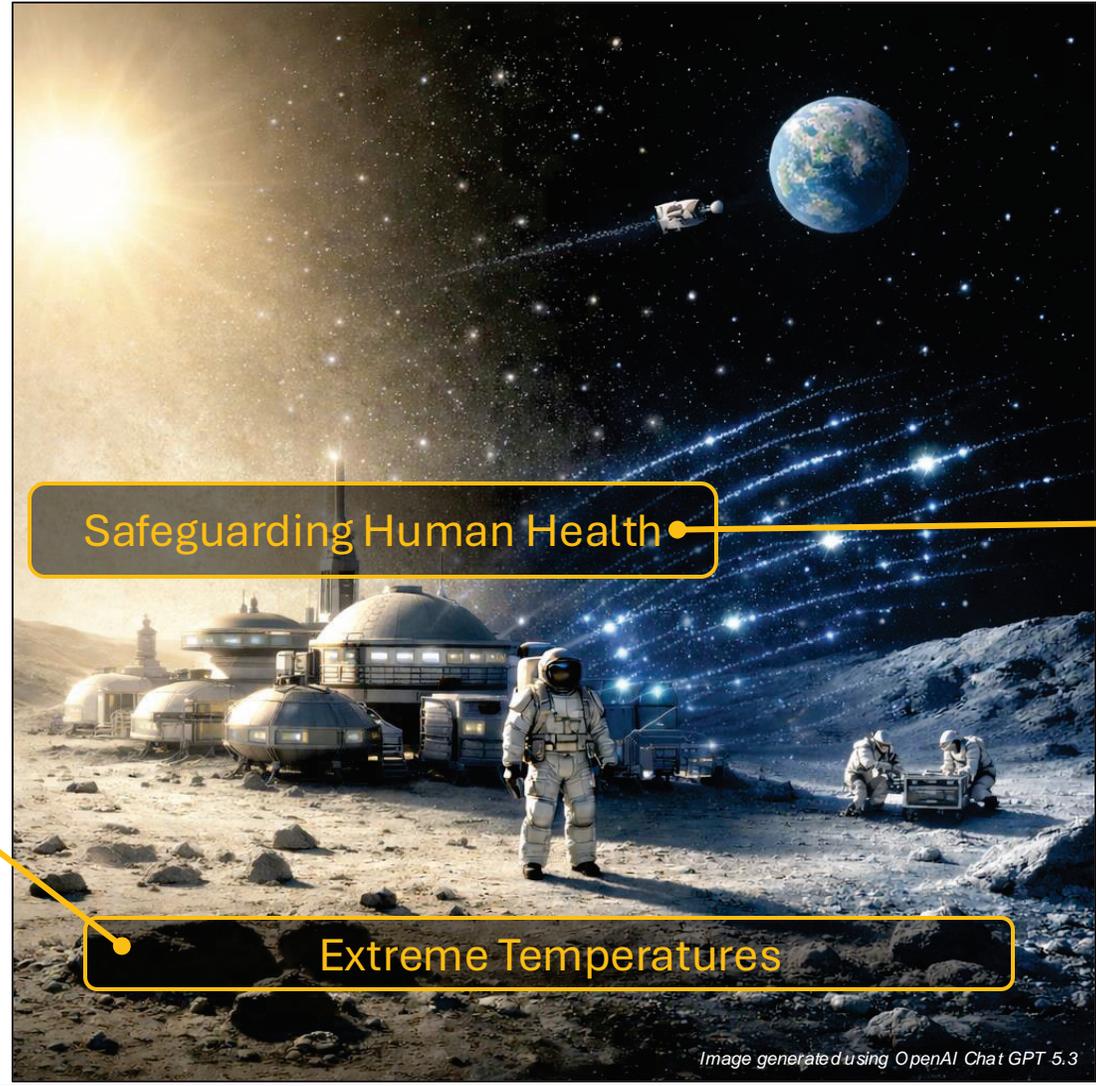
Challenges in Civil Space Industry

Ionizing Radiation:
#1 Risk to Human Space
Exploration

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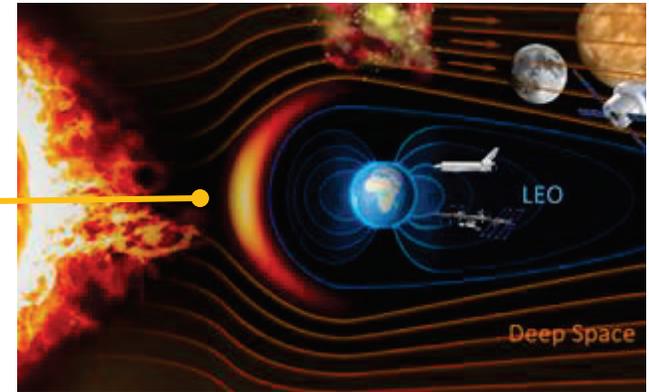


Values collected from the Lunar Reconnaissance Orbiter (LRO)



Safeguarding Human Health

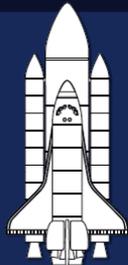
Extreme Temperatures



Liv Weiner, Radiation Shielding in Space, StemRad, 2021

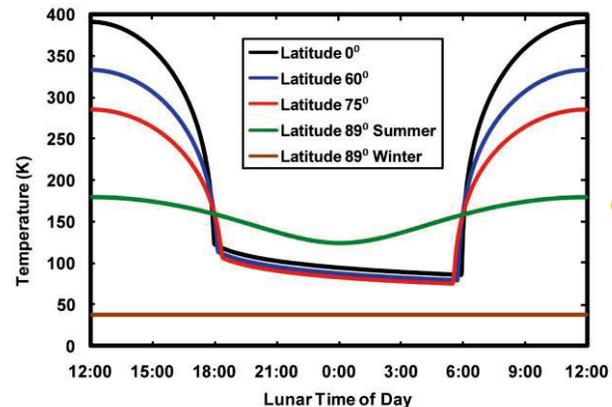
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Challenges in Civil Space Industry

NASA Space Shuttle	SpaceX Falcon 9
	
FIRST LAUNCHED: 1976	FIRST LAUNCHED: 2020
PRICE: \$1.5 billion	PRICE: \$62 million
COST PER KG: \$54,500	COST PER KG: \$2,720

<https://www.eversana.com/ko/insights/a-spacex-philosophy-to-launching-in-pharma/>

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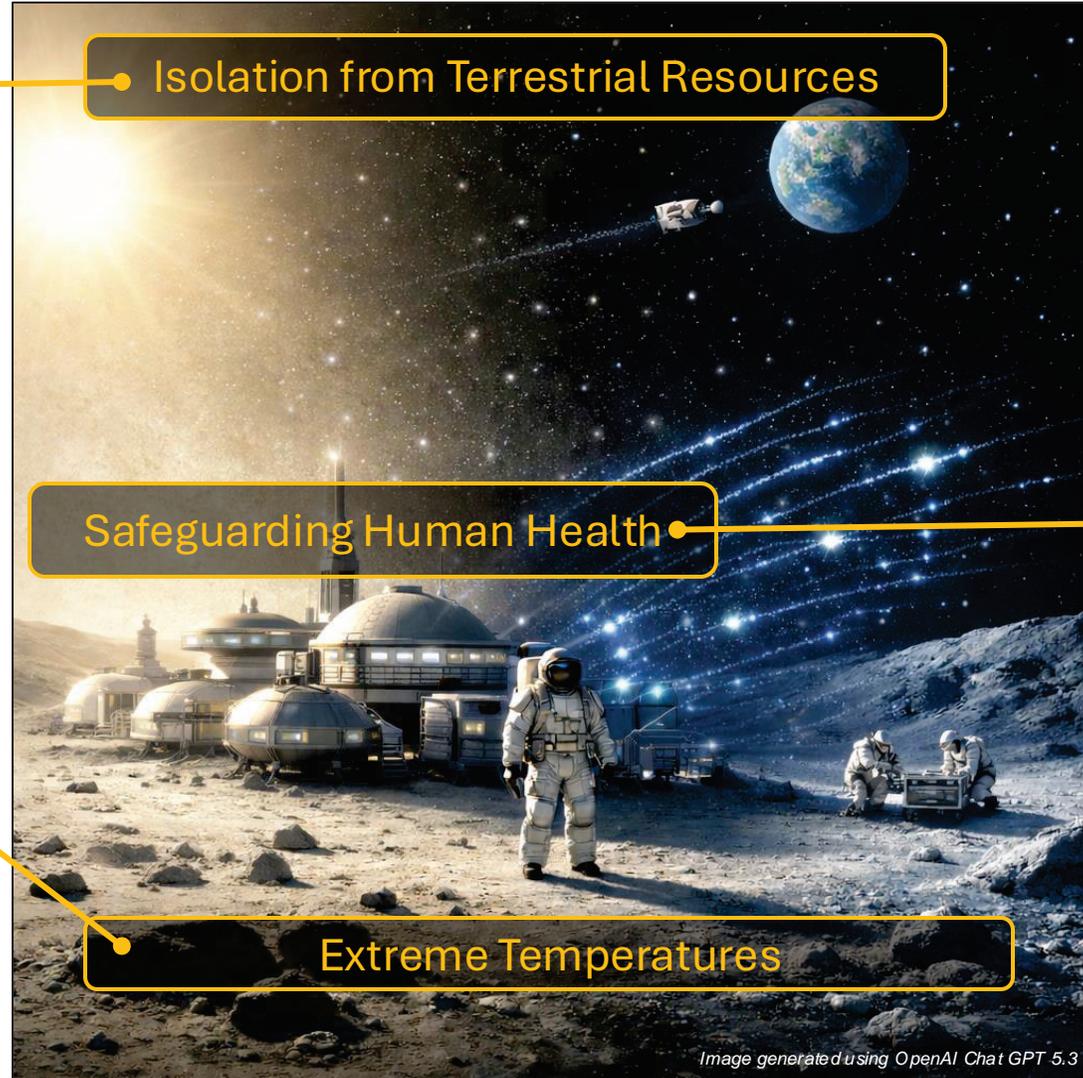
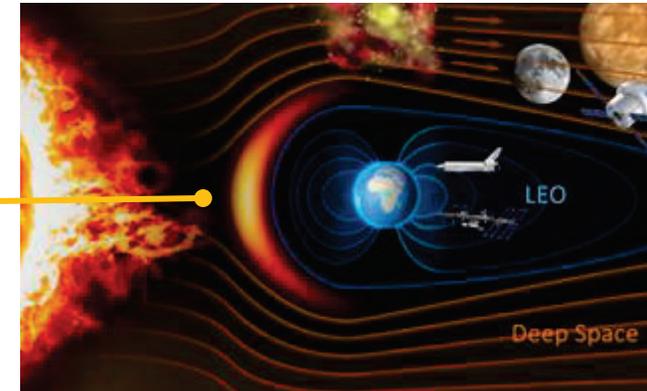


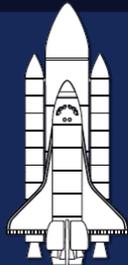
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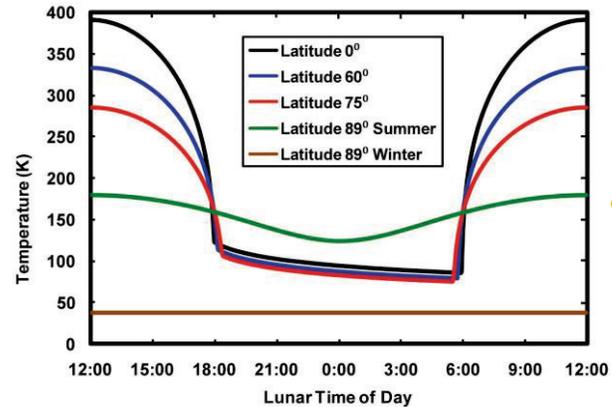
Liv Weiner, Radiation Shielding in Space, StemRad, 2021

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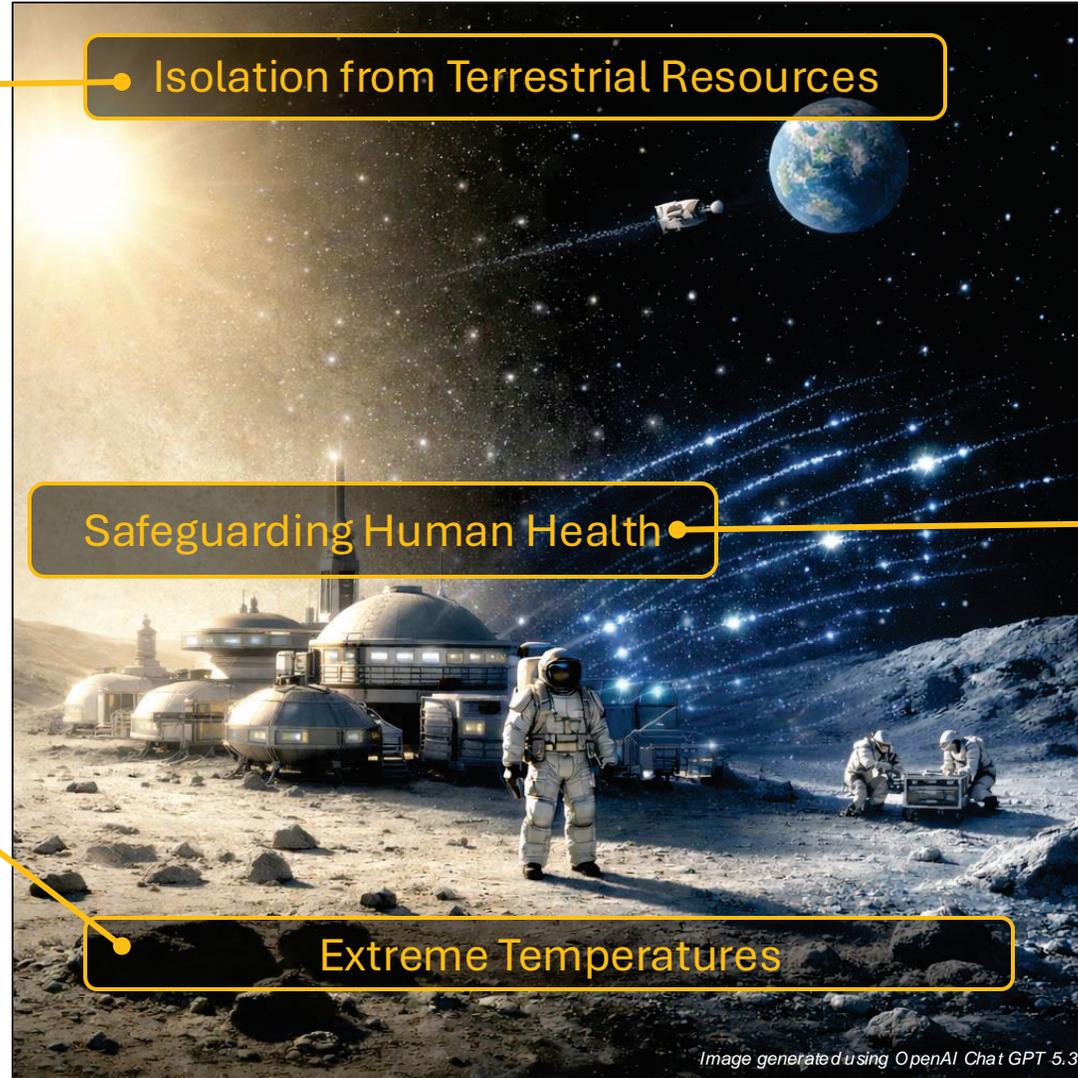
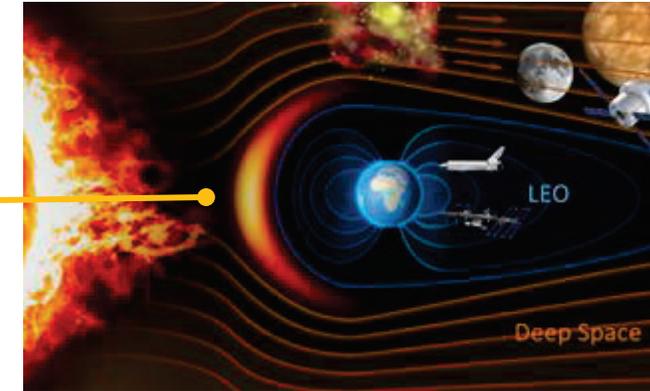


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Ionizing Radiation:
#1 Risk to Human Space
Exploration



Liv Weiner, Radiation Shielding in Space, StemRad, 2021

Can these challenges be solved with printing technology?

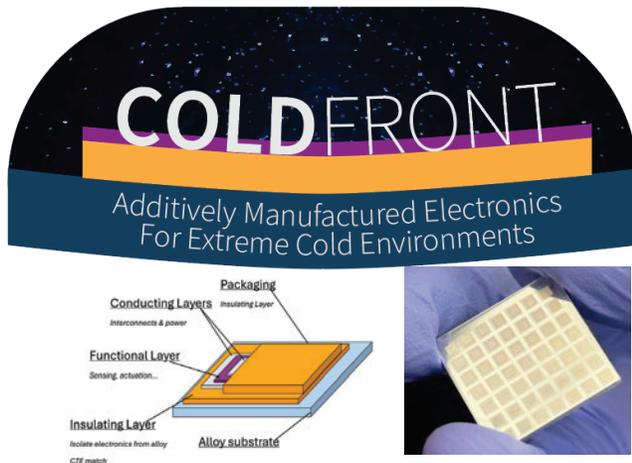
Addressing these Challenges with Printing

Cold Survivable Electronics

Challenge Addressed:
Extreme Temperatures

Enova Concepts' Contribution
NASA STTR 2024 Research

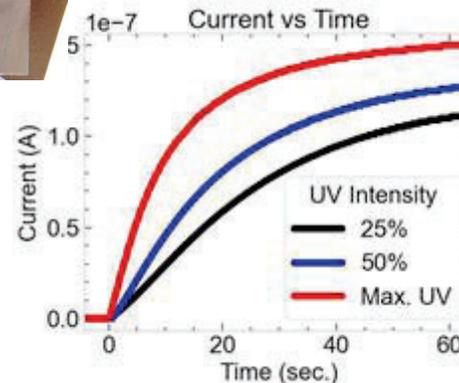
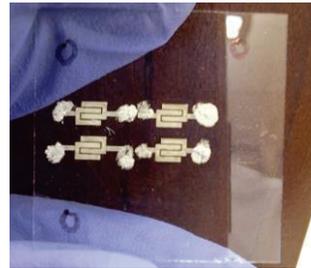
Presented Today:
COLDFRONT Materials Set and Demonstration



Printable Radiation Detection

Challenge Addressed:
Safeguarding Human Health

Enova Concepts' Contribution
Preliminary research in
collaboration with UT San Antonio



In Space Manufacturing

Challenge Addressed:
Isolation from Terrestrial Resources

Enova Concepts' Contribution
Use of ISM-Compliant Techniques:
Inkjet Printing, Direct Ink Writing

Demonstration examples of mg impacts

Inkjet and EHD printing in μg

Printed Part	Material	Resolution	Throughput	Print Speed	Print Area	Print Volume	Print Weight
Printed Part 1	Ag	100 μm	1000 $\mu\text{m}^2/\text{min}$	1000 $\mu\text{m}^2/\text{min}$	1000 μm^2	1000 μm^3	1000 μg
Printed Part 2	Ag	100 μm	1000 $\mu\text{m}^2/\text{min}$	1000 $\mu\text{m}^2/\text{min}$	1000 μm^2	1000 μm^3	1000 μg
Printed Part 3	Ag	100 μm	1000 $\mu\text{m}^2/\text{min}$	1000 $\mu\text{m}^2/\text{min}$	1000 μm^2	1000 μm^3	1000 μg

Crystal growth

- From the studies of 500 entries in last 50 years, 89% of macromolecules crystals, 79% of inorganic crystals, and 81% of semiconductor crystals reported improved crystal structures in mg.

Trench filling - Fabrication

- Micro-structures of printed patterns results in denser structure with less porosity
- Silver loading can be increased from 35% (at 1g) to 50% (at mg) due to less agglomeration \rightarrow 8.1 times higher conductivity
- Under mg, larger voltage can be used for reducing printed line width (higher resolution) for EHD mechanism.

MP3 Workshop 10.17.23

Jones et al, In Space Manufacturing Workshop, NASA MSFC 2023

SBIR/STTR Program

The NASA Small Business Innovation Research / Small Business Technology Transfer (SBIR/STTR) program is part of America's Seed Fund, the nation's largest source of early-stage non-dilutive funding for innovative technologies. Through this program, entrepreneurs, startups, and small businesses with less than 600 employees can receive funding and non-monetary support to build, mature, and commercialize their technologies, advancing NASA missions and helping solve important problems facing our country. Whether your destination is the Moon, Mars, or the marketplace, the NASA SBIR/STTR program wants to help get

Program Phases

Learn more by visiting the applicable page on the Opportunities menu dropdown



TX12: Materials, Structures, Mechanical Systems, and Manufacturing

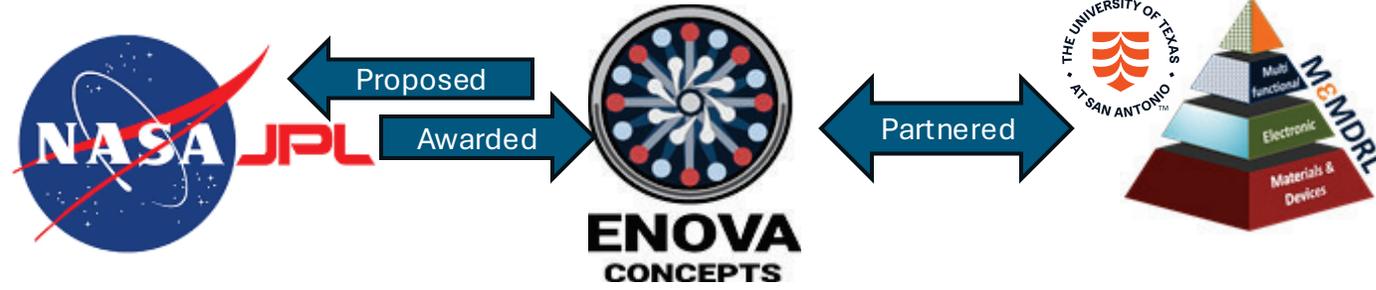
This area covers technologies for developing new materials with improved or combined properties, structures that use materials to meet system performance requirements, and innovative manufacturing processes.

T12.01 Additively Manufactured Electronics for Severe Volume Constrained Applications (STTR)

Related Subtopic Pointers: H5.01, H5.05, H8.01, S12.02, Z4.07
Lead Center: JPL
Participating Center(s): GRC, GSFC, MSFC

Subtopic Introduction:

This subtopic is focused specifically on additive manufacturing of electronics. While there is some overlap in the techniques, there are specific challenges in creating structures that utilize both conductive and insulative elements. This area has had activity for well over 10 years, but over the past 5 years, this area has grown significantly as a relevant technology that is approaching/in commercialization. NASA is looking for innovative approaches to address this complex issue related to additive manufacturing of electronics for use in space.



Use Case:
 Probing for Signs of Life on Saturn's Moon

- *Rover must navigate complex terrain*
- *Must survive deep cold temperatures*
- *Operate Autonomously (Machine Learning) and with Severe Volume Constraints*

Research

Cold Survivable Printed Electronics

Experimental Methods

Techniques

Modeling – Thermal Analysis – temperature dependent materials models and classical laminate theory

Fabrication – Inkjet Printing & Direct Ink Writing

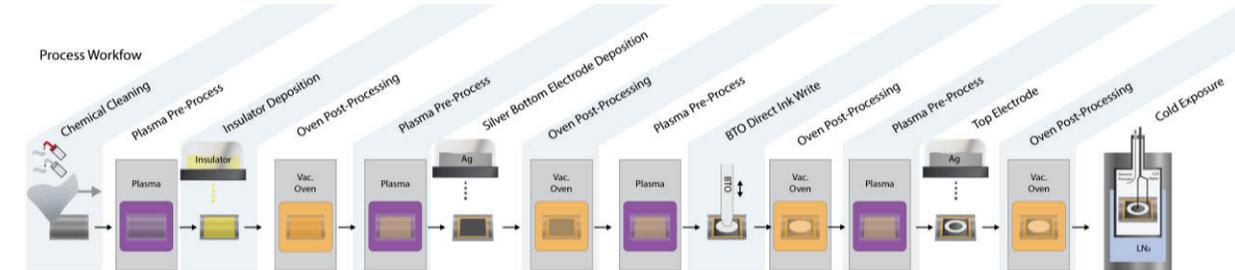
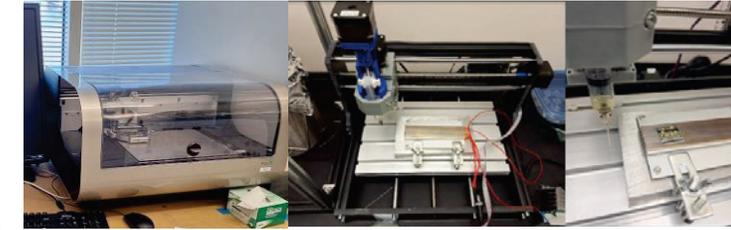
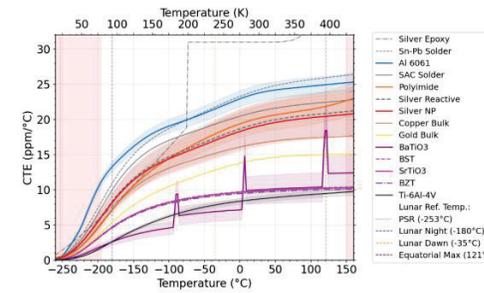
Materials – Alloy Substrates, Commercial and Custom-Formulated Inks (Conductive, Insulating, and Multifunctional)

Pre-Processing - Plasma

Post-Processing – Thermal Post-Processing

Testing – Cryogenic Exposure + Dielectric Evaluation, ASTM D3359 Adhesion Test, Rheosense MicroVisc Viscometer

Characterization – Scanning Electron Microscopy, Microelectronics Probe Station



Key Aims

- Establish a core materials set with properties tailored to lunar temperature profile
- Conduct evaluation of cold survivability of printed electronics
- Identify strategy for ensuring cold survivability of printed electronics

Results

Materials Selection and Analysis

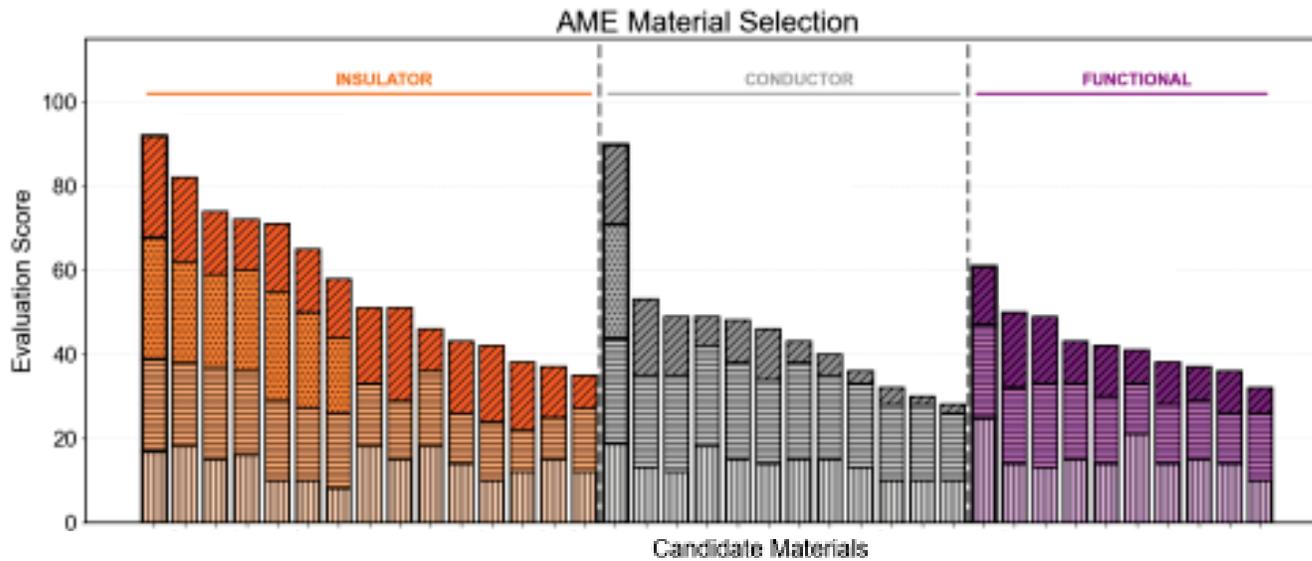
Formulation of a Printable Insulator Material

Processing Optimization

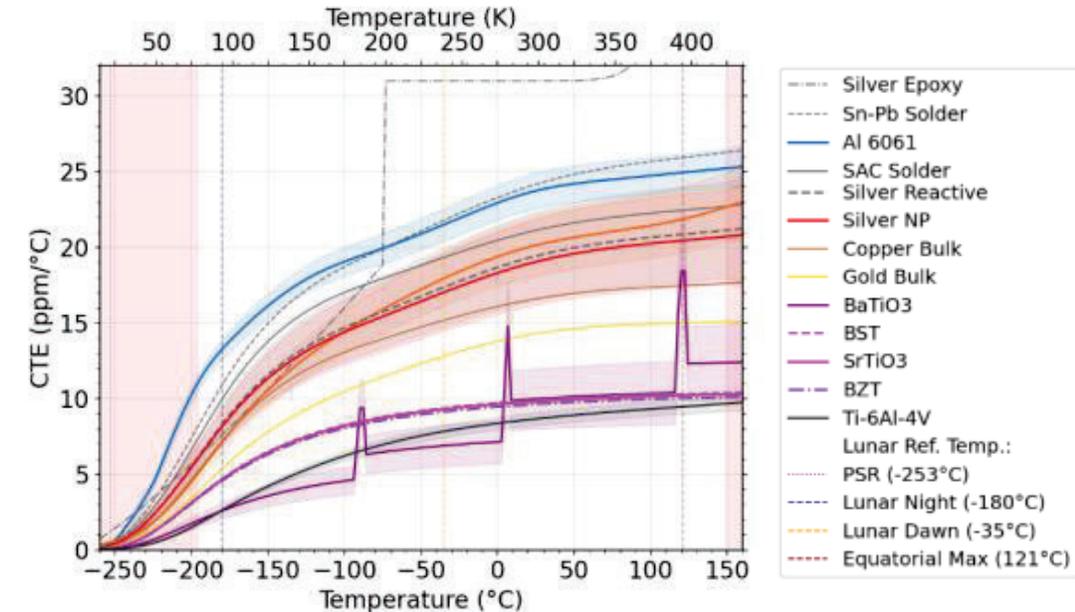
Cold Evaluation of Printed Materials Survival

Direct Ink Writing + Mechanical Adhesion Testing

Materials Selection and Analysis

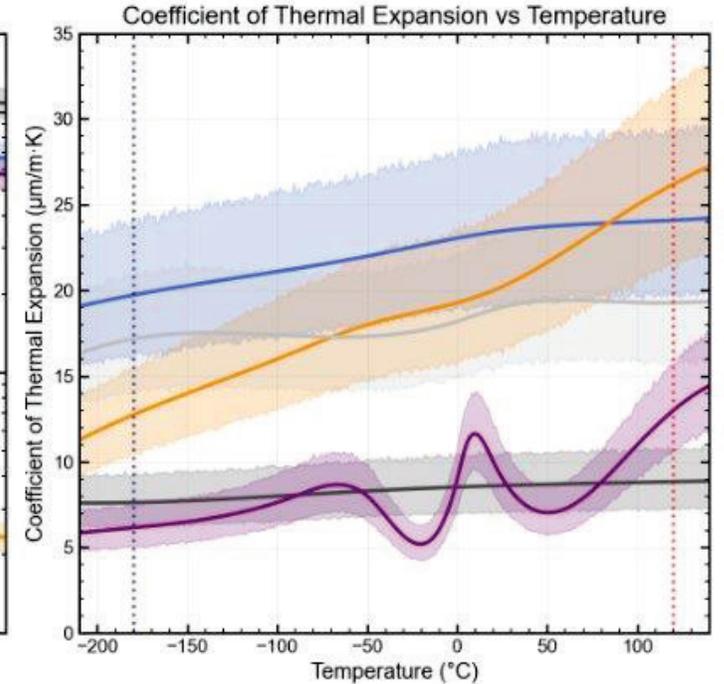
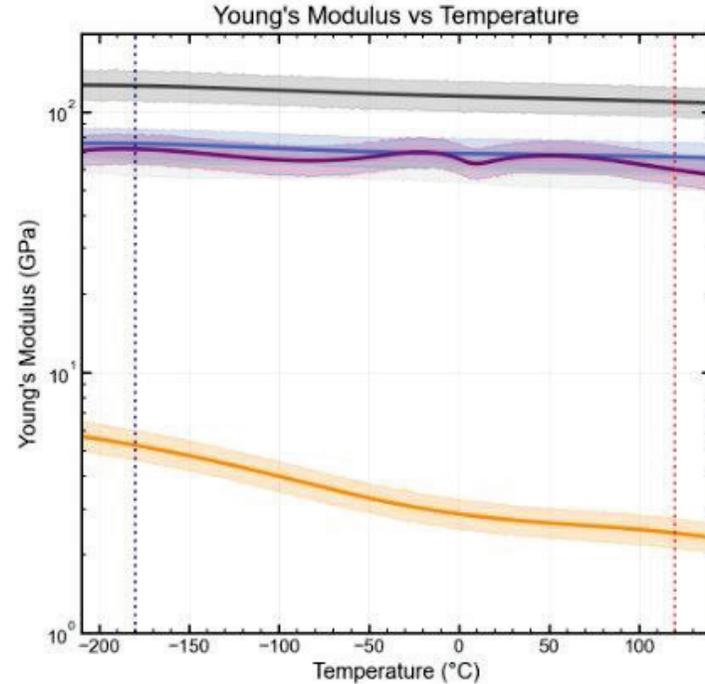
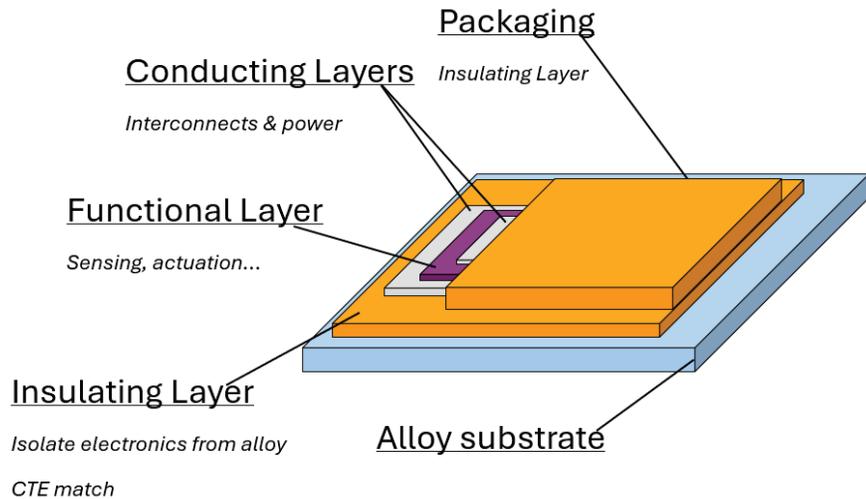


AME Materials selection approach: evaluation of a prospective materials set based on available data from NASA, literature, and materials databased.



Temperature dependent coefficient of thermal expansion for subset of candidate materials.

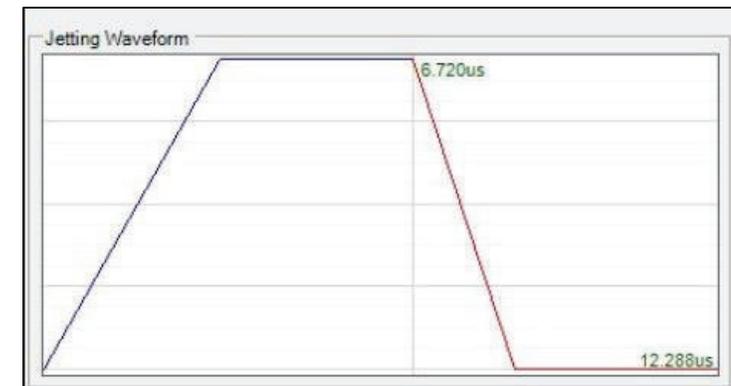
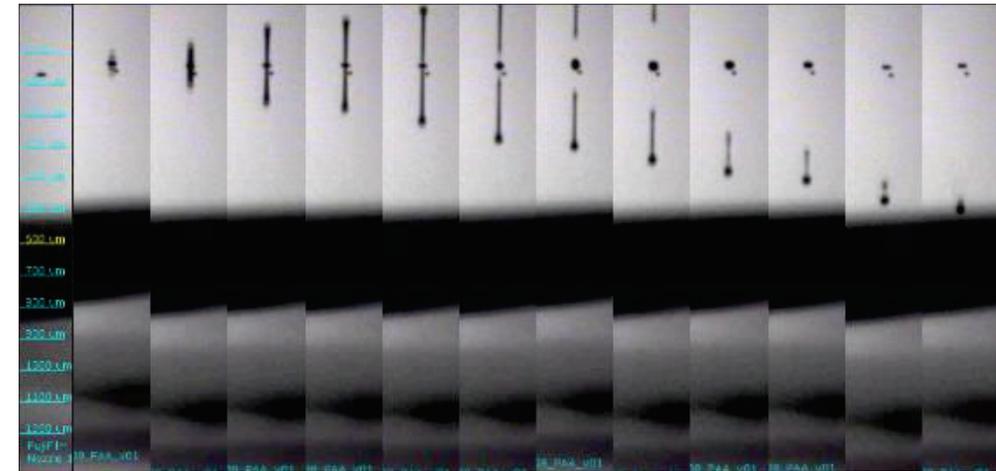
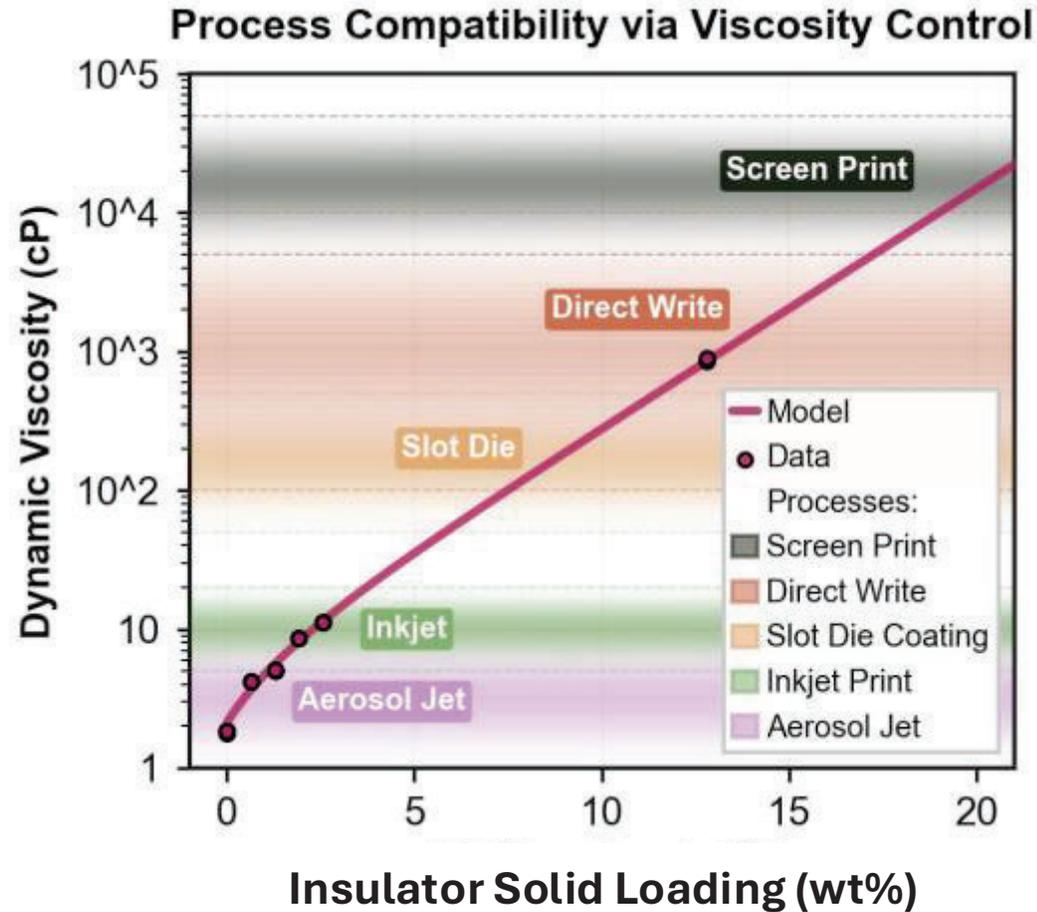
Materials Selection and Analysis



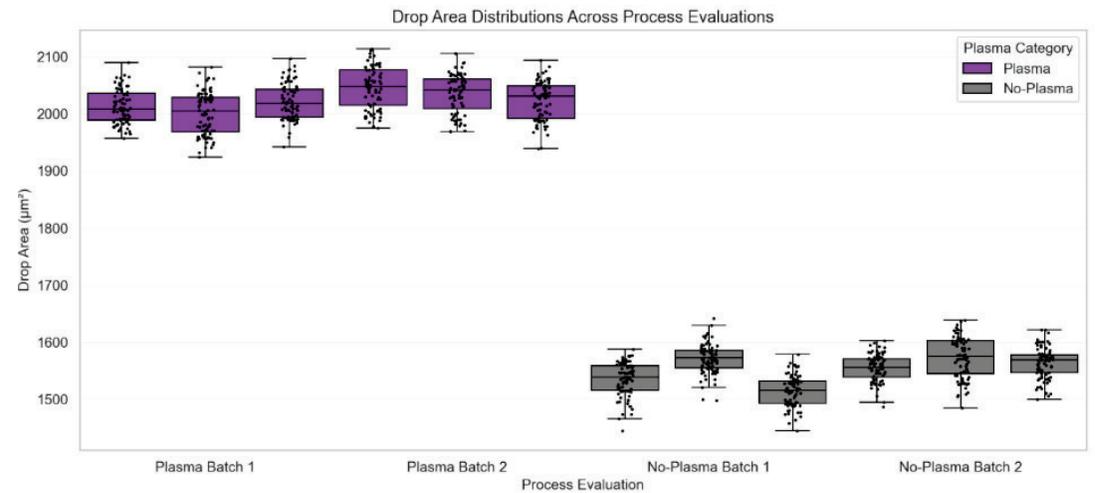
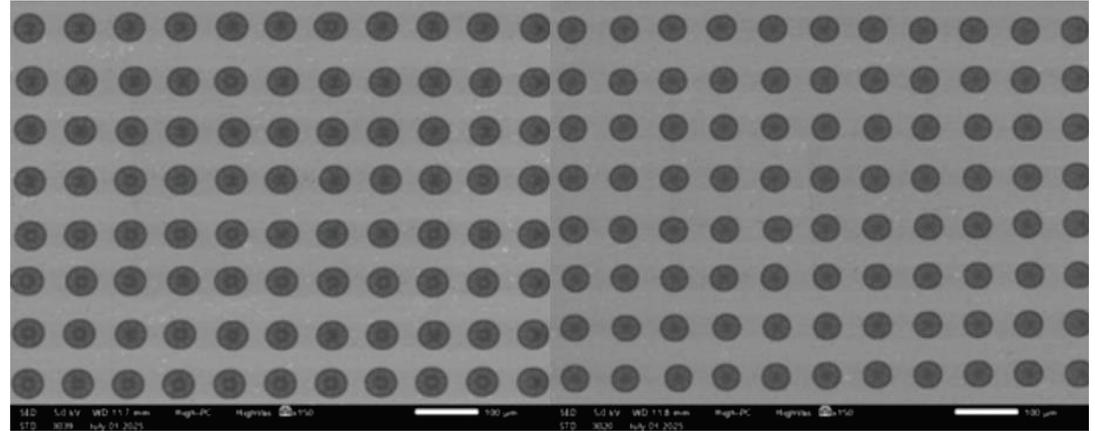
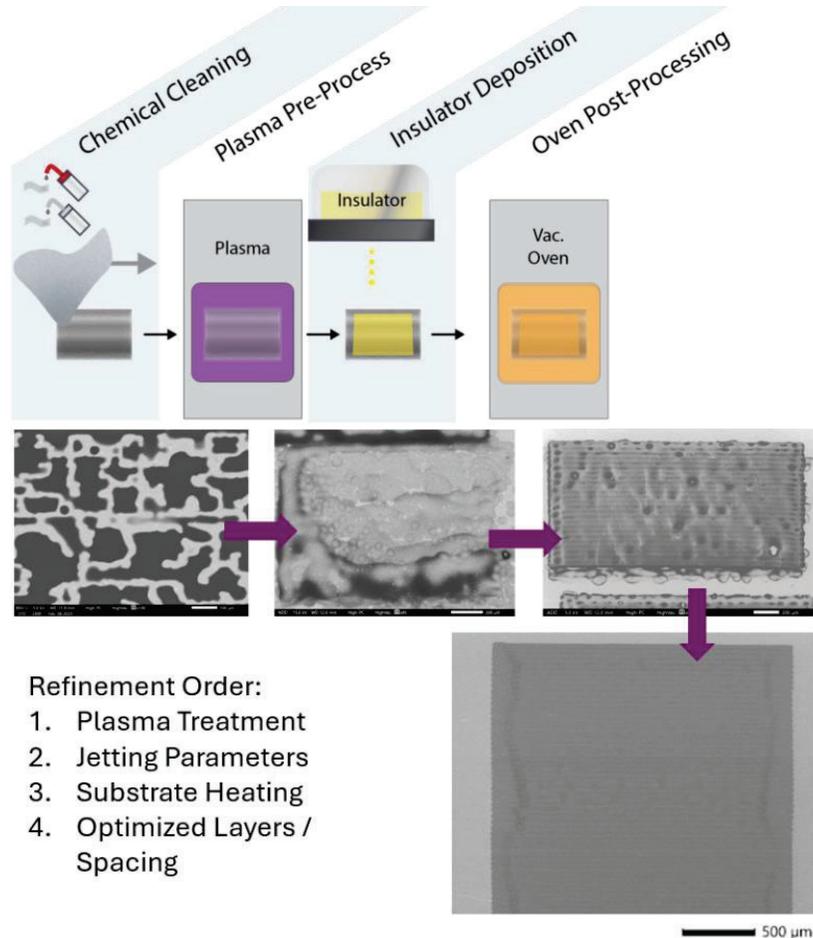
Thermal Analysis by Temperature
Dependent Materials Models, Monte Carlo
Method, and Classical Laminate Theory

Thermal Analysis by Temperature Dependent Materials Models, Monte
Carlo Method, and Classical Laminate Theory

Formulation of a Printable Insulator Material

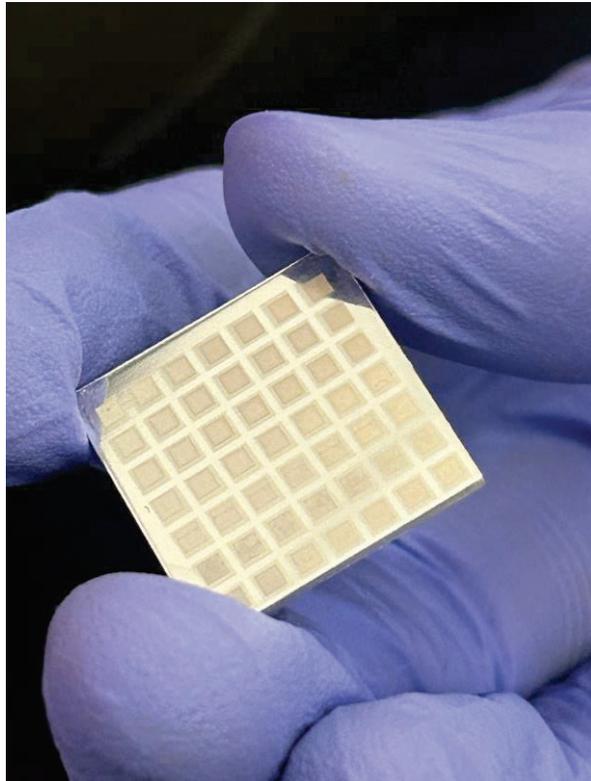


Processing Refinement



Cold Evaluation of Printed Material Survival

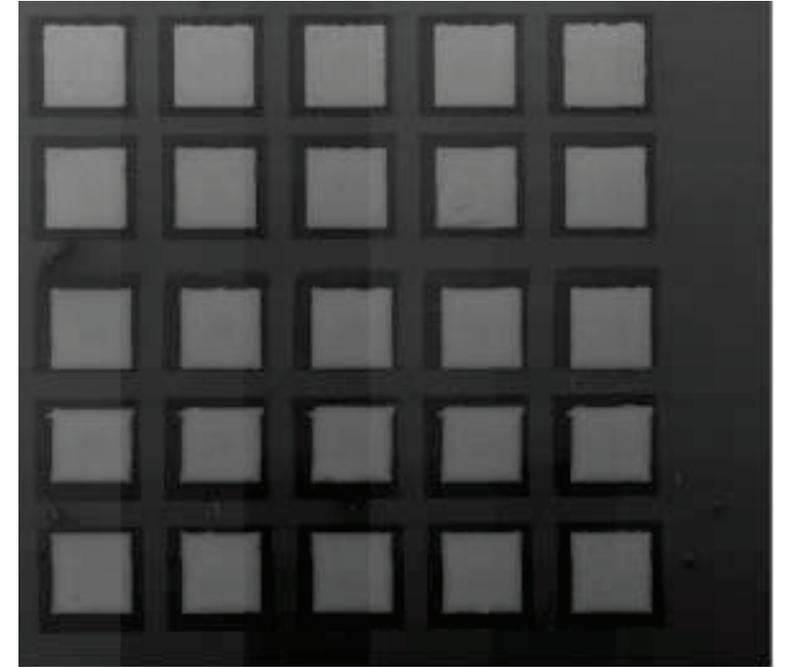
Secondary scanning electron microscope images



20mm x 20mm Al 6061 alloy card with printed insulator and silver films

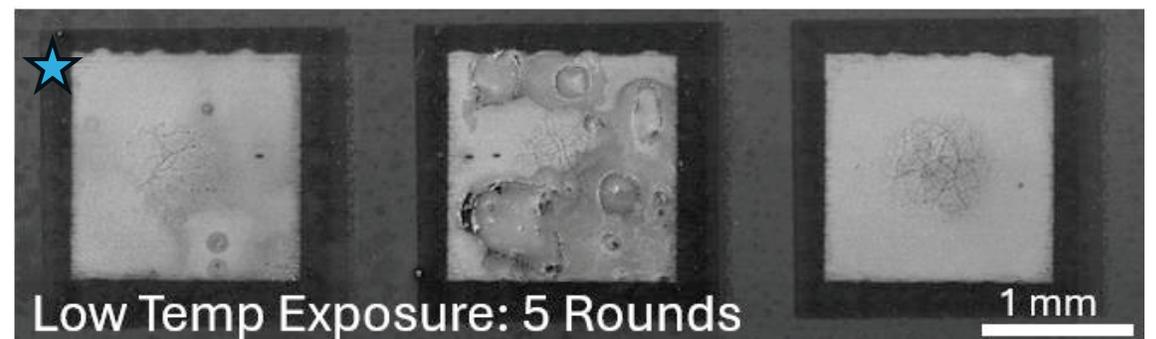
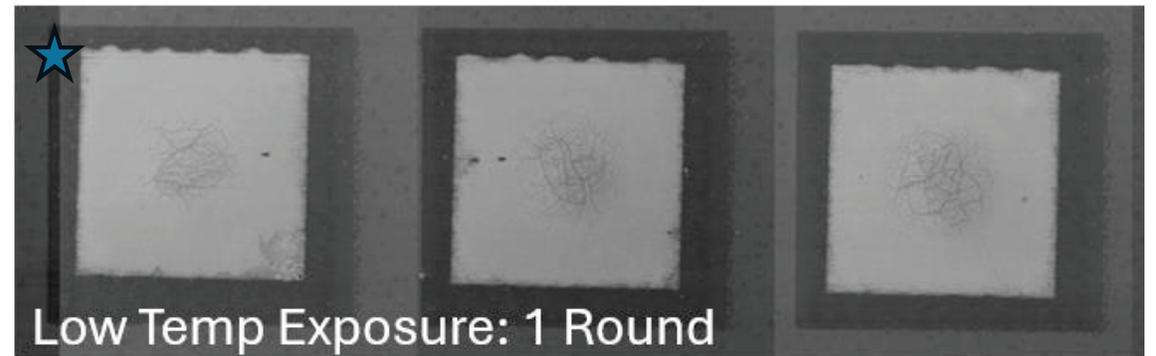
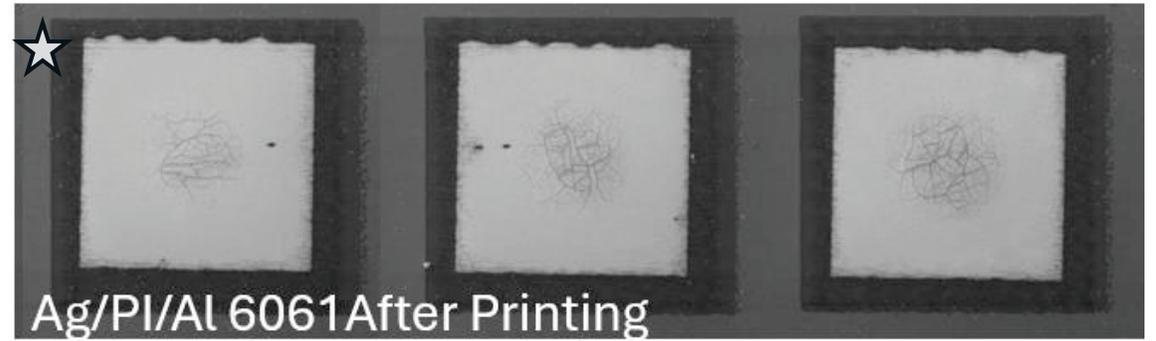
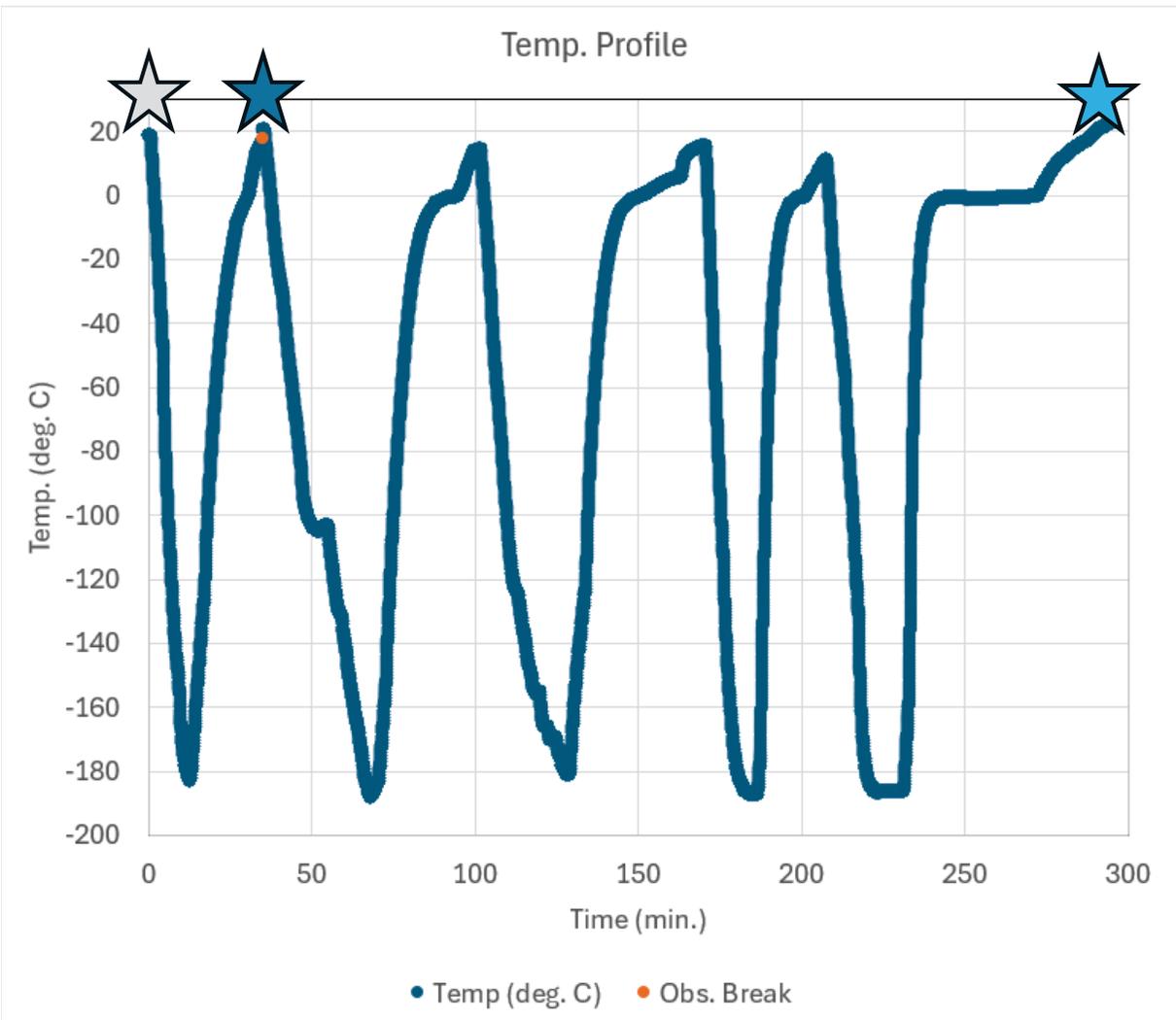


Printed Insulator

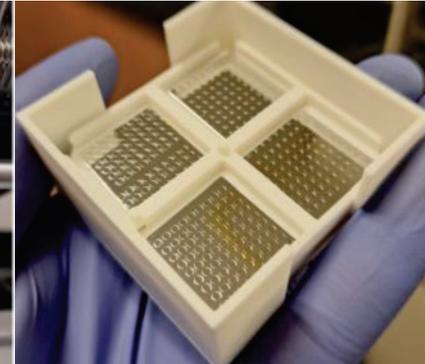
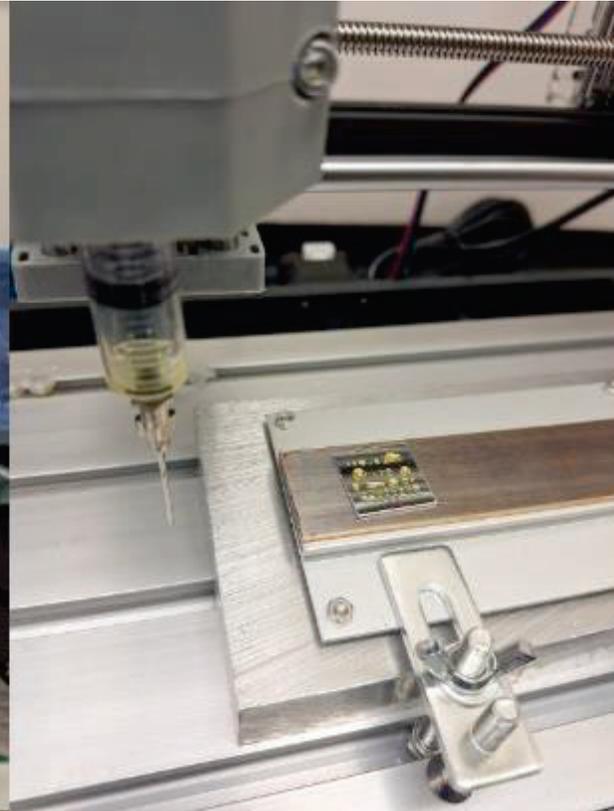
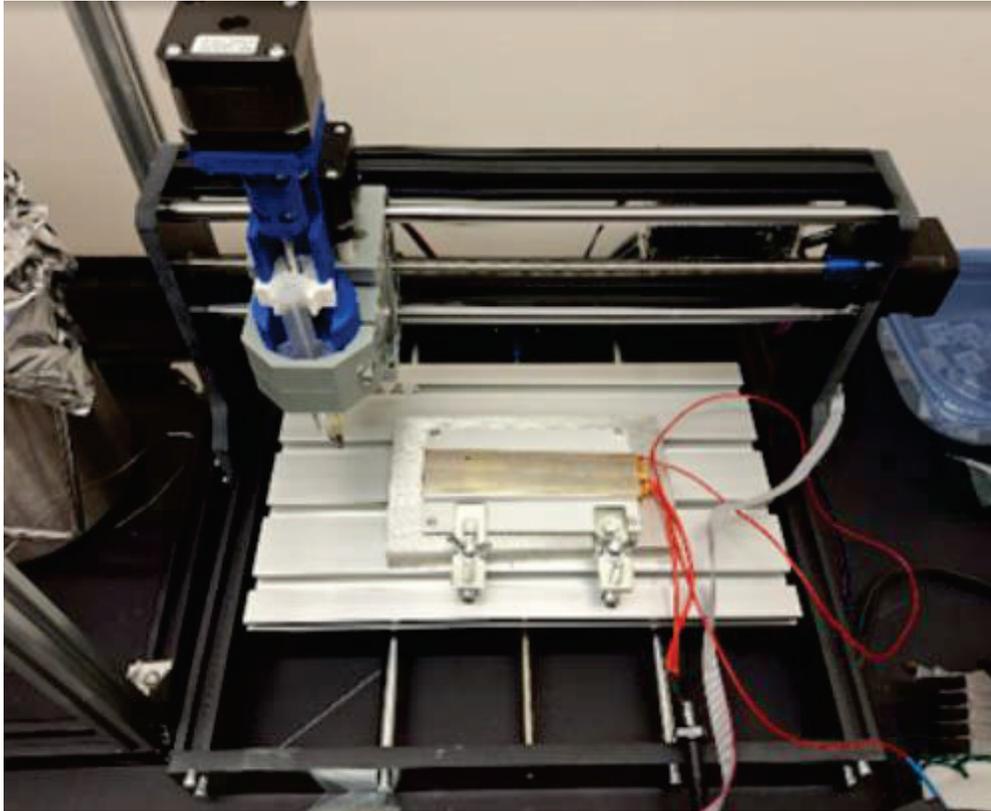


Printed Silver
(Novacentrix JS102A)

Cold Evaluation of Printed Material Survival



Direct Ink Writing + Mechanical Adhesion Testing



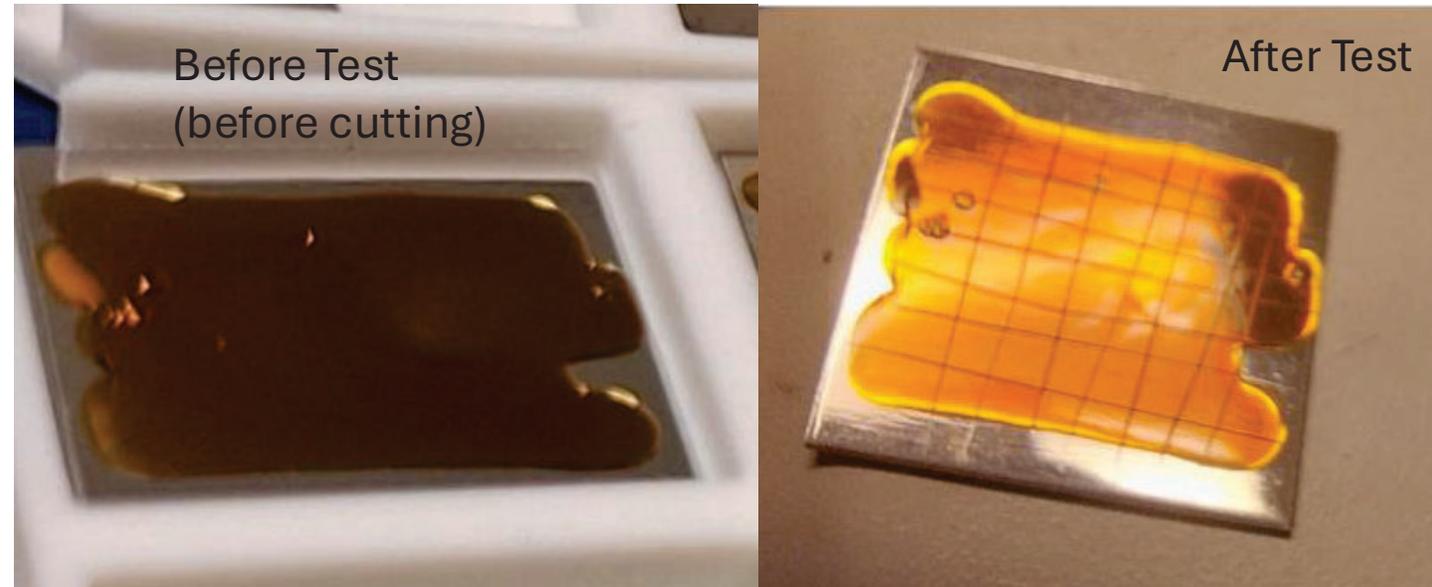
Direct Ink Writing + Mechanical Adhesion Testing

Example Appearance		Description	Classification	
Minimum Removal	Maximum Removal		ISO/JIS	ASTM
		The edges of the cuts are completely smooth; none of the squares of the lattice is detached.	0	5B
		Detachment of flakes of the coating at the intersections of the cuts. A cross cut area not greater than 5% is affected.	1	4B
		The coating has flaked along the edges and/or at the intersections of the cuts. A cross cut area greater than 5%, but not greater than 15% is affected.	2	3B
		The coating has flaked along the edges of the cuts partly or wholly in large ribbons, and/or it has flaked partly or wholly on different parts of the squares. A cross cut area greater than 15%, but not greater than 35%, is affected.	3	2B
		The coating has flaked along the edges of the cuts in large ribbons and/or some squares have detached partly or wholly. A cross cut area greater than 35%, but not greater than 65%, is affected.	4	1B
		Any degree of flaking that cannot be classified even by classification 4 or 1B	5	0B

ASTM D3359-17 Procedure:

- Preparation: Ensure the surface is clean and dry.
- Make a grid of 6 or 11 cuts, 1-2 2mm apart, using a cross-hatch tool.
- Tape Application: Apply pressure-sensitive 3M tape firmly over the cuts.
- Removal: Remove the tape rapidly (within 90s) at a 180 degree angle.
- Rating: Inspect the, for example, cross-hatch pattern for detachment, rating on a scale of 0 (highest removal) to 5 (no removal)

Sample passed with a grade of 5B



Conclusions

Findings & Discussion

Key Findings

Designed a materials set with coefficient of thermal expansion tailored to minimize thermal stress.

Formulated a printable insulator with evidence of mechanical robustness across multi-cycle cold shock testing and ASTM D3359 adhesion testing

Demonstrated the effect of plasma treatment to improving film uniformity and statistical process repeatability

Implications & Open Questions

Interest in printing technology from the broader engineering community presents an opportunity to graphics industry companies and professionals

Demonstration of low-cost materials deposition with custom direct ink writing rig

Development toward structurally-integrated electronics for terrestrial applications:

- Avionics
- Arctic systems
- Low temperature electronics (e.g. quantum)

Challenges achieving critical insulation thickness with inkjet printing

Future Work & Opportunities

Future Work:

Fabrication of sensor demonstrator – Printed Radiation Detector, Pressure Sensor

Development of New Printing Techniques:

- Non-Planar Direct Ink Writing
- In situ processing

Working with Commercialization Partner on materials set as product

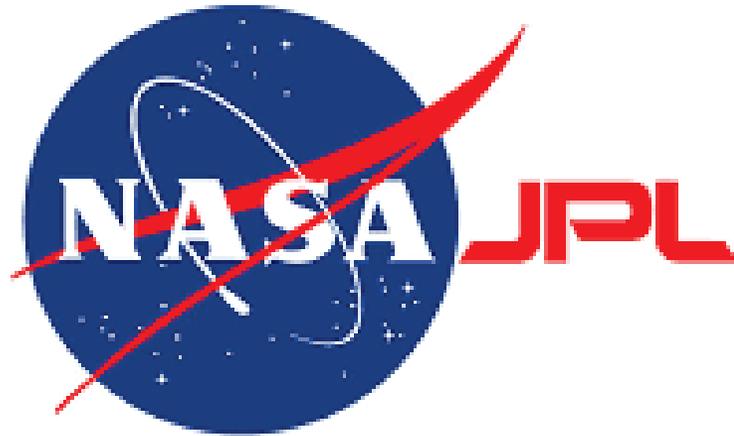
Opportunities:

Enova Concepts is actively seeking industrial and institutional partners for future collaboration toward advancing novel applications of printing technology

Contact Sean Garnsey:
sgarnsey@enovaconcepts.com

Acknowledgements

- NASA Small Business Technology Transfer Research Grant
 - Contract #: 80NSSC24PB230
 - NASA Jet Propulsion Laboratory, Technical Monitor Joseph Riendeau, Ph.D.
- UT San Antonio Multifunctional Electronic Materials & Devices Research Laboratory
 - University Principal Investigator: Amar S. Bhalla, Ph.D.
 - Collaborator: Ruyan Guo, Ph.D.



Thank you for your attention!

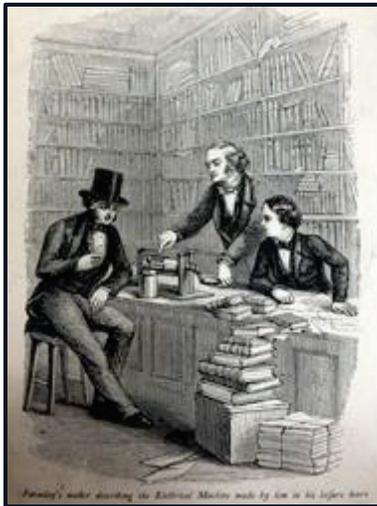
Q&A

Contact Sean Garnsey:
sgarnsey@enovaconcepts.com

A Shared History: Printing & Electronics

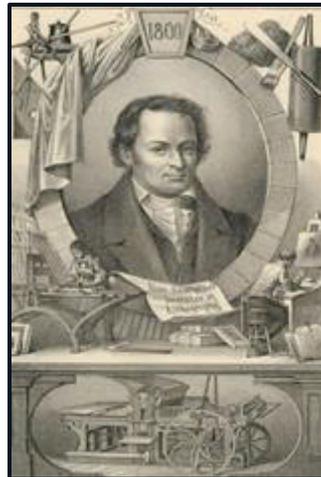
There are many intersections between the world of printing and electronics

Faraday, the
Bookbinder



*Hewitt Skin Deep Vol. 48 on
Michael Faraday*

Senefelder's
Lithography



*Library Company of
Philadelphia, Alois Senefelder*

Paul Eisler's
Printed Circuit
Board



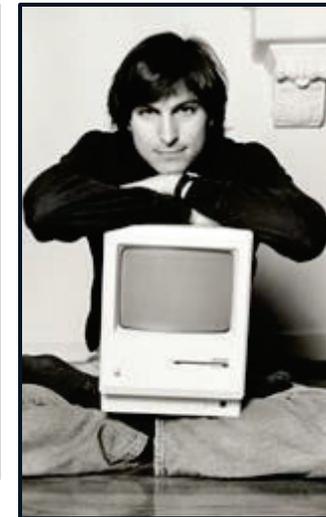
Paul Eisler, Wiki Commons

Rob Noyce,
Photolithographic
Process for Silicon
Chips



*MIT Technology Review; Chip ... Shape
the Future, 2023, Rob Noyce*

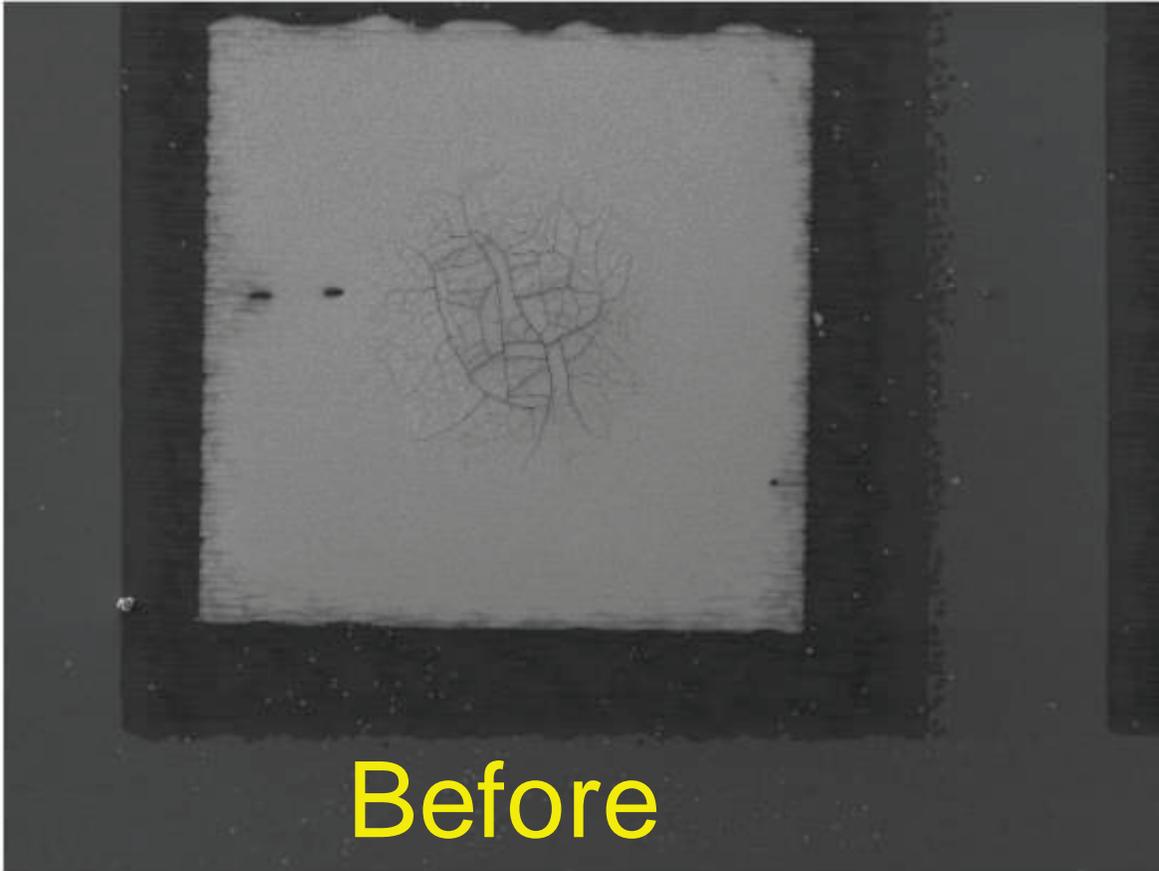
Steve Jobs'
Apple PC



*Holden Luntz Gallery, Steve
Jobs, Mac on Lap*

Printing parameter refinement efforts result in improved printed film quality

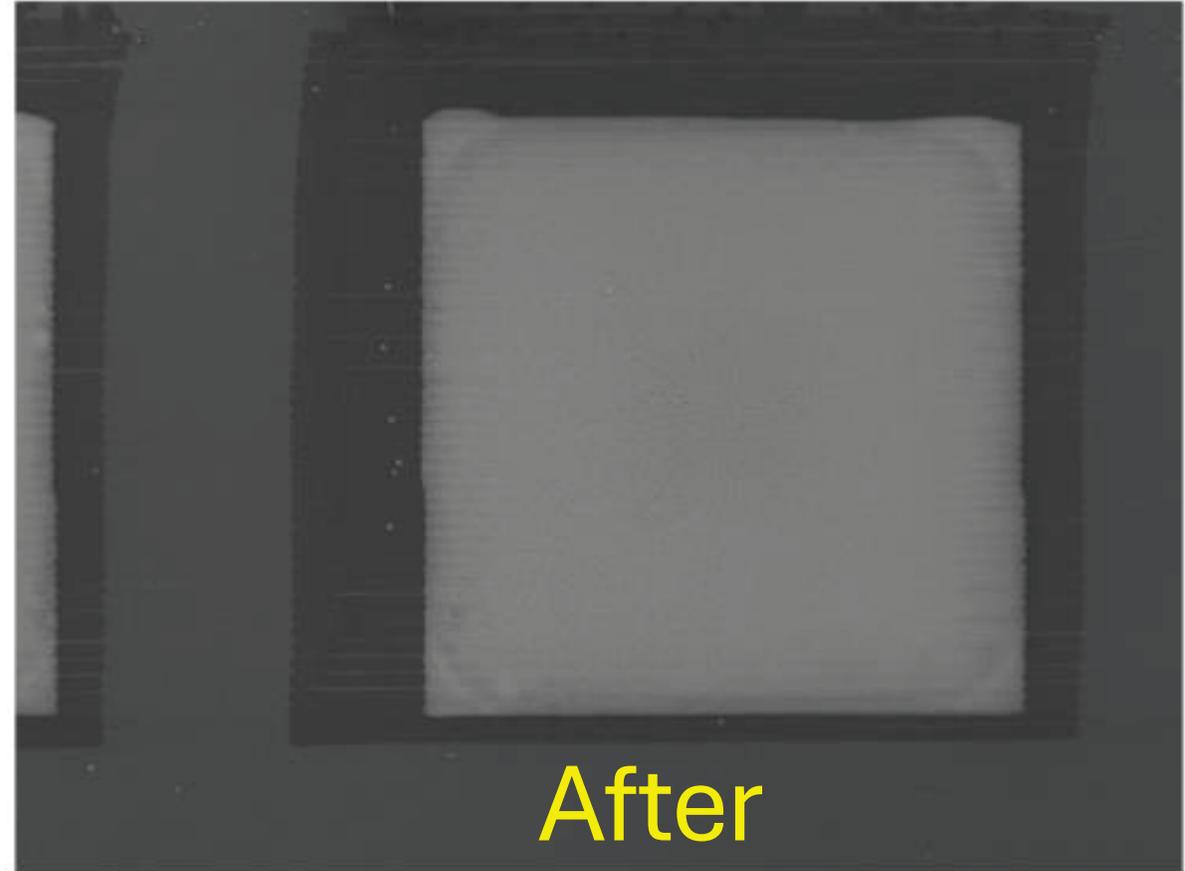
Grp_001_SED_X002_Y007



Before

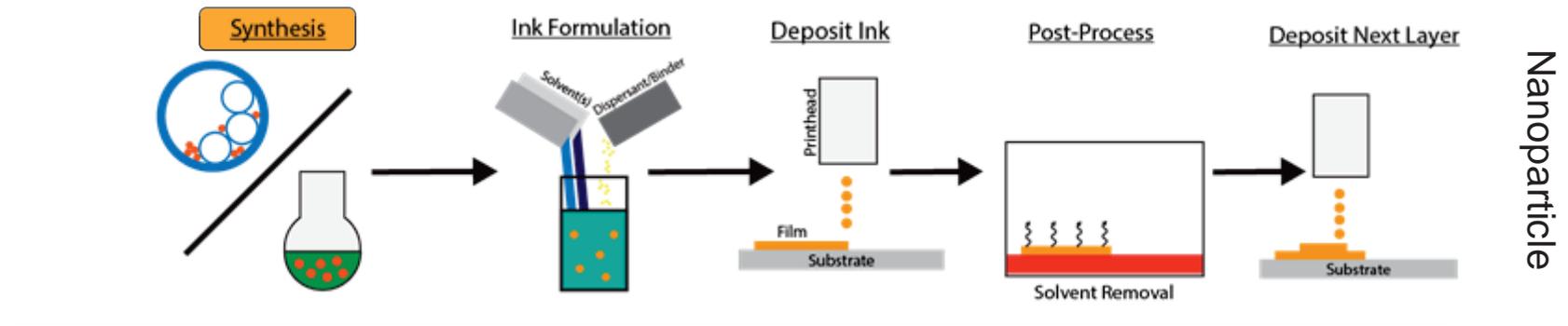
500 μm

Grp_001_SED_X002_Y007

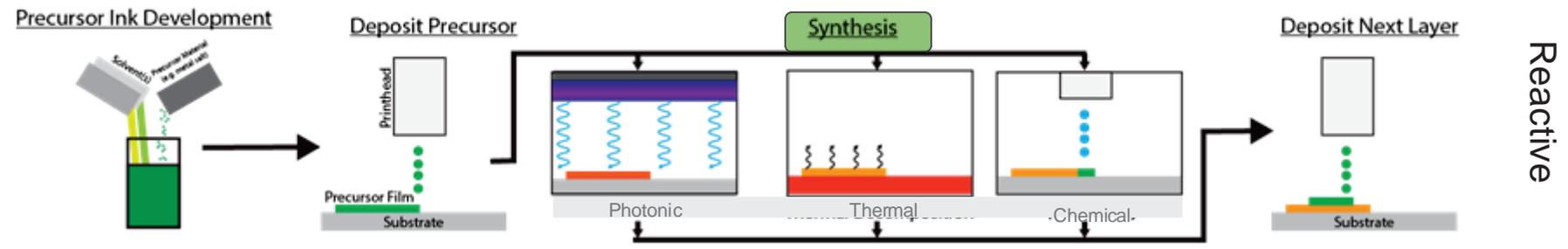


After

500 μm



Nanoparticle

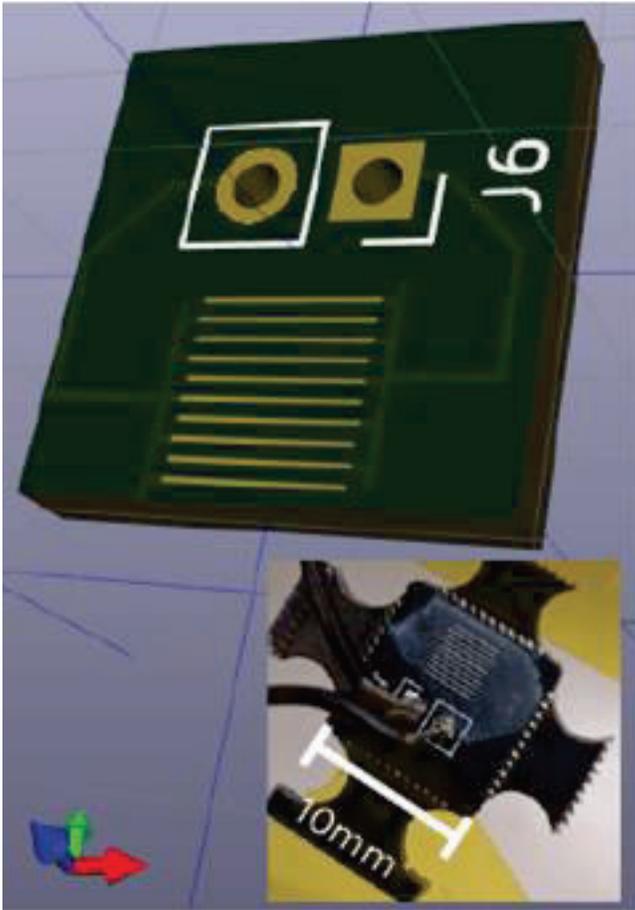


Reactive

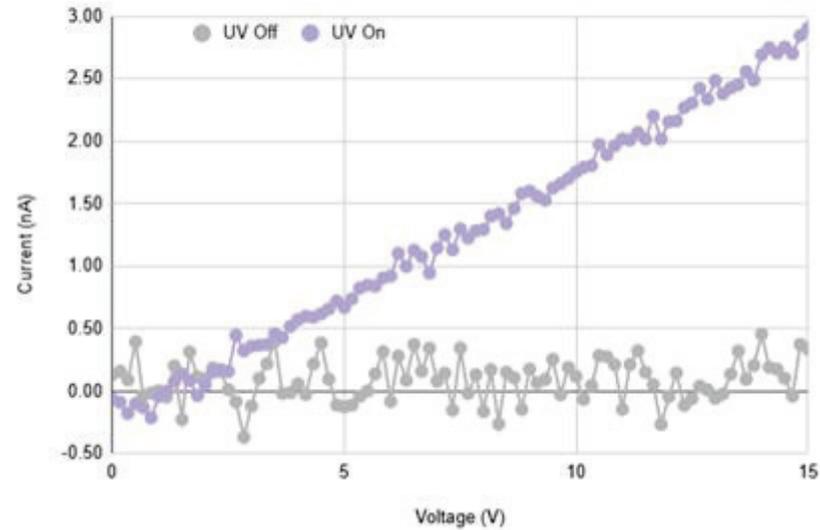
Mitigation strategy: RIPE CSD
 Tailor material properties at the substrate



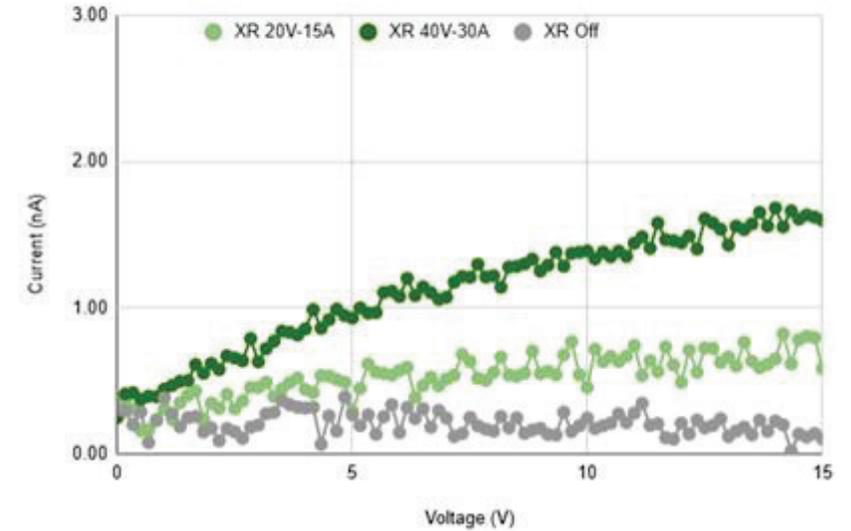
UV / X-Ray Photodetector



I-V Characteristics of Zinc Oxide NP: UV Irradiation
Processed with UV light on custom interdigitated PCB



I-V Characteristics of Zinc Oxide NP: X-Ray Irradiation
Processed with UV light on custom interdigitated PCB



Omnigure S2000
High Pressure 200 Watt
Mercury Vapor Short Arc
WL: 320-500 nm



Shimadzu XRD 6000
Cu Ka1 1.54 Ang source



UV / X-Ray Photodetector

