GE Aerospace

High temperature capable multilevel die interconnect for 600°C operation.

Emad Andarawis, Mehrnegar Aghayan , Robert Gossman, Tammy Johnson, Shubhodeep Goswami, Collin Hitchcock.

iMAPS 2025 HiTEC Conference April 15-17, 2025

Distribution Statement A. Approved for public release: distribution is unlimited. (AFRL-2025-1877)

Presentation Outline

Background
Motivation
Evaluation approach – test structures
Test results
Comparison to model predictions
Current density testing
Summary, next steps and conclusion

Distribution Statement A. Approved for public release: distribution is unlimited. (AFRL-2025-1877)

Impact of High Temperature Electronics



DISTRIBUTED CONTROLS

- Smart Sensors & Actuators
- Power Conversion
- Engine Sensing & Controls



DOWNHOLE SENSING & ACTUATION

- High Temperature downhole tools
- High Temperature communication
- Geothermal monitoring
- 200°C - 300°C ambient temperature



SPACE

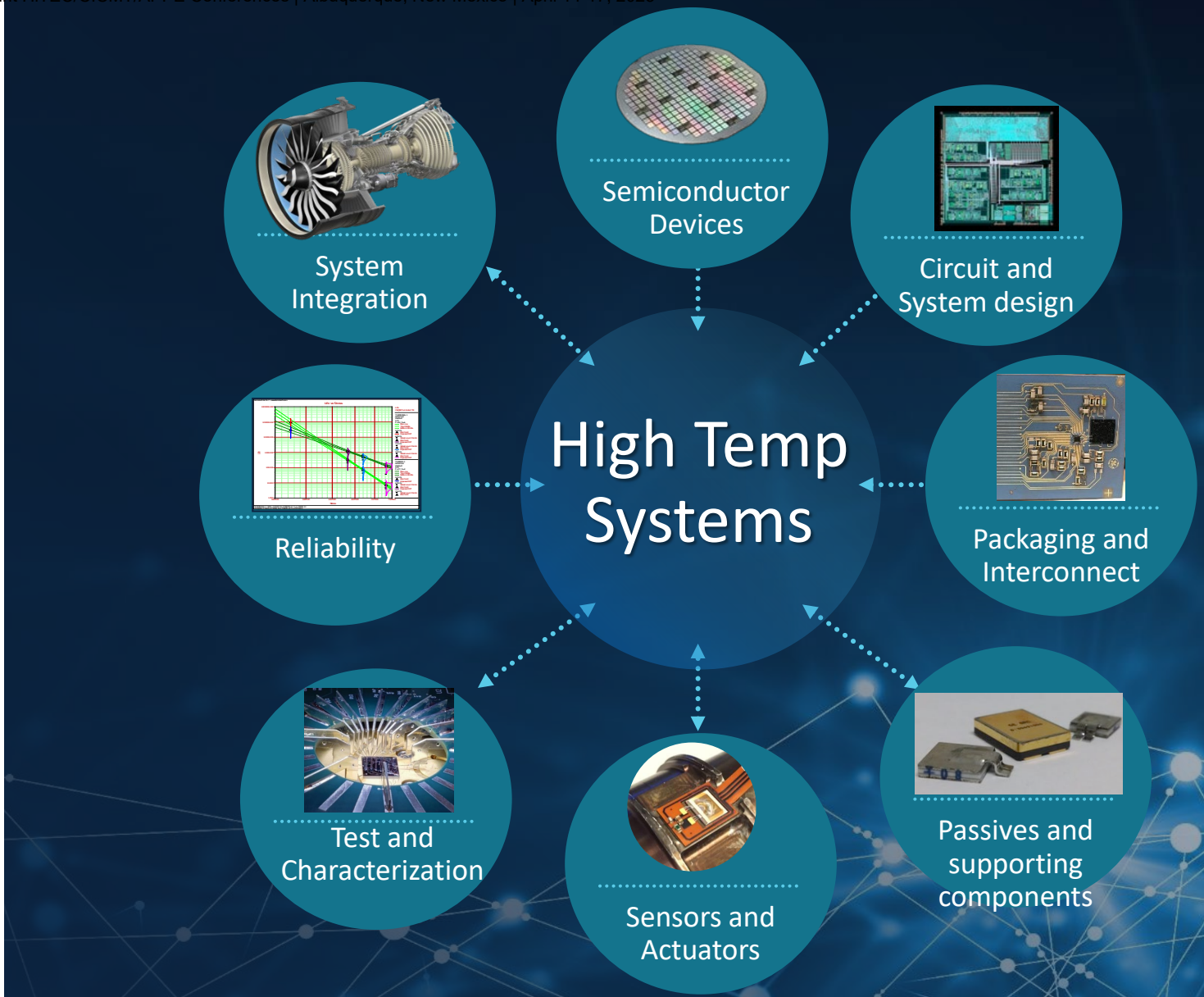
- Exploration Modules
- UV Imaging
- Planetary Science
- 500°C ambient (Venus surface temperature)

High temperature electronics needed to solve the world's toughest challenges

Distribution Statement A. Approved for public release: distribution is unlimited. (AFRL-2025-1877)

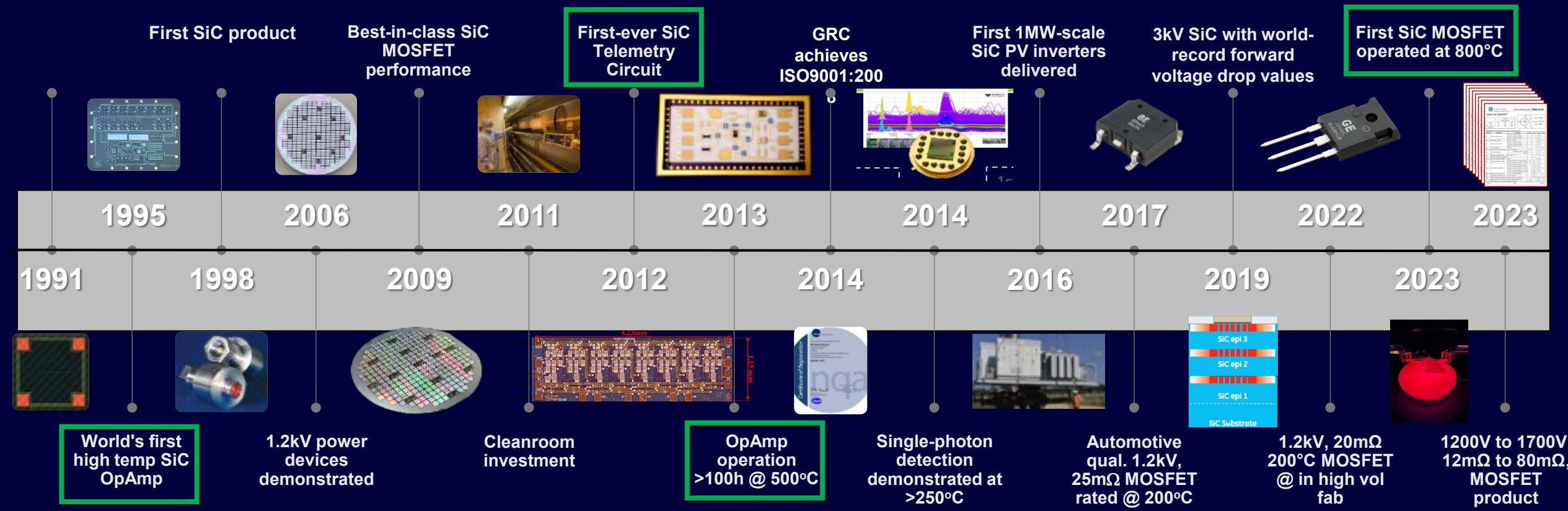
Enabling High Temperature Sensing and Actuation System

- Successful implementation of High Temperature electronics requires complex engineering across multiple disciplines
- Material interactions at temperature
- Understanding of component functionality and tradeoffs at temperature
- Development of test methods to replicate complex environments & understand failure modes
- Years of reliability testing at the component & sub assembly level



Distribution Statement A. Approved for public release: distribution is unlimited. (AFRL-2025-1877)

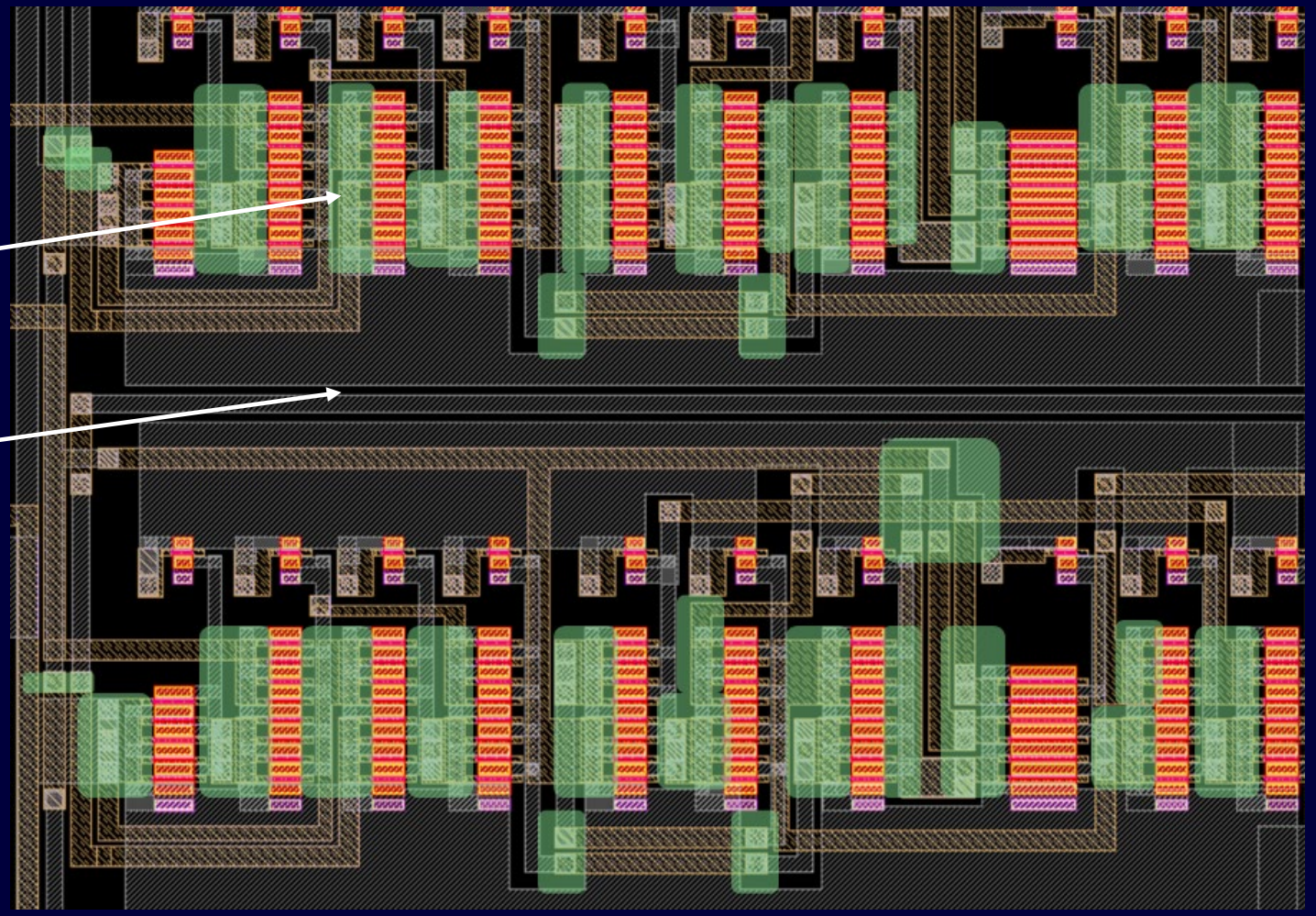
30+ year of SiC expertise - From inventions to fielded products



Proven track record in SiC power devices and high temperature integrated circuits

Distribution Statement A. Approved for public release: distribution is unlimited. (AFRL-2025-1877)

Motivation



Routing bottlenecks impact device/circuit density

Distribution Statement A. Approved for public release: distribution is unlimited. (AFRL-2025-1877)

Evaluation Approach

90-segments/88 vias per test structure alternating between two routing layer

Two string structures:

PolySi to Metal-1

Metal-1 to Metal-2

Scaling of trace and via widths:
5 scaling variants

(100% ==baseline)

[100%, 80%, 50%, 20%, 10%]

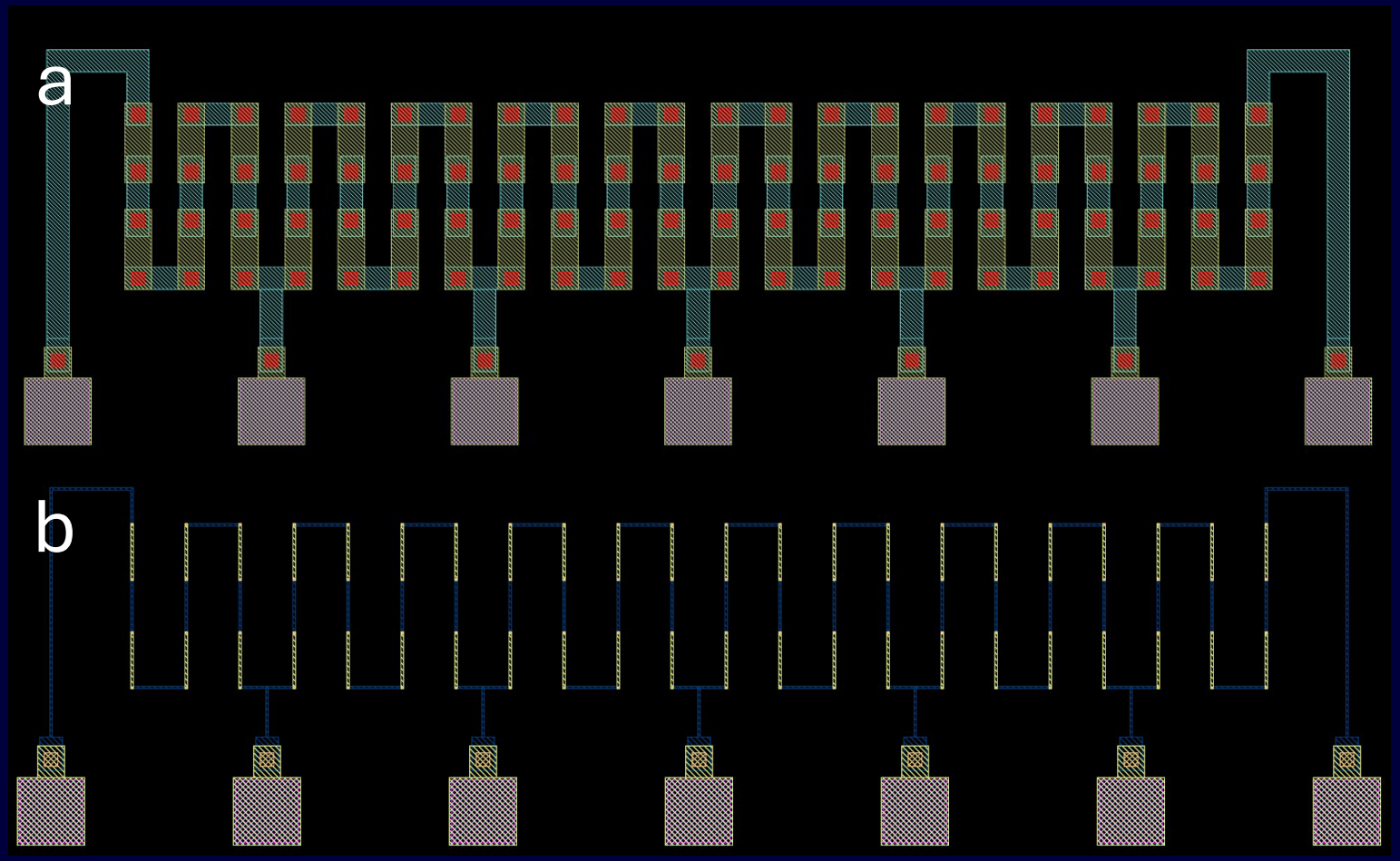
PolySi trace width 2.5μm-25μm

Metal trace width 3μm to 30μm (M1)

Metal trace width 6μm to 60μm (M2)

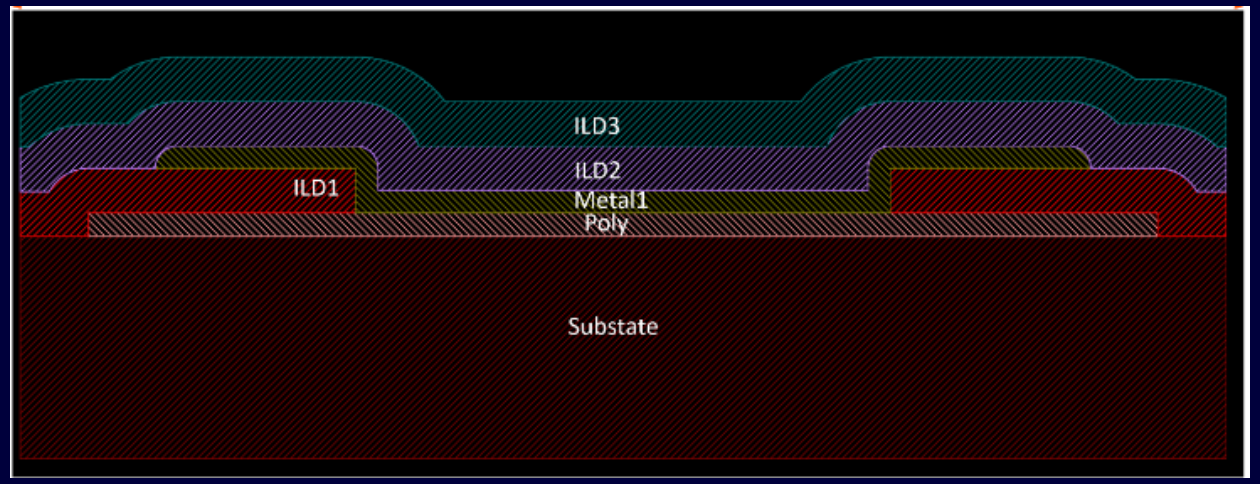
Vias sizes from 1.5μm-15μm (Via1)

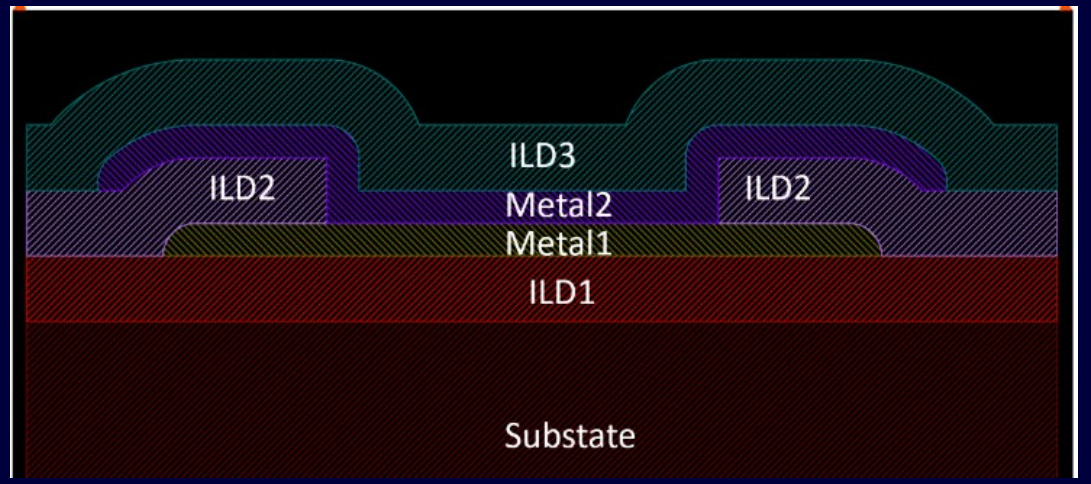
Vias sizes from 3μm-30μm (Via2)



Distribution Statement A. Approved for public release: distribution is unlimited. (AFRL-2025-1877)

Test structure cross-sectional views



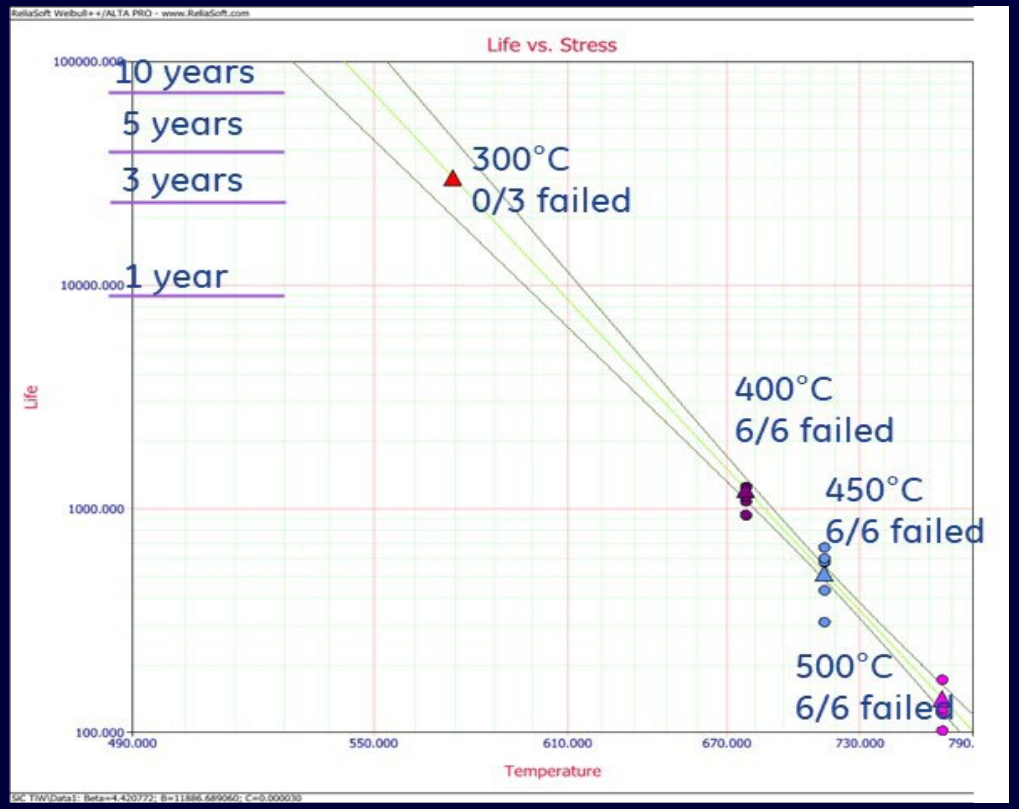


Schematic diagram of polysilicon to metal 1 and Metal1-to-Metal2 fabrication splits

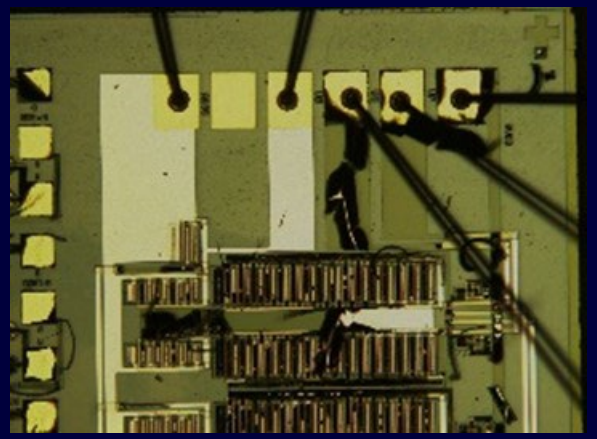
Polysilicon traces covered with metal to further reduce the resistance

Distribution Statement A. Approved for public release: distribution is unlimited. (AFRL-2025-1877)

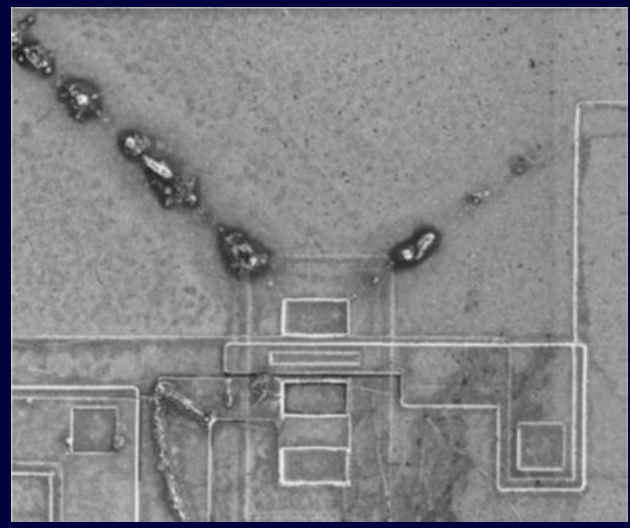
High temperature reliability challenges historical perspective



Prior results showed early failures due to die back-end-of-line materials



Metallization corrosion and adhesion loss



Corrosion and stress cracking

**HT BEOL material and passivation prior work:ASMC 2022; doi: 10.1109/ASMC54647.2022.9792481.

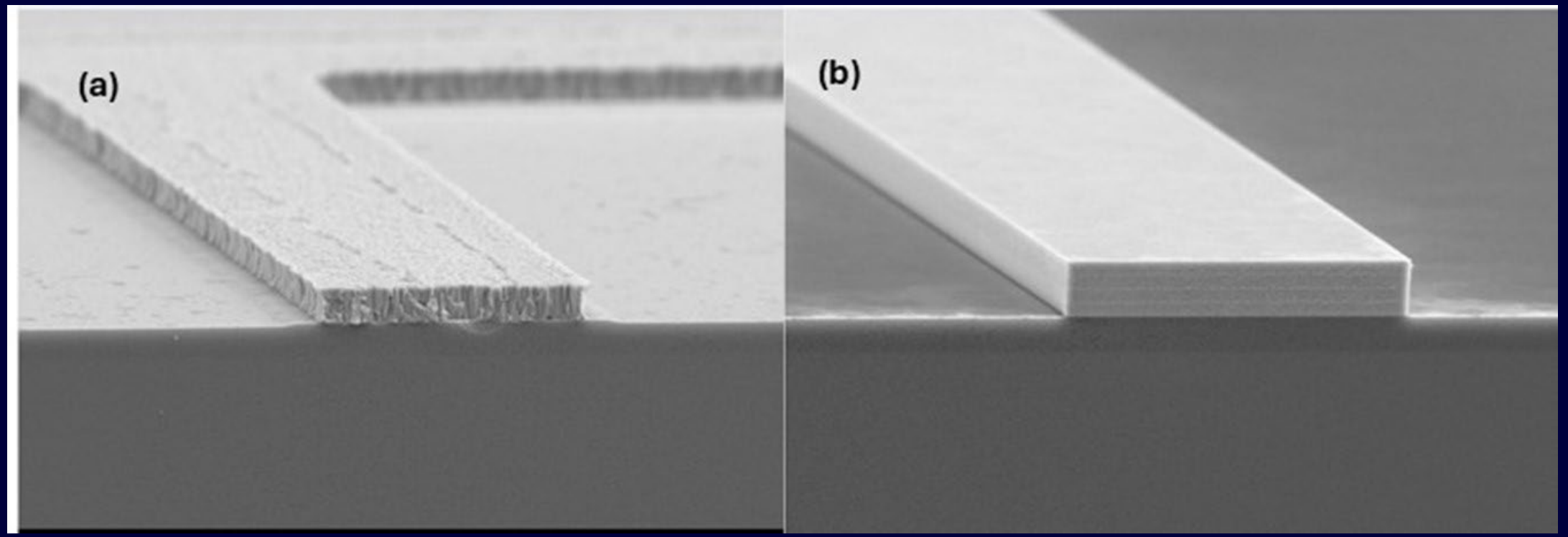
Material choices critical to achieving reliability at temperature

Distribution Statement A. Approved for public release: distribution is unlimited. (AFRL-2025-1877)

Fabrication approach and challenges

TiW

$TaSi_2$

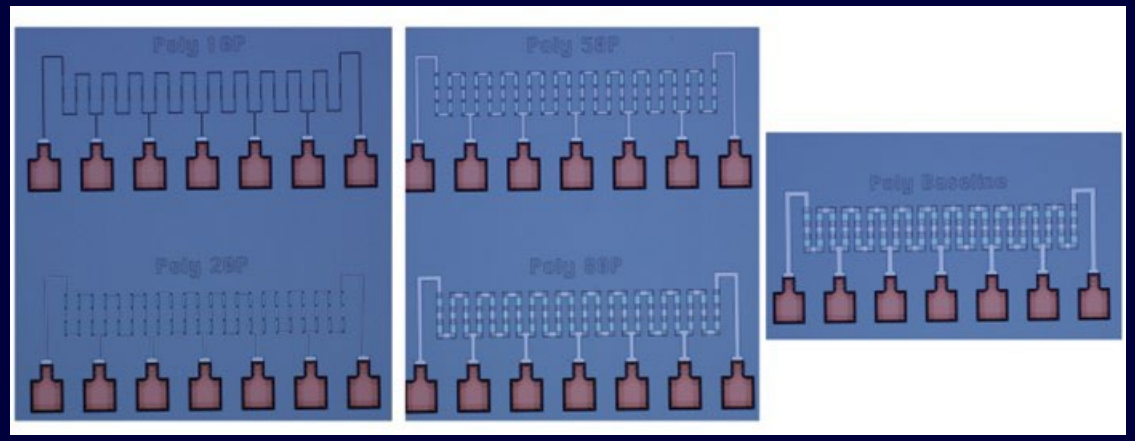


Current Etch tooling constraints favors $TaSi_2$ over TiW.

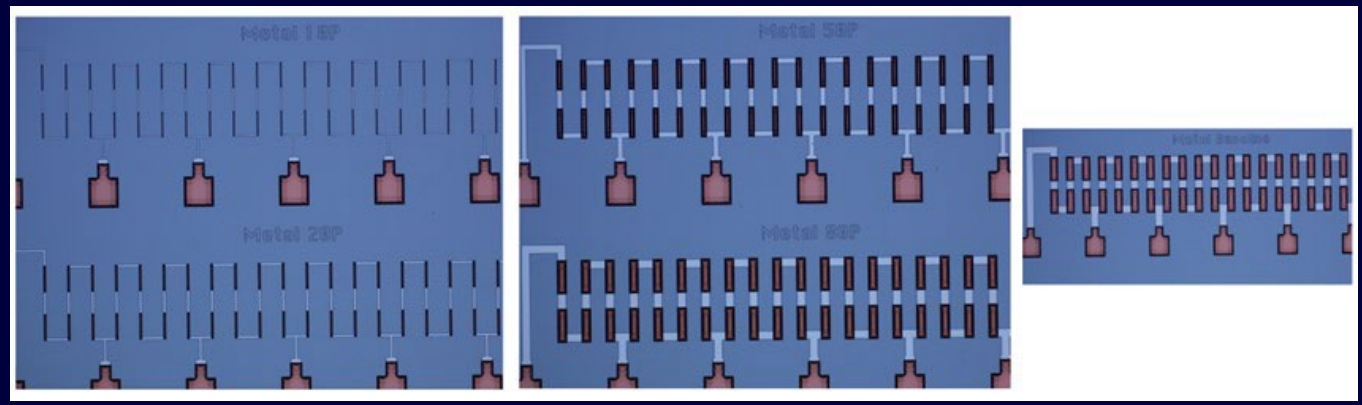
$TaSi_2$ selected for initial evaluation

Distribution Statement A. Approved for public release: distribution is unlimited. (AFRL-2025-1877)

Fabricated devices



Optical microscope images of the baseline and scaled design variations of the polysilicon to metal split.



Optical microscope images of the baseline and scaled design variations of the metal1 to metal2 split.

Distribution Statement A. Approved for public release: distribution is unlimited. (AFRL-2025-1877)

Testing Approach

Wafer level auto probing at 25°C to +300°C

- Measure resistance over temperature
- Assess resistance variation and yield across wafer

Current density capability

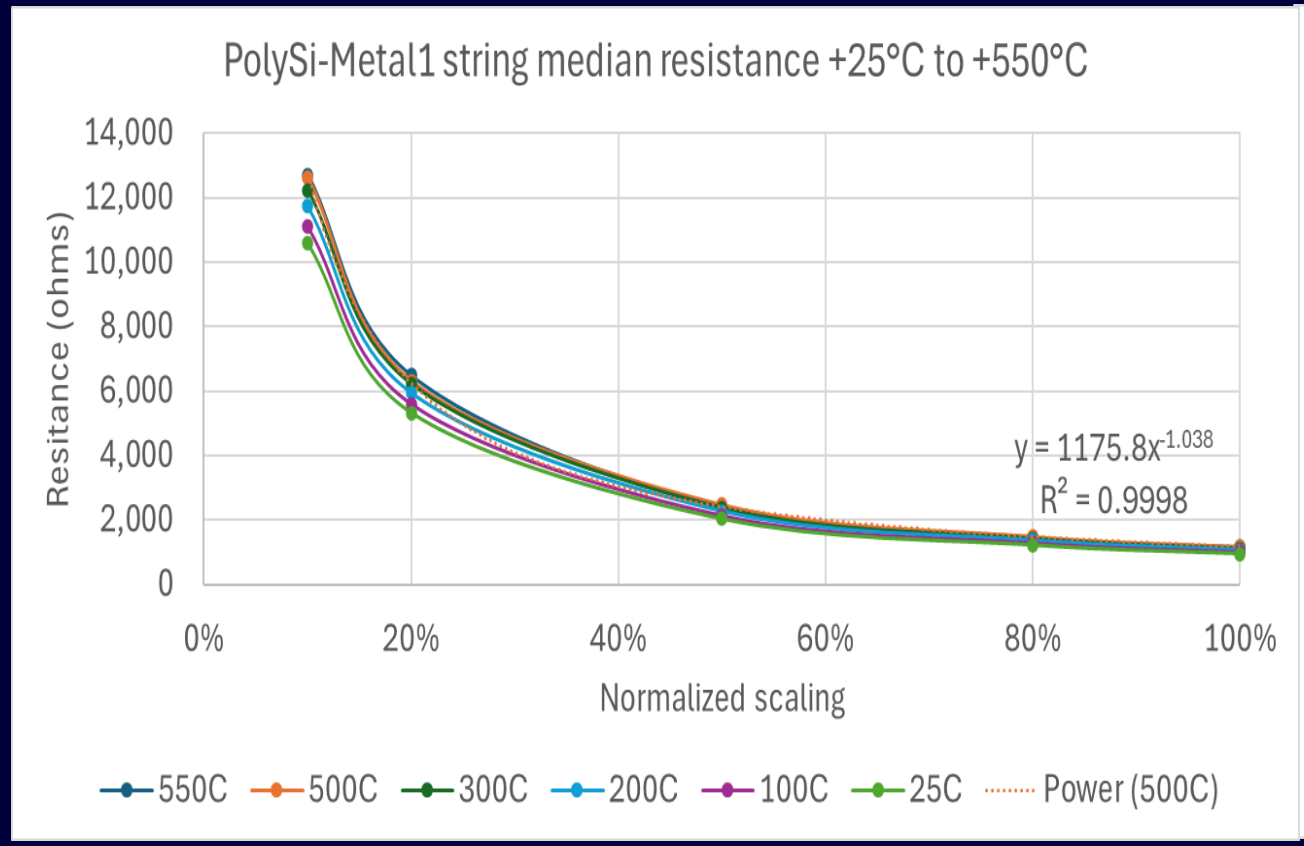
- Sweep current from 0 to 100mA
- Extract current capability at 25°C and 300°C

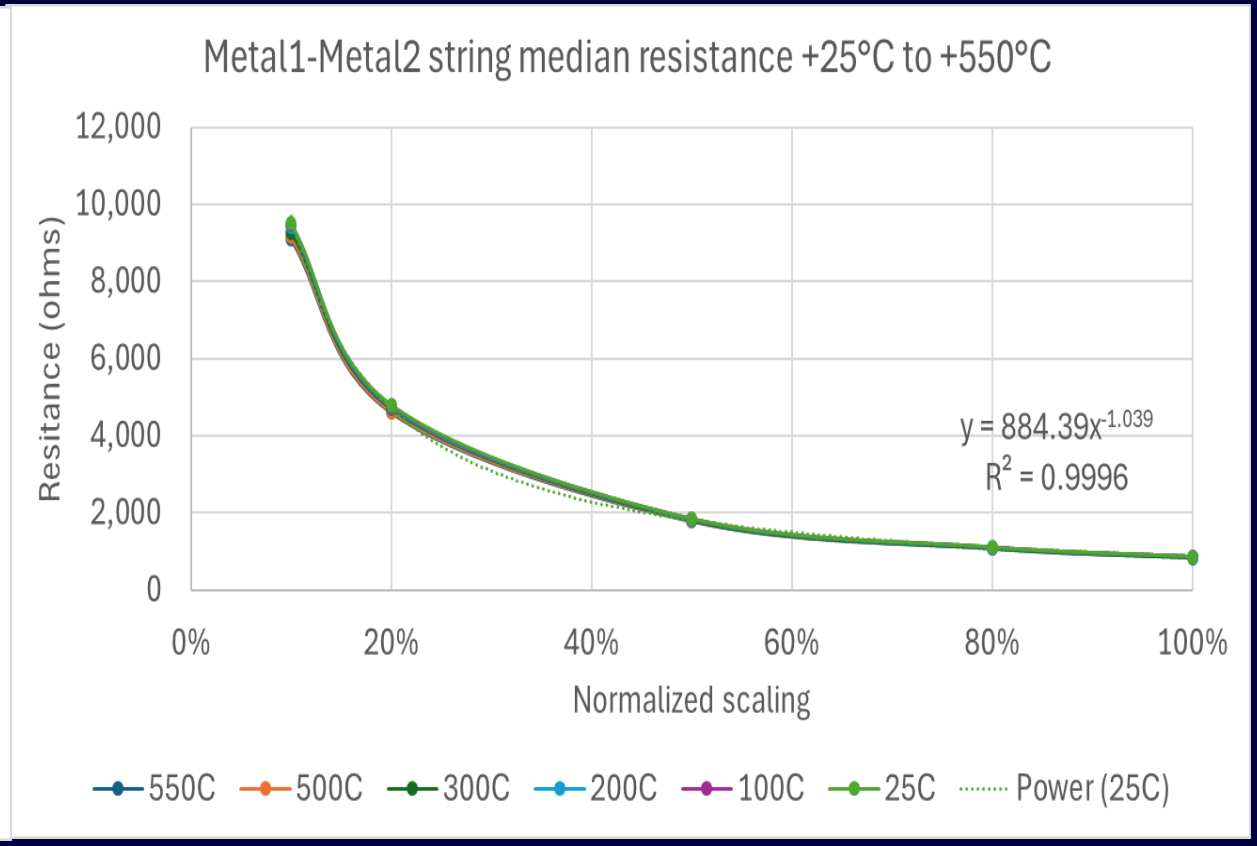
Manual probing at >300°C

- Measure resistance at 300°C, 500°C and 550°C
- Conduct current density capability sweep at 500°C

Distribution Statement A. Approved for public release: distribution is unlimited. (AFRL-2025-1877)

Resistance scaling as a function of trace size and temperature





Power law fit with an inverse linear dependence on the dimensionality of the scaled trace widths

Resistance largely dominated by the linewidth

Resistance consistent with scaling

Distribution Statement A. Approved for public release: distribution is unlimited. (AFRL-2025-1877)

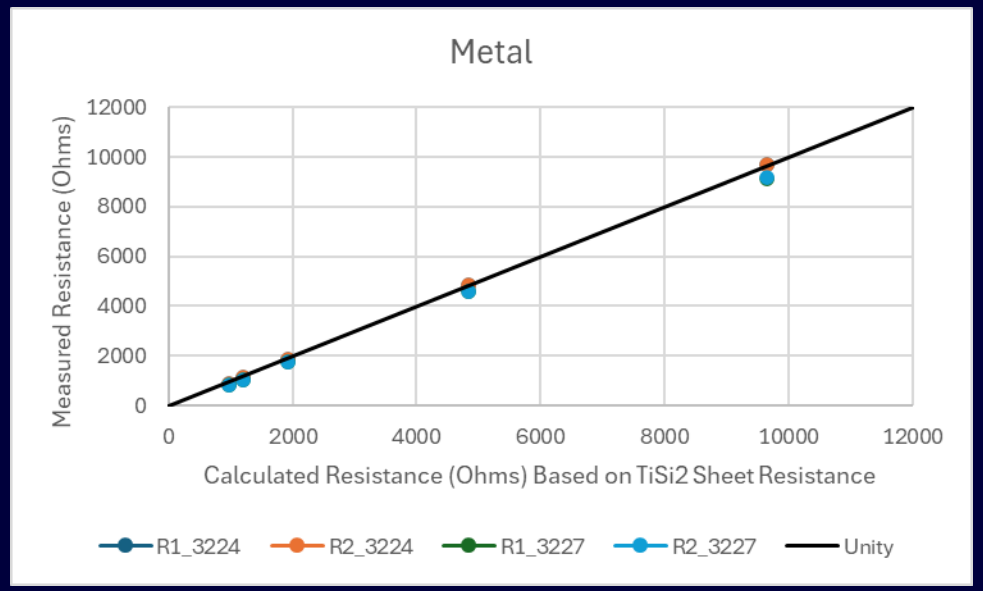
Calculated resistance versus experimental results

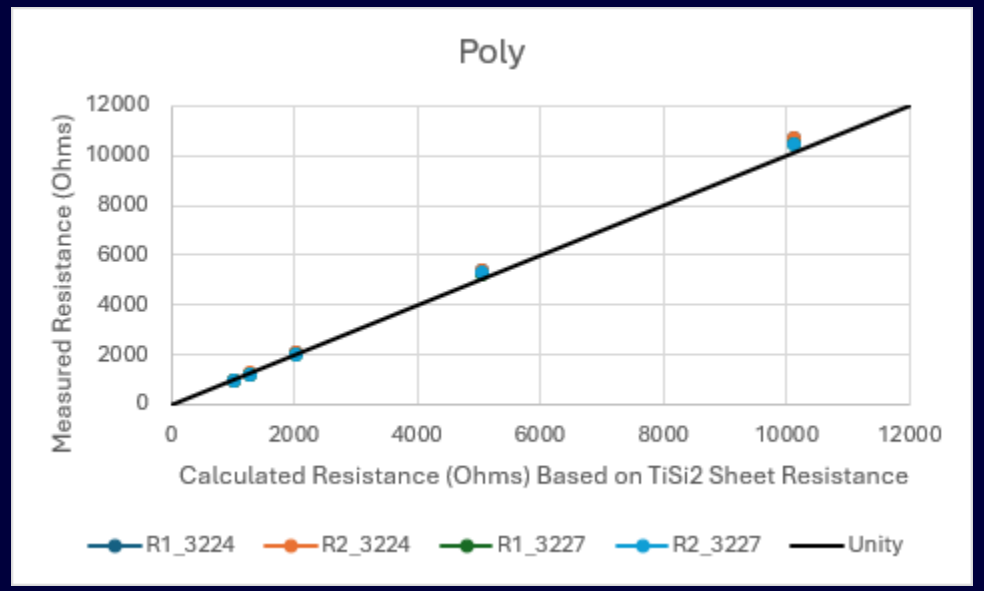
Sheet resistance as measured on witness wafers:

TaSi2 = 4.32 ohm/sq

PolySi = 41.54 ohm/sq

**Resistance dominated by TaSi2 resistivity and trace dimensions.





Good agreement between predicted and measured resistance values

Distribution Statement A. Approved for public release: distribution is unlimited. (AFRL-2025-1877)

Resistance value distribution statistics

	Polysilicon-Metal Wafer 1 Sample size=314		Polysilicon-Metal Wafer 2 Sample size=314	
Scaling	Mean	Standard deviation	Mean	Standard deviation
Baseline (100%)	969.1	8.9	937.8	6.4
80%	1241.9	11.4	1201.0	8.3
50%	2068.6	18.9	1999.6	14.2
20%	5417.8	51.2	5245.5	40.6
10%	10689.2	138.5	10427.7	165.0

	Metal_1-Metal_2 Wafer 1 Sample size=314		Metal_1-Metal_2 Wafer 2 Sample size=314	
Scaling	Mean	Standard deviation	Mean	Standard deviation
Baseline (100%)	878.6	5.9	827.8	14.7
80%	1125.8	7.4	1060.8	18.8
50%	1871.8	12.6	1764.2	31.3
20%	4857.0	39.3	4581.2	85.1
10%	9646.7	119.7	9164.8	196.2

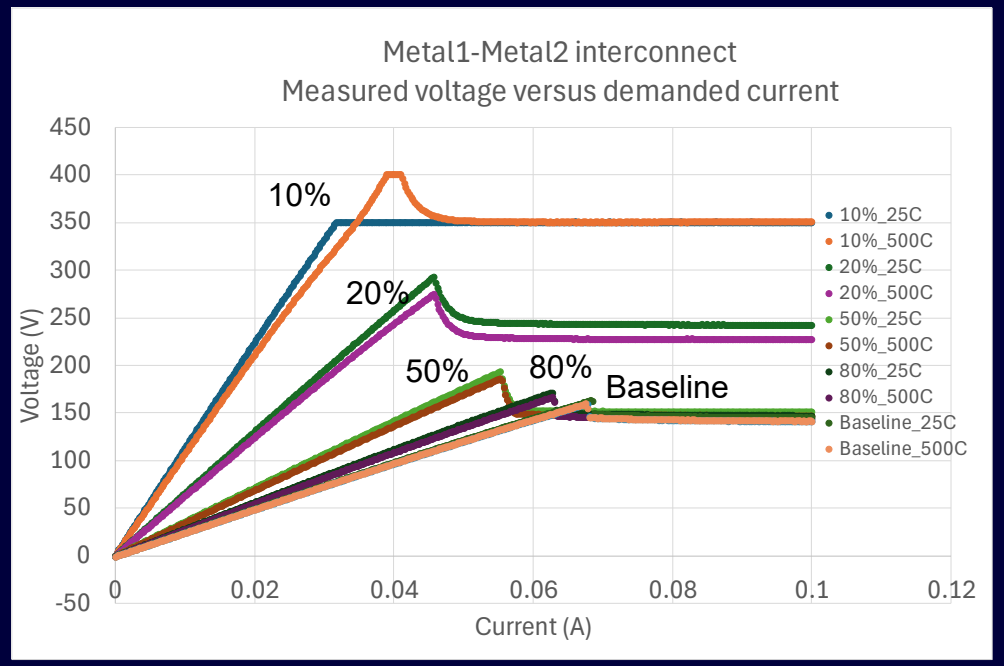
Polysilicon-Metal1 resistance std dev : 1.6% for smallest size structures

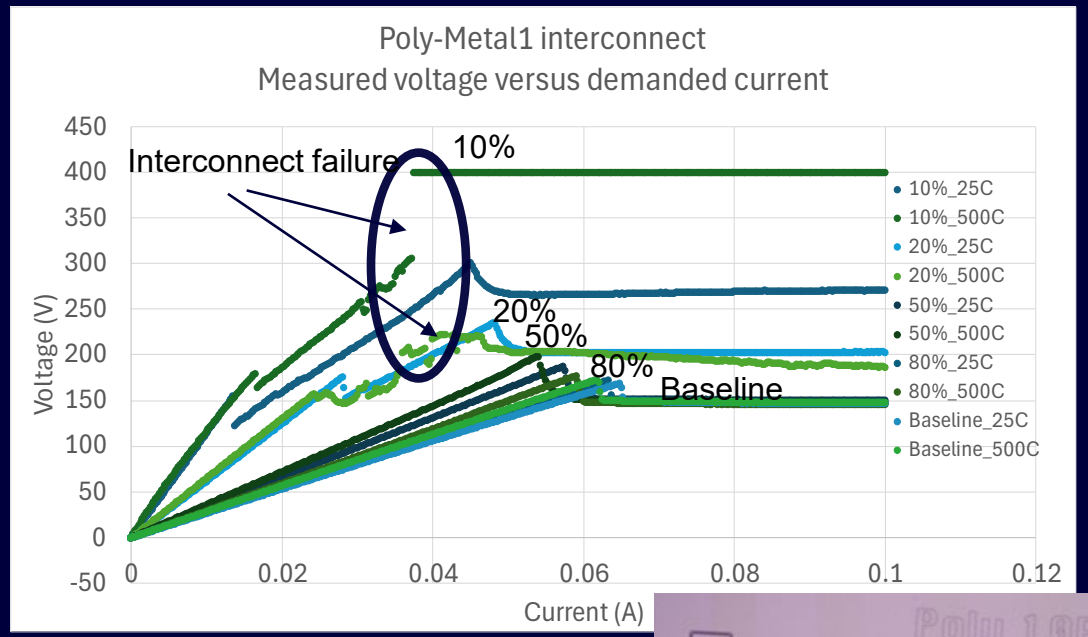
Metal1-Metal2 resistance std dev: 2.14% for smallest size structures

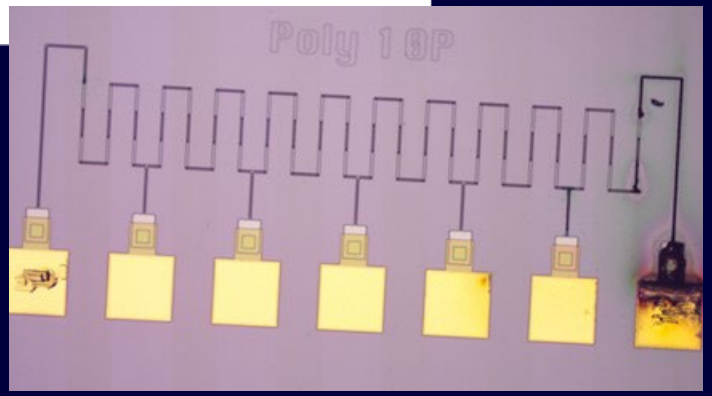
Variance is lower for larger feature size structures.

Distribution Statement A. Approved for public release: distribution is unlimited. (AFRL-2025-1877)

Current Density testing







Current was swept from 0 to 100mA's.

No failures were observed on the Metal1-Metal2 interconnect pattern

Poly-Metal1 10% scaled structure experienced failures at ~37mA @ 300°C and 500°C

20% scaled structure experienced failure at ~45mA at 500°C. No failures observed at 25°C or 300°C

Distribution Statement A. Approved for public release: distribution is unlimited. (AFRL-2025-1877)

Summary, Next Steps and Conclusions

Multilevel metal interconnect shown operational at 550°C
Demonstrated metal-clad polysilicon routing layer
Evaluated interconnect and via scaling over a 10:1 range
    1.5μmx1.5μm via_1 & 2.5μm trace width
    3μmx3μm via_2 & 6μm trace width
<3% trace resistivity variation across wafer at the smallest scaling
Current density > 10mA/μm at 500°C for 10% poly-metal1 structure

Next steps
Evaluate further interconnect scaling potential below 10% of baseline
Test current density with shorter strings
Process development for TiW interconnect metal to achieve further resistance reduction
Evaluate benefits and process development for scaling to 3+ metal routing layers
Evaluate interconnect capability above 600°C

Distribution Statement A. Approved for public release: distribution is unlimited. (AFRL-2025-1877)

Acknowledgements

This material is based on research sponsored by Air Force Research Laboratory under Agreement Number FA8650-20-2-5506 in support of Office of the Secretary of Defense. The U.S. Government is authorized to reproduce and distribute reprints for Governmental Purposes notwithstanding any copyright notation thereon." "The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of Air Force Research Laboratory, the Office of the Secretary of Defense or the U.S. Government.

Distribution Statement A. Approved for public release: distribution is unlimited. (AFRL-2025-1877)

Thank You.



Andarawis@geaerospace.com

Distribution Statement A. Approved for public release: distribution is unlimited. (AFRL-2025-1877)


GE Aerospace