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Laser Processing of Polyimide and Molybdenum Substrates for Extreme Environment Electronics

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Advisor: Dr. Michael Hamilton

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Outline

1. Introduction
2. Fabrication
3. Cryogenic Evaluation
4. Conclusion and Future Work
5. References
6. Acknowledgement

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Introduction

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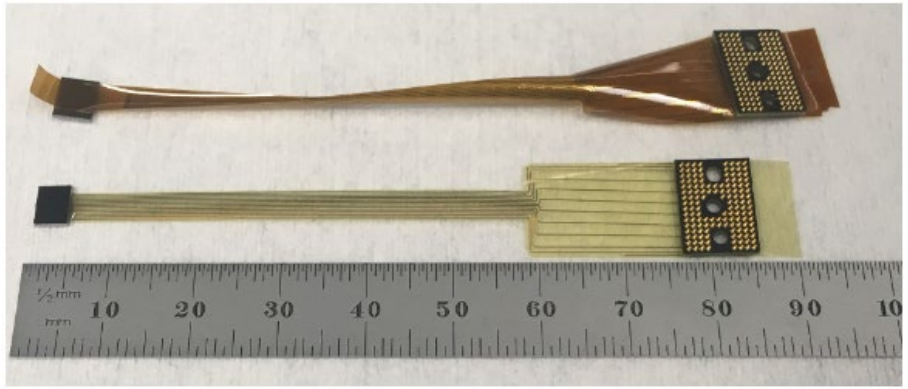
Introduction – Extreme Environment Packaging

- Advances in extreme environment packaging is essential for many applications.
  - Space technology.
  - Cryogenic/quantum.
  - Automotive.
- This work explores a packaging approach for cryogenic temperatures, but may also be viable for various extreme environments.



Previously designed, fabricated, and tested flexible cryogenic interconnects [1].

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[1] Peek, Sherman, et al. Fabrication and Flip-Chip Assembly Processes For Cryogenic Applications Using Indium-Indium and SAC-Indium Bump Connections on Flexible Interconnects. (2021). 00182

Introduction – Molybdenum

- Robust material with comparable specs to Si.
- Mo compared to Si
  - Pros:
    - Higher tensile strength.
    - Comparable thermal conductivity.
  - Cons:
    - Electrically conductive.
      - Superconducting.
    - Slightly higher CTE.
    - More dense.

Material Property	Mo	Si
Density	10.22 g/cm^3	2.33 g/cm^3
Melting Point	2617°C	1415°C
Hardness	1.4 GPa	8.3 GPa
Young's Modulus	330 GPa	130 GPa
Thermal Conductivity	138 W/(mK)	150 W/(mK)
Coefficient of Thermal Expansion	5.4 ppm/K	2.6 ppm/K
Tensile Strength	324 MPa	165 MPa

Material properties of Mo and Si at room temperature [2-4].

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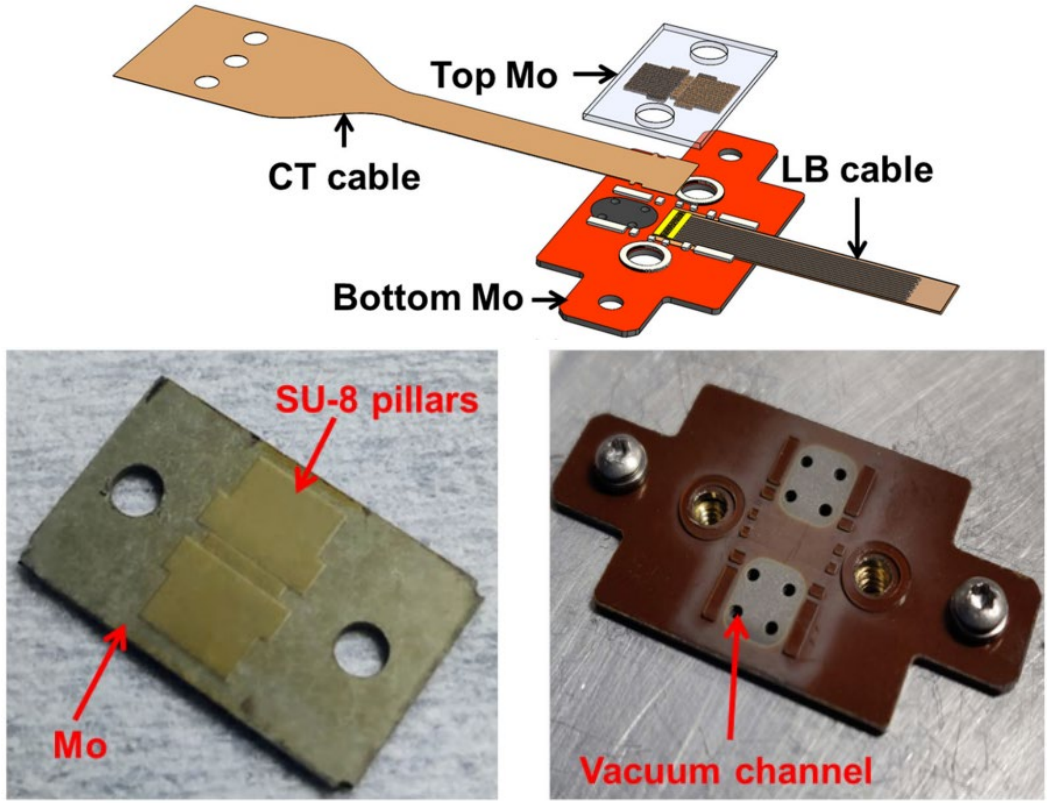
[2] Gökçe, H., Çiftçi, İ. and Demir, H. Cutting parameter optimization in shoulder milling of commercially pure molybdenum. J Braz. Soc. Mech. Sci. Eng. 40, 360 (2018). https://doi.org/10.1007/s40430-018-1280-8
[3] Martienssen, W, and Hans Warlimont. Springer Handbook of Condensed Matter and Materials Data. Heidelberg: Springer, 2005. Print.
[4] Venkatachalam, Sivaramakrishnan. Predictive modeling for ductile machining of brittle materials. Georgia Institute of Technology, 2007.

Introduction – Molybdenum in Cryogenic Applications

- Face-to-face connector scheme.
  - Mo substrates used as passive mechanical structures.
  - SU-8 and polyimide on Mo.
  - Mechanical drilling for holes.
    - Costly without coolants from tool wear.
    - Time-consuming.
  - Initial process development for laser cutting Mo performed for this application.



Cryogenic application using Mo as a cable-to-cable connector scheme [5].

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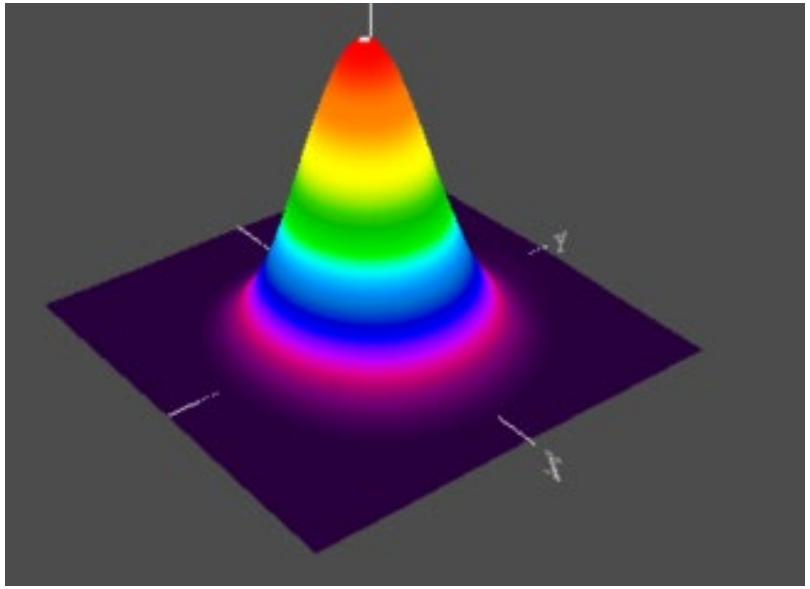
[5] Yelamanchili, B. et al., "Face-to-Face Cable Interconnect Scheme for Thin Flexible Superconducting Stripline Cables," in IEEE Transactions on Applied Superconductivity, vol. 32, no. 4, pp. 1-5, June 2022, Art no. 3500105, doi: 10.1109/TASC.2022.3149729

Introduction – Laser Processing

- Photoablation [6]:
  - Evaporation, sublimation, or plasma formation.
    - Dependent on laser flux.
  - Managing thermal damage and influences.
    - Shorter pulse duration = less thermal influence.
- Wavelength contributions:
  - Spot size
  - Energy/fluence
  - Absorption in material
    - Penetration depth



Beam profile prior to objective lens.

[6] Chichkov, B. et al. Femtosecond, picosecond and nanosecond laser ablation of solids. Applied Physics A: Materials Science & Processing, vol. 63, no. 2, pp. 109–115, Aug. (1996).

Fabrication

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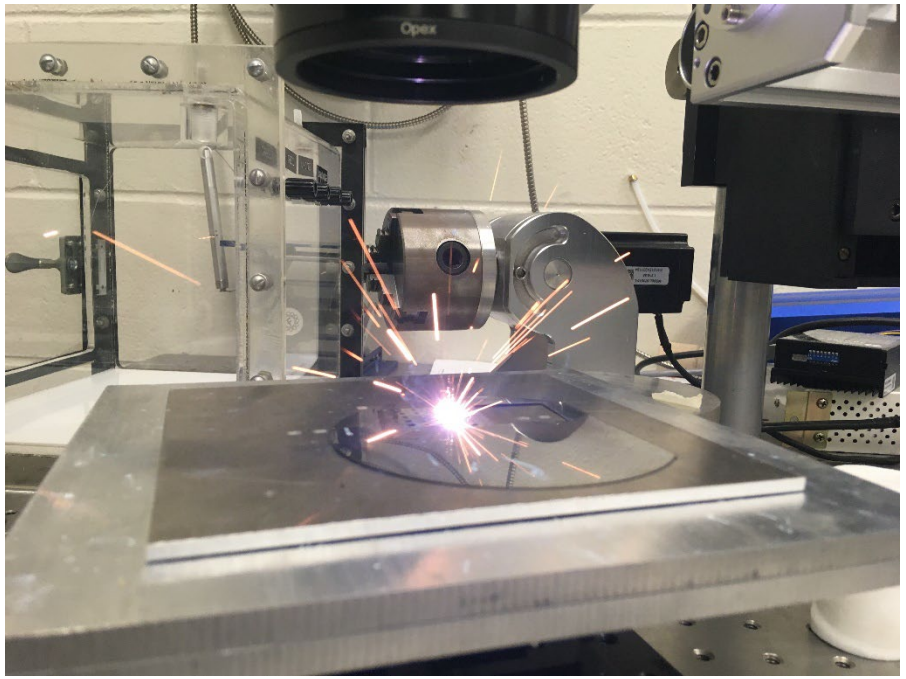
Fabrication – Overview

- Materials:
  - 300 µm Mo wafer
  - HD-4100 series polyimide
- Equipment:
  - 5 ns pulse fiber laser w/ galvoscanning motion.
    - Mo laser processing.
  - 420 fs laser w/ x, y, z translation stage.
    - Spectra-Physics® Spirit®
    - PI laser processing.
  - Abrasive blasting cabinet.
    - Silicon carbide media.



Laser environment for Mo processing.

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Fabrication Step 1 – Mo Laser Drilling

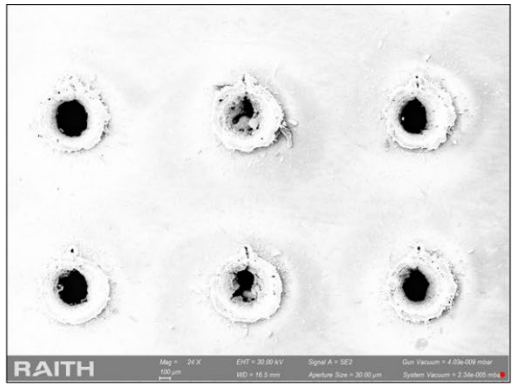
Mo

Parameter	A	B	C
Lens Objective	F-theta Lens	F-theta Lens	F-theta Lens
Power	130 W	130 W	130 W
Wavelength	1060 nm	1060 nm	1060 nm
Pulse Duration	5 ns	5 ns	5 ns
Repetition Rate	130 kHz	130 kHz	130 kHz
Repetitions	20	20	20
Scan Speed	600 mm/sec	600 mm/sec	1200 mm/sec
Line Fill Pitch	80 µm	40 µm	20 µm

Case A

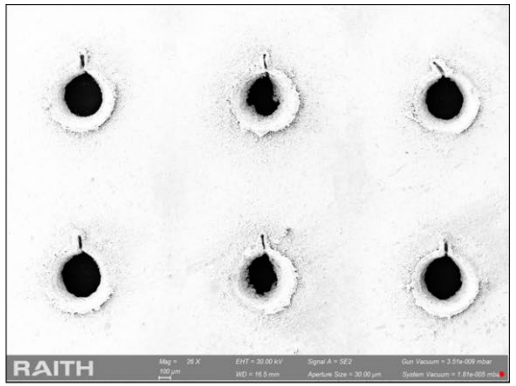
(a)

Case B

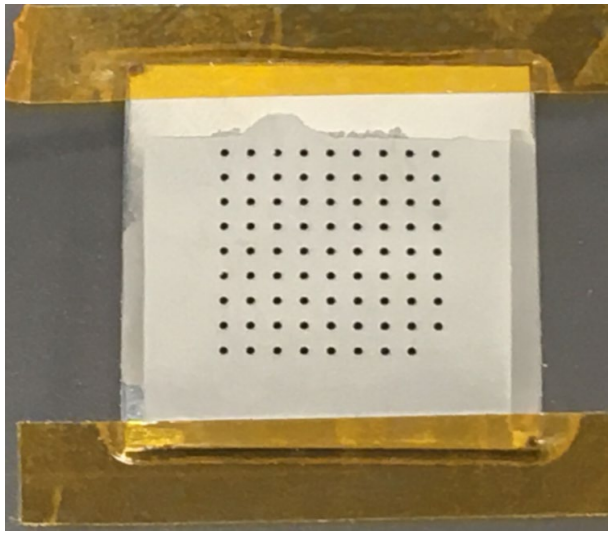


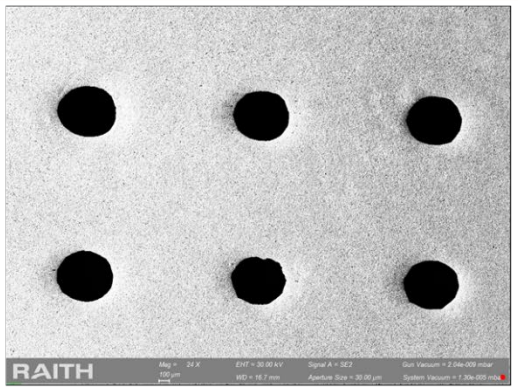
(b)

Case C

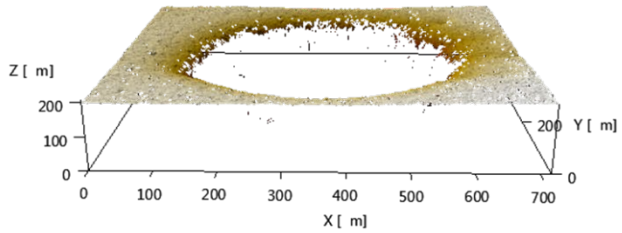


(c)





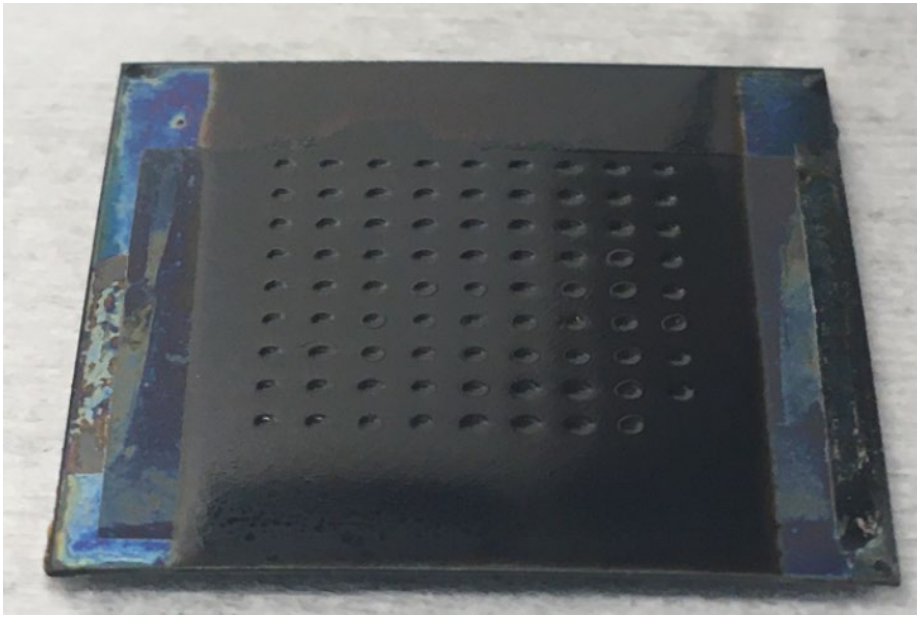
(d)



(e)

Fabrication Step 2 – Polyimide Processing

- Spin coat and cure polyimide on both sides of molybdenum.
  - Process per manufacturer data sheet.
- Vacuum used after spin coating to facilitate hole fills.
- Four separate curing cycles performed, two on each face of the Mo sample.



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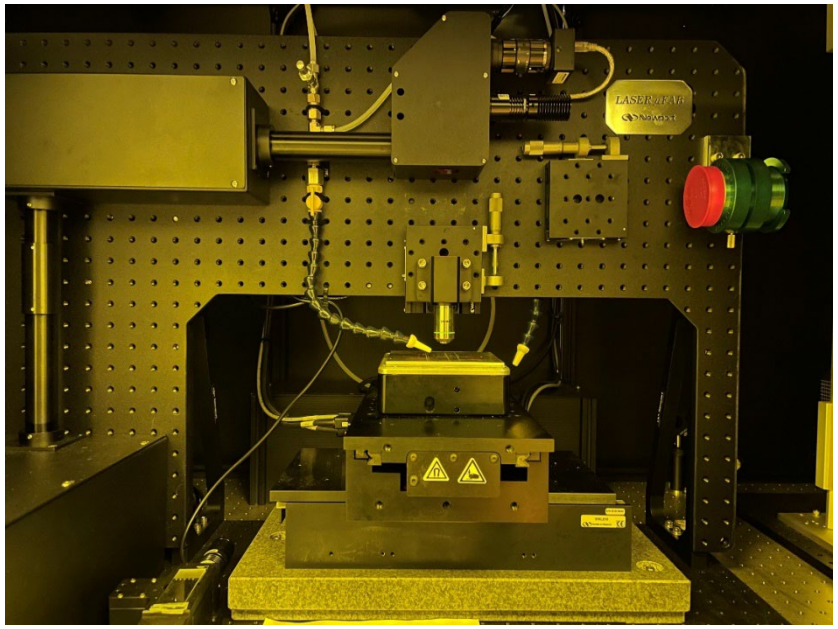
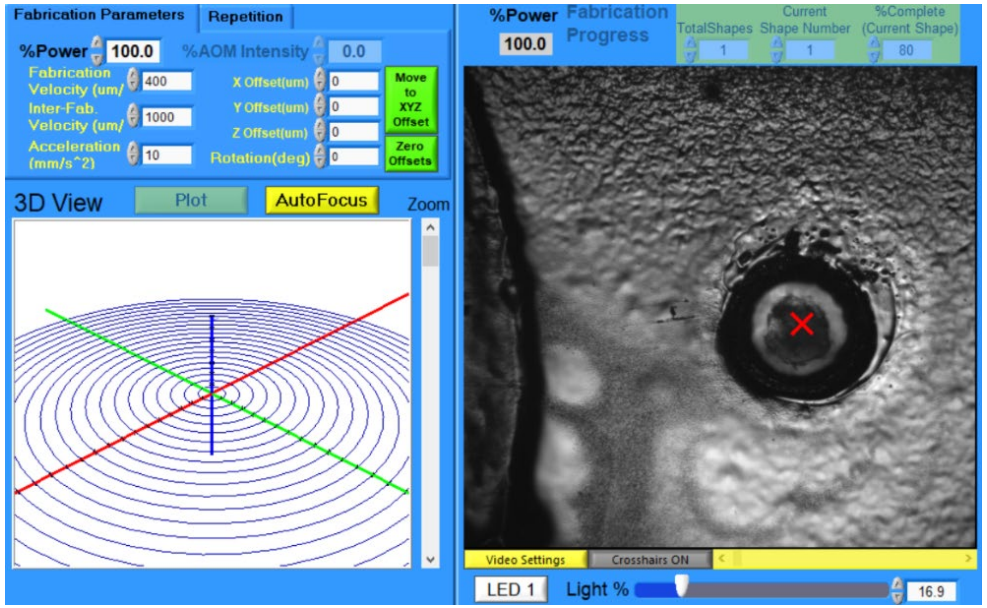
Fabrication Step 3 – Polyimide Processing

- Newport µFab system
  - X, Y, & Z translation stage
- Drills designed with concentric circles.
  - Can be reduced in future iterations.

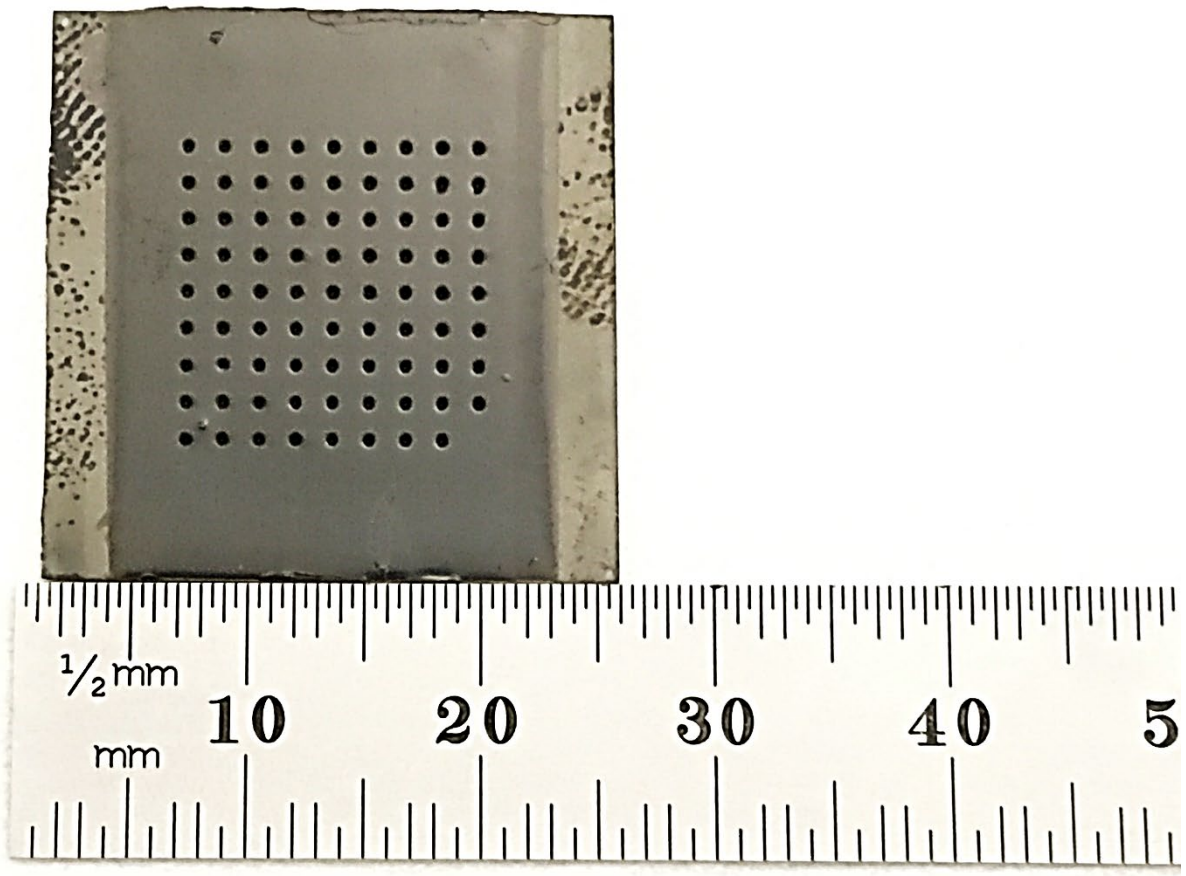


Parameter	Value
Lens Objective	4x/NA: 0.1
Max Power (Prior To Lens)	970 mW
Wavelength	520 nm
Pulse Duration	420 fs
Repetition Rate	200 kHz
Pulse Picker Divider	100
Repetitions Per Via	10
Scan Speed	0.4 mm/sec
Concentric Circle Spacing	10 µm



Fabrication – After Processing

Mo



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Cryogenic Evaluation

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Cryogenic Evaluation

- Cryogenic thermal cycling:
  - Direct liquid nitrogen submersion.
    - 77 K
  - 5x thermal cycles:
    - RT to 77 K return to RT
- Evaluation performed with confocal scanning acoustic microscopy before and after thermal cycling.

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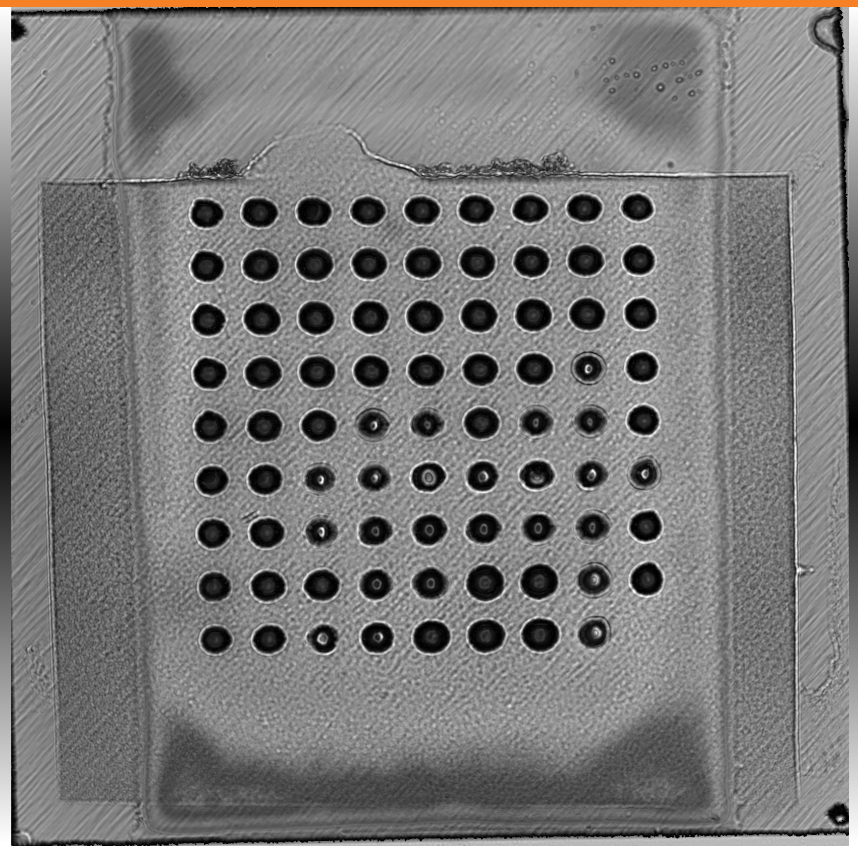
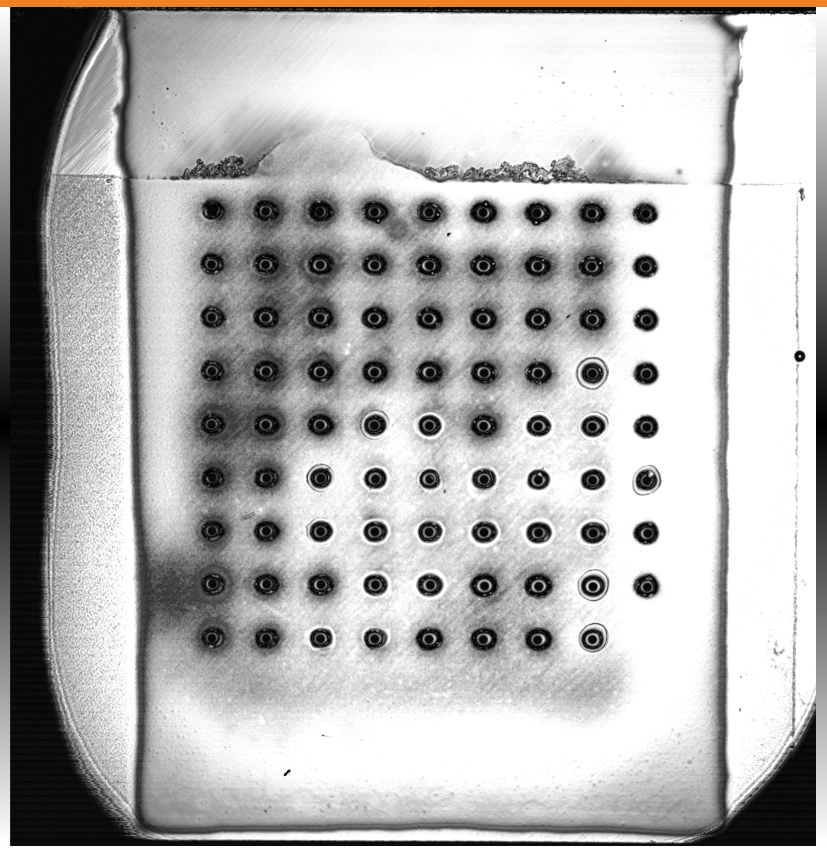
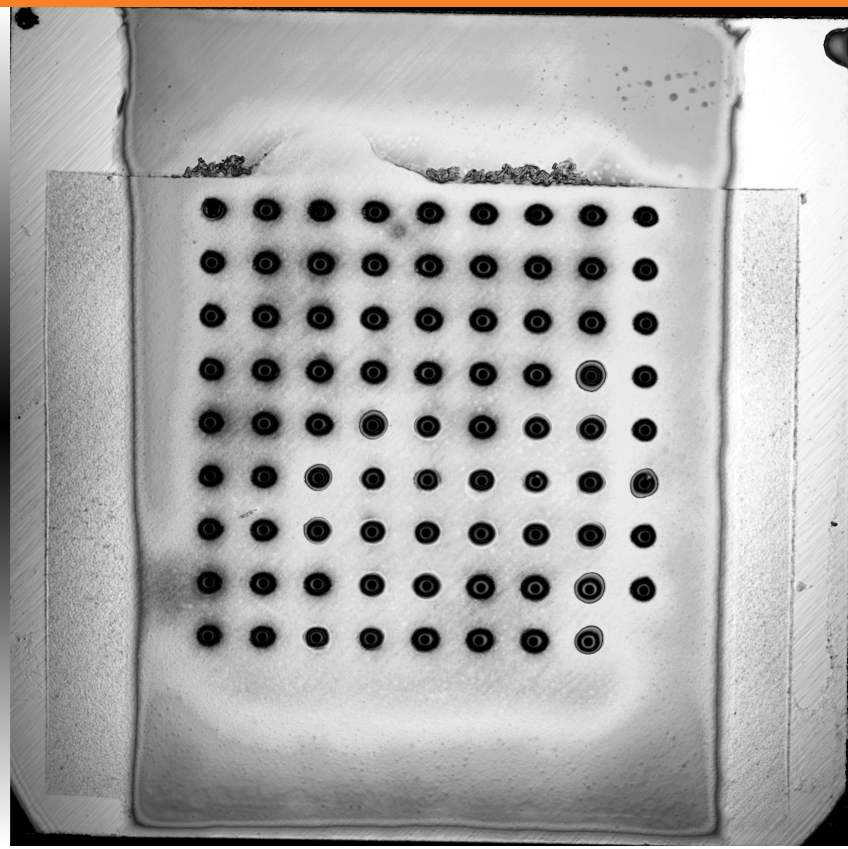
Cryogenic Evaluation – CSAM Imaging



Before Laser Drilling PI



After Laser Drilling PI



After Thermal Cycling

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Minimal differences between before and after thermal cycling.

Conclusion and Future Work

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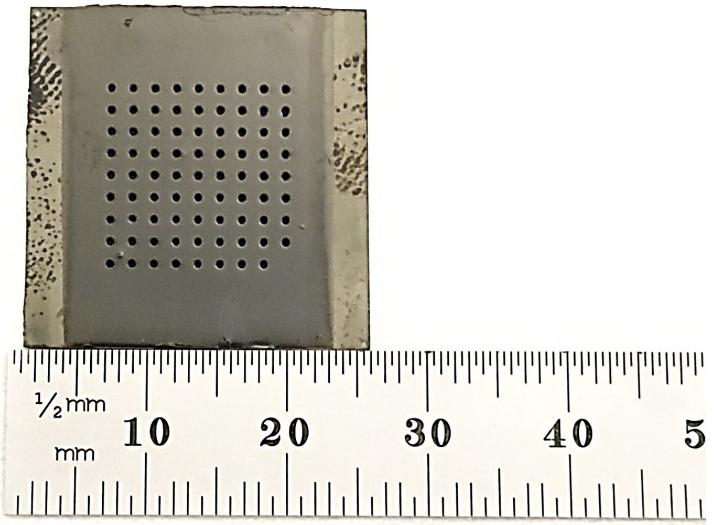
Conclusion and Future Work

- Work presented is encouraging for future cryogenic interposers with materials more robust under a tensile load than Si.
  - Molybdenum is used for a variety of applications, transfer of processes is viable.
- Next milestones:
  - Full electrical isolation.
    - Improve insulated coating of holes.
  - Minimize warping.
  - Electroplating and scaling.



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References

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[2] Gökçe, H., Çiftçi, İ. and Demir, H. Cutting parameter optimization in shoulder milling of commercially pure molybdenum. J Braz. Soc. Mech. Sci. Eng. 40, 360 (2018). https://doi.org/10.1007/s40430-018-1280-8

[3] Martienssen, W, and Hans Warlimont. Springer Handbook of Condensed Matter and Materials Data. Heidelberg: Springer. (2005). Print.

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Questions

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