Si-Ge Nano-structured with Tungsten Silicide Inclusions

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NASA Cooperative Agreement: NNX08AB43A

Objectives

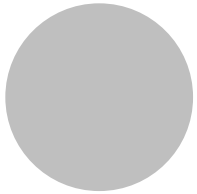
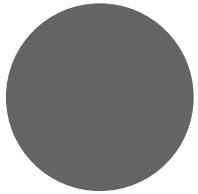
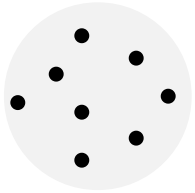
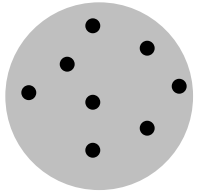
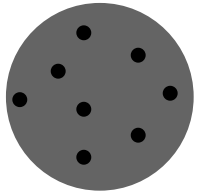
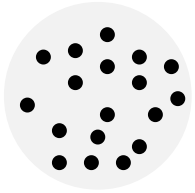
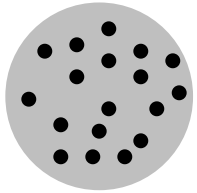
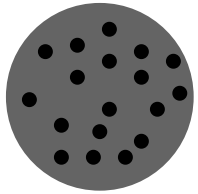
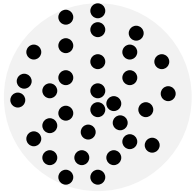
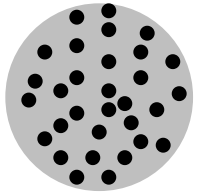
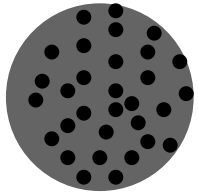
- Investigate composite strategies with proven Si/Ge thermoelectrics.
- Validate theoretical modeling for silicide inclusion in Si/Ge, requires 10nm inclusions.
- Develop reliable uncertainty analysis for thermoelectric transport properties.
- Study thermal stability of composites.

$$Material\ ZT = \frac{\alpha^2 \sigma}{\lambda} T$$

$$\lambda = \lambda_{Elec.} + \lambda_{Lattice}$$

Test Matrix

2% Dopant
P-Type, B
N-Type, P

Tungsten Silicide Volume Fraction	Si/Ge at% Ratio 70/30	80/20	90/10
0%			
1%			
2%			
5%			

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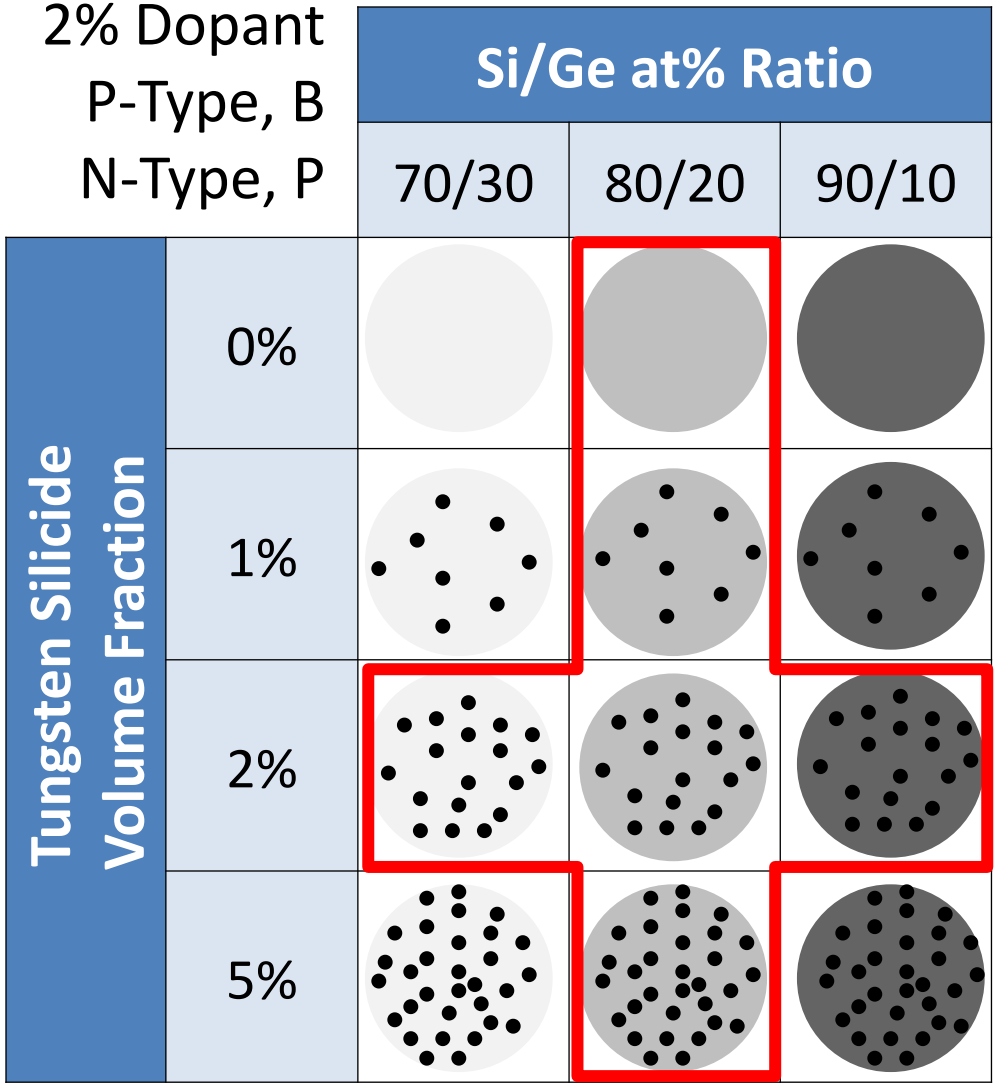
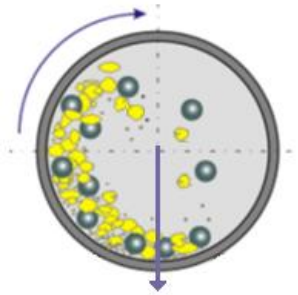
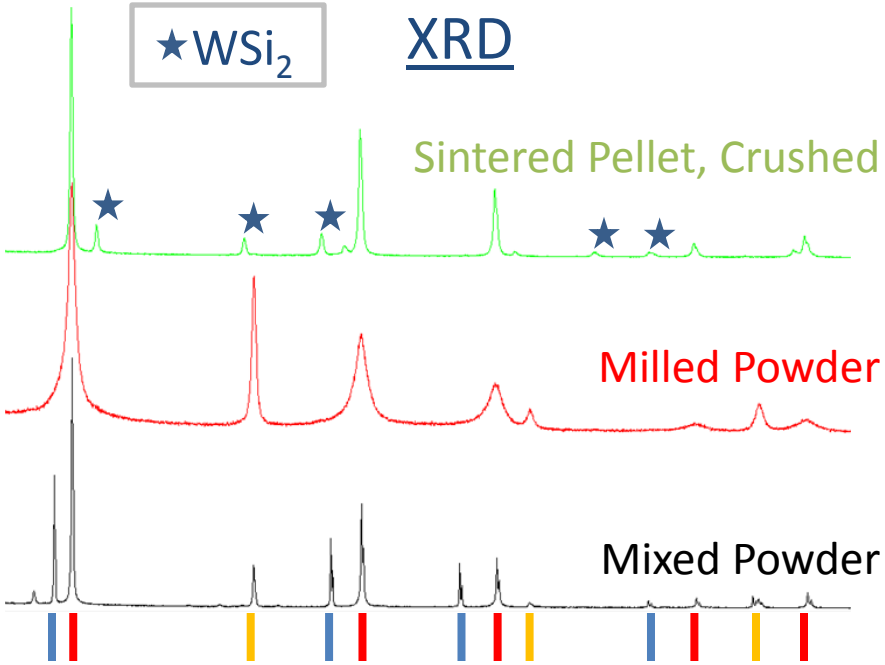




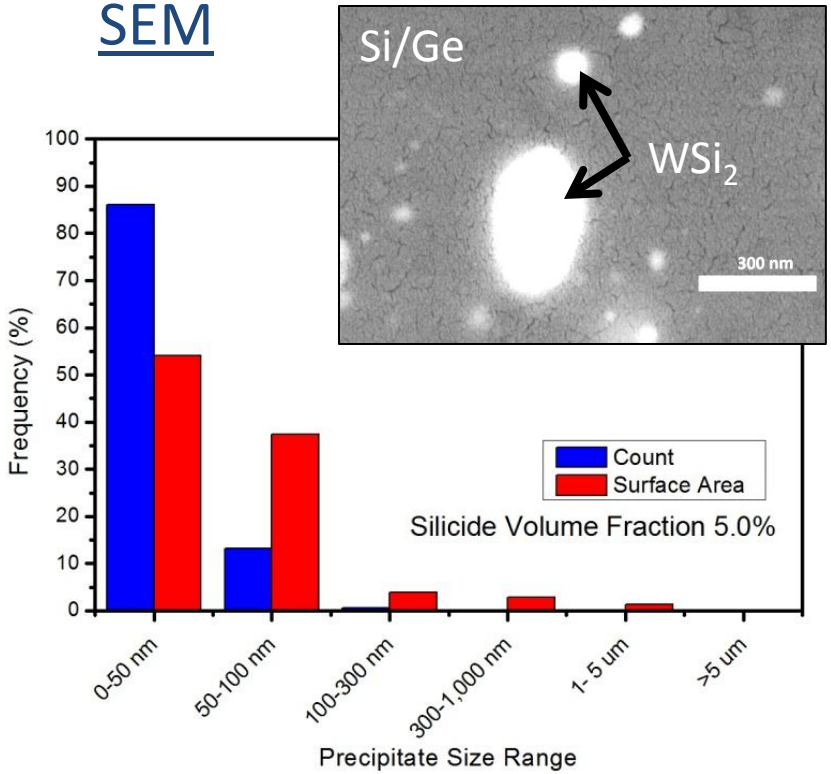
Powder Processing

- Planetary Milling
  - 8 Hours @ 300-580 rpm
  - Ball to powder ratio 3-5
- Spark Plasma Sintering (AFRL)
  - 800-1100°C @ 70-90 MPa
  - 5-10 min Hold

XRD

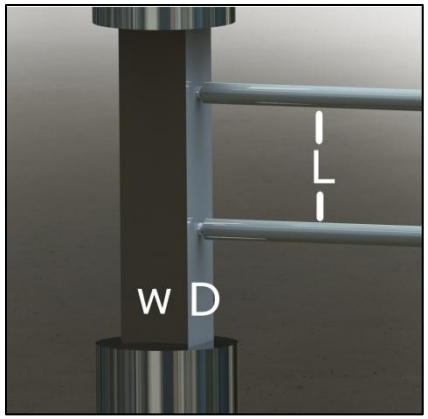


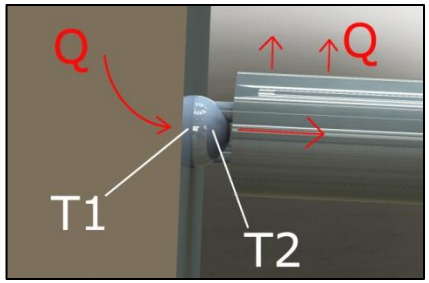
SEM



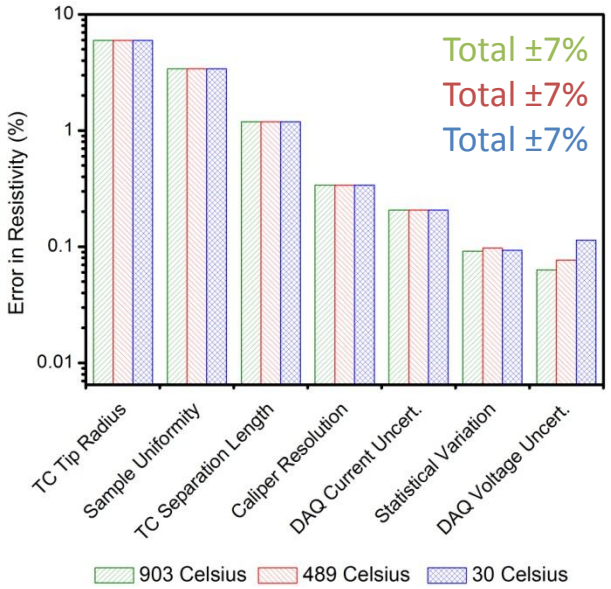
1” Diameter

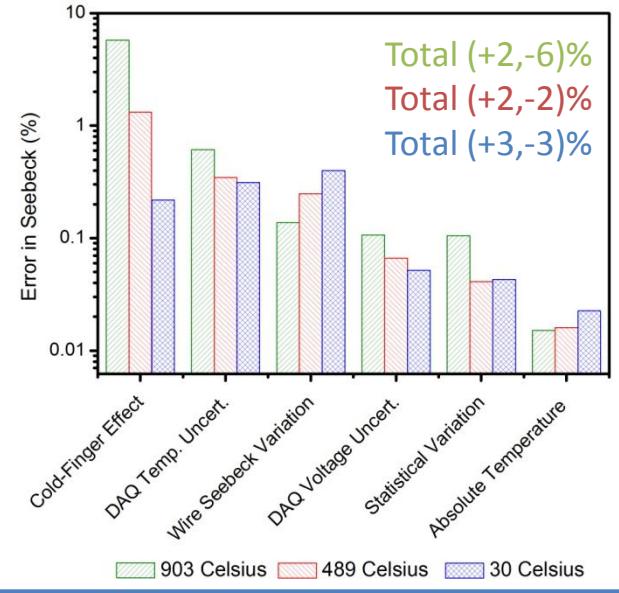
Sources of Error

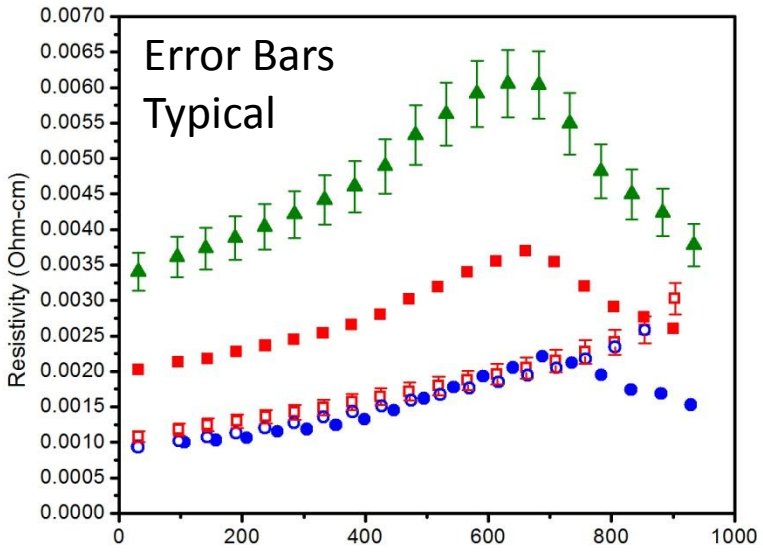


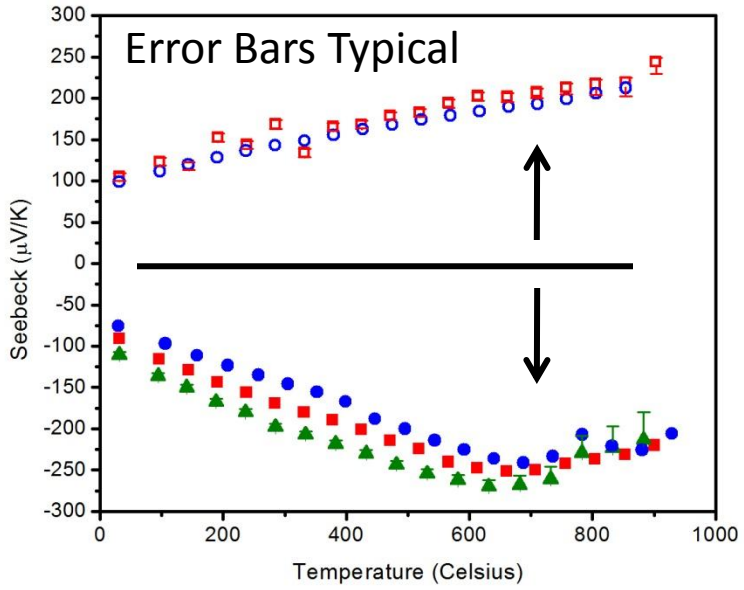


	Source	Magnitude
Resistivity	Thermocouple radius	0.25 mm
	Sample uniformity	±0.1 mm
	Thermocouple separation	±0.1 mm
	Caliper resolution	0.01 mm
	Statistical variation	Calculated
	DAQ voltage uncertainty	50ppm+1.2μV
	DAQ current uncertainty	0.2%+0.3mA
Seebeck	Cold-finger effect	Calculated
	Wire Seebeck variation	±3 %
	Statistical variation	Calculated
	Absolute temperature	±2 K
	DAQ voltage uncertainty	50ppm+1.2μV
	DAQ temp. uncertainty	50ppm+1.2μV



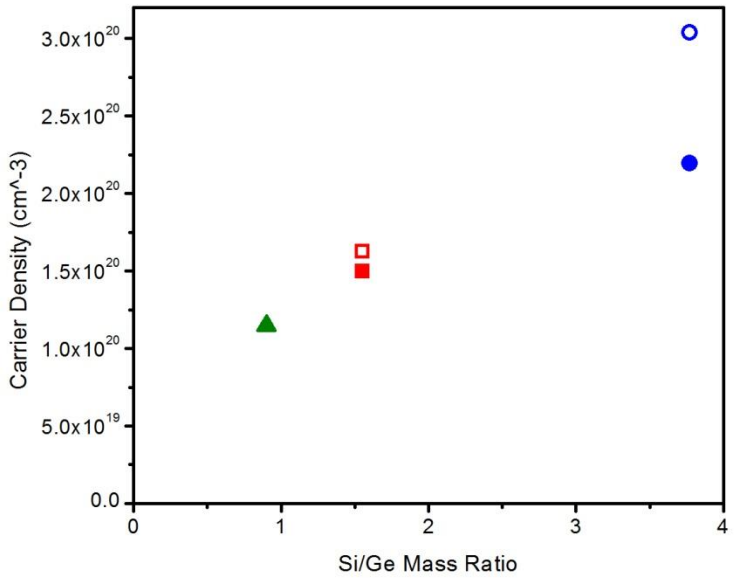


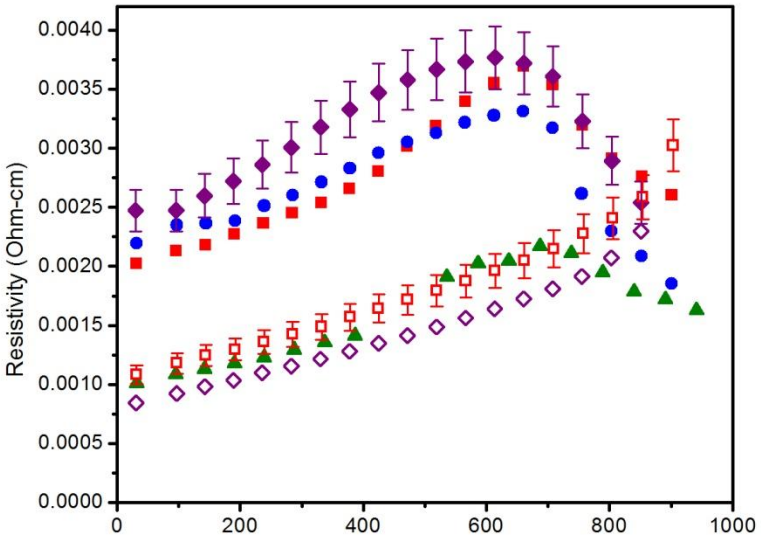


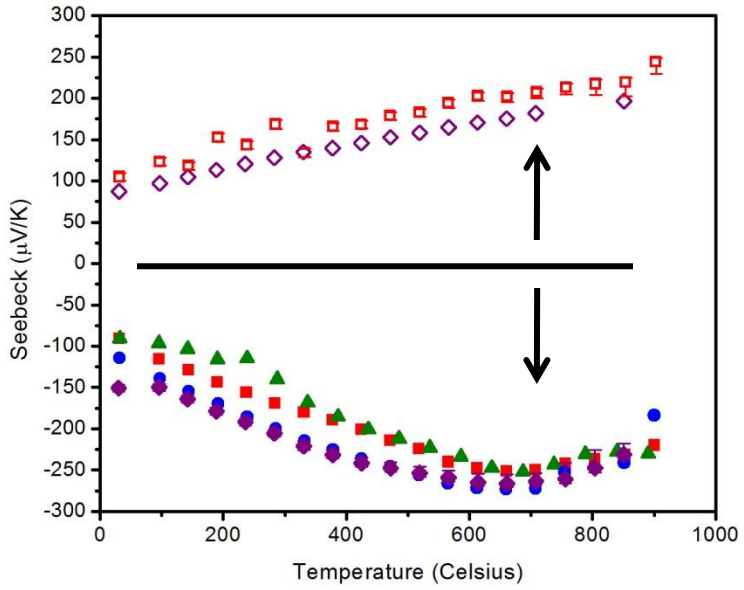


2% Doped
○ P-type, B
● N-type, P

Tungsten Silicide Volume Fraction	Si/Ge at% Ratio 70/30	80/20	90/10
0%	X	X	X
1%	X	X	X
2%	▲	■	●
5%	X	X	X







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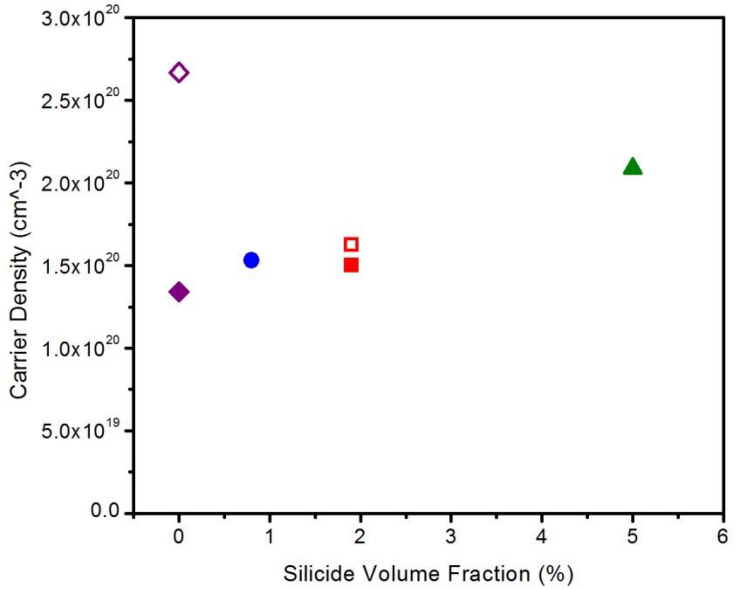

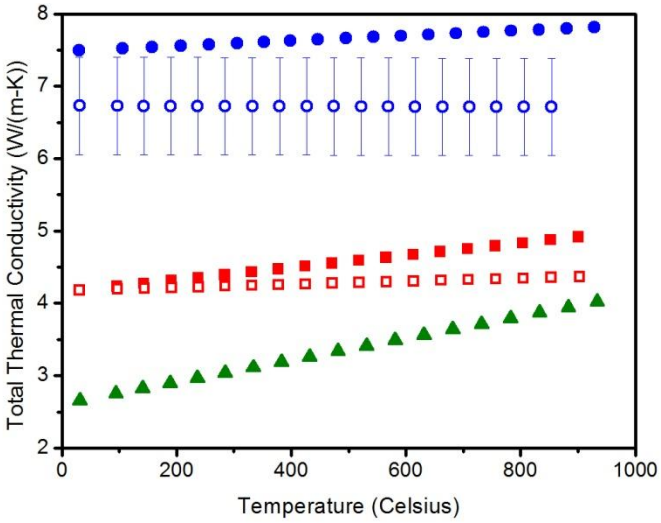

Increasing Ge

V.F.	Si/Ge at% Ratio 70 30	80 20	90 10
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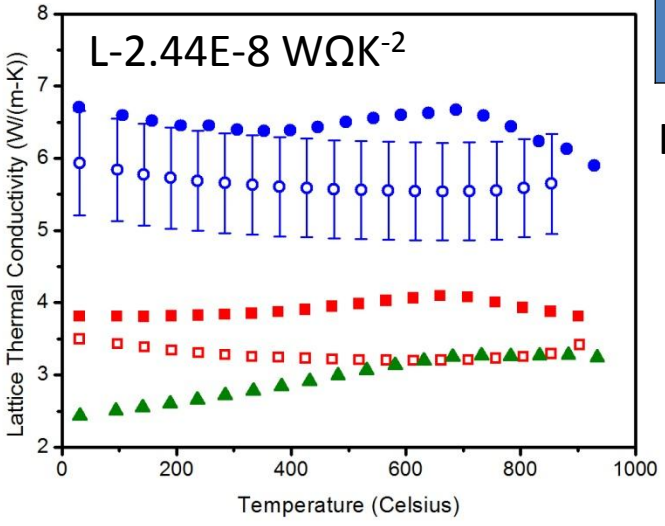
2%	▲	■	●
5%	X	X	X



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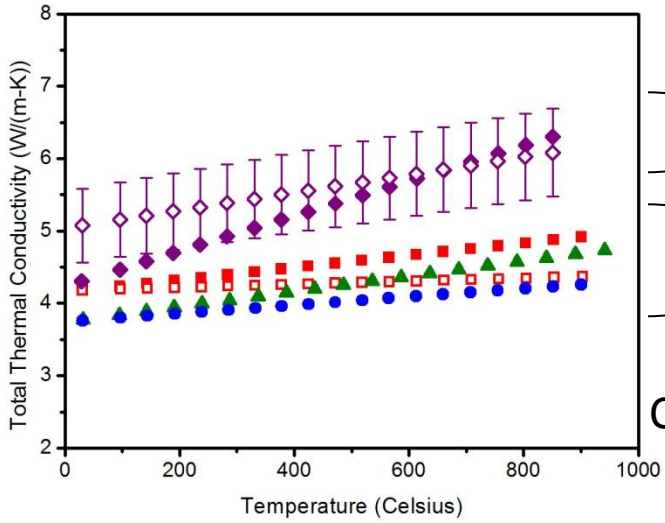

Si/Ge

Silicide Composites

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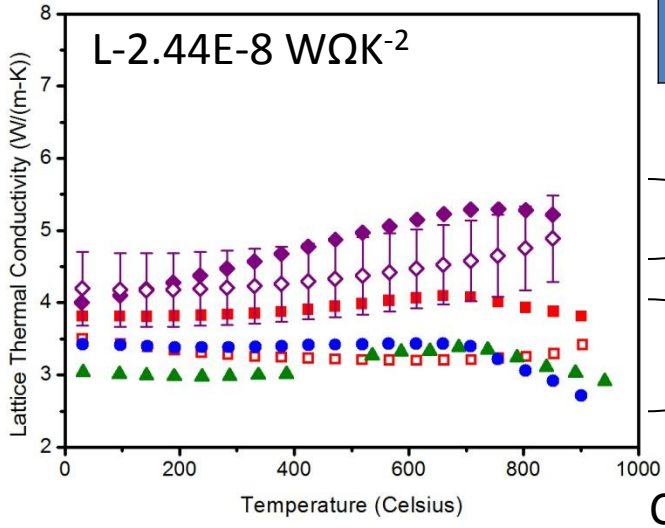

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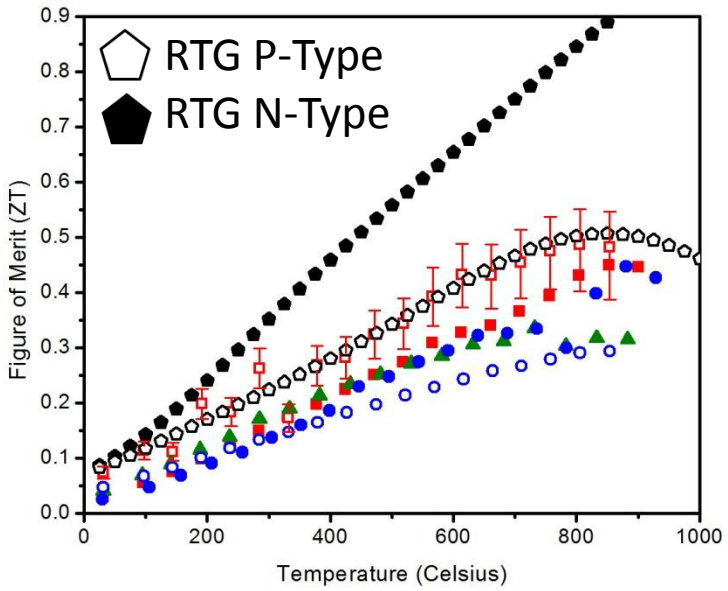

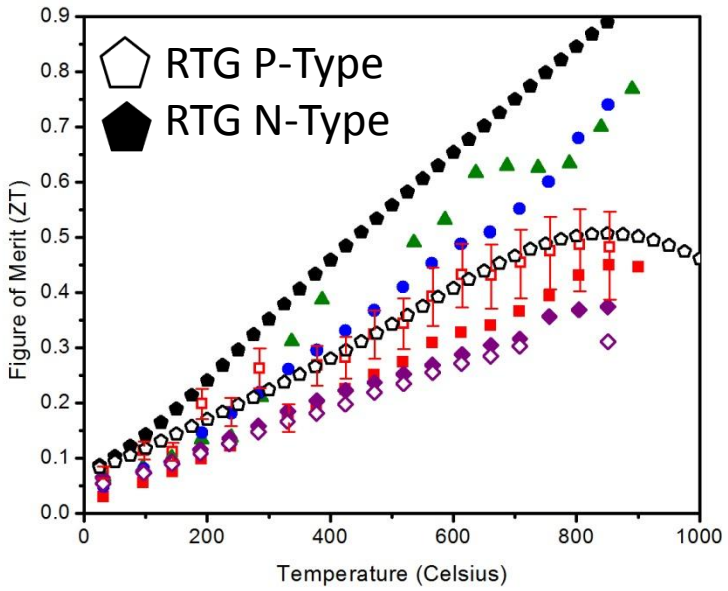

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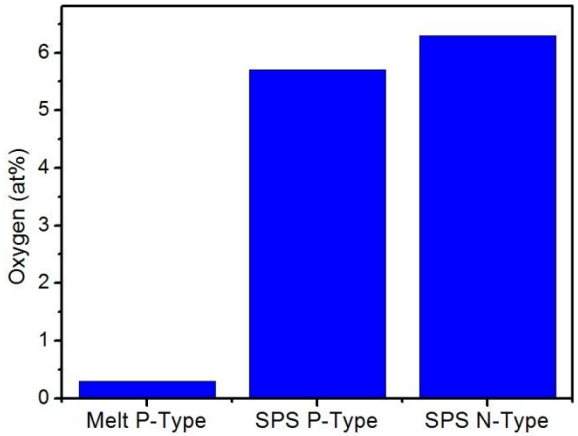

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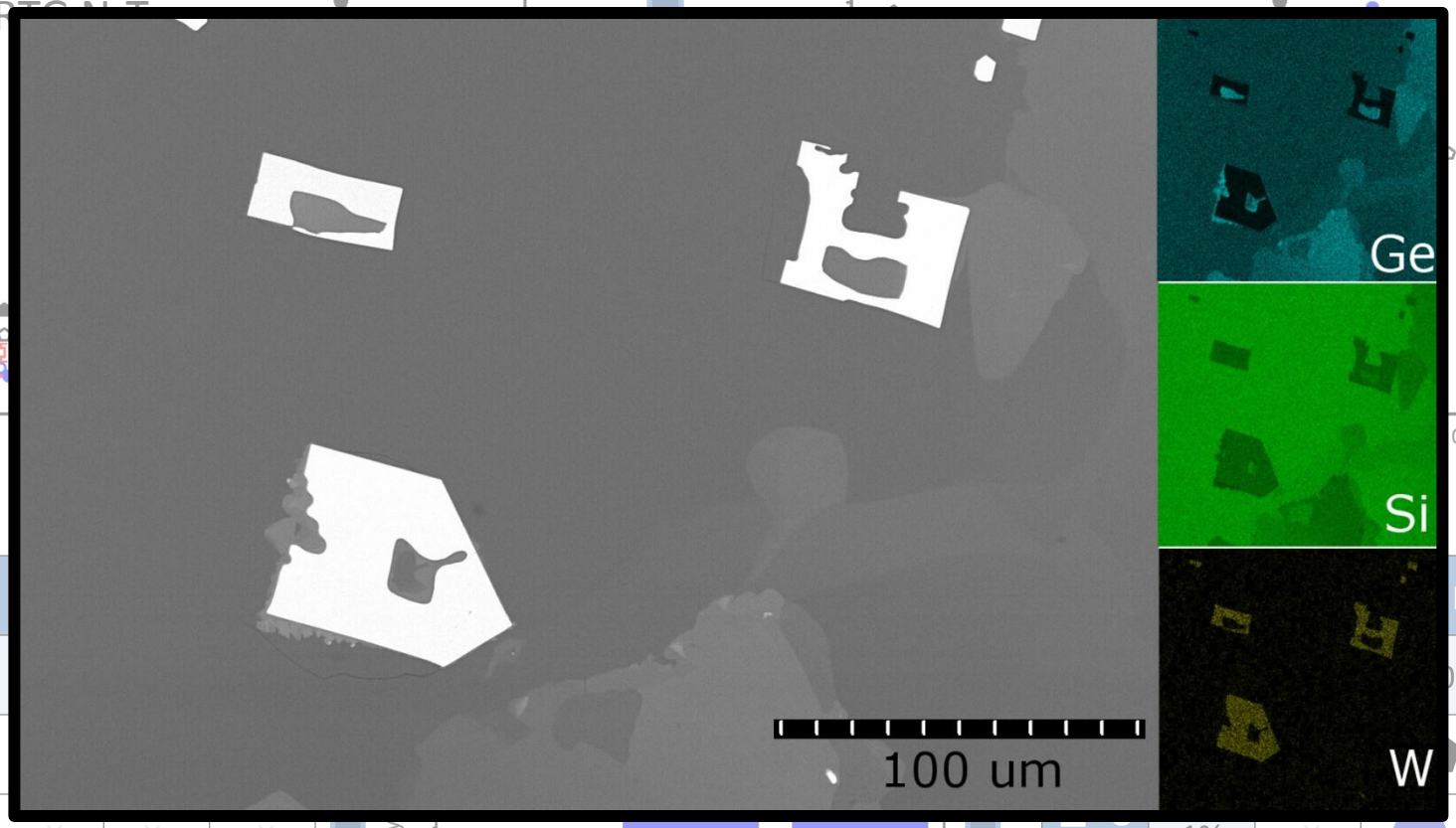
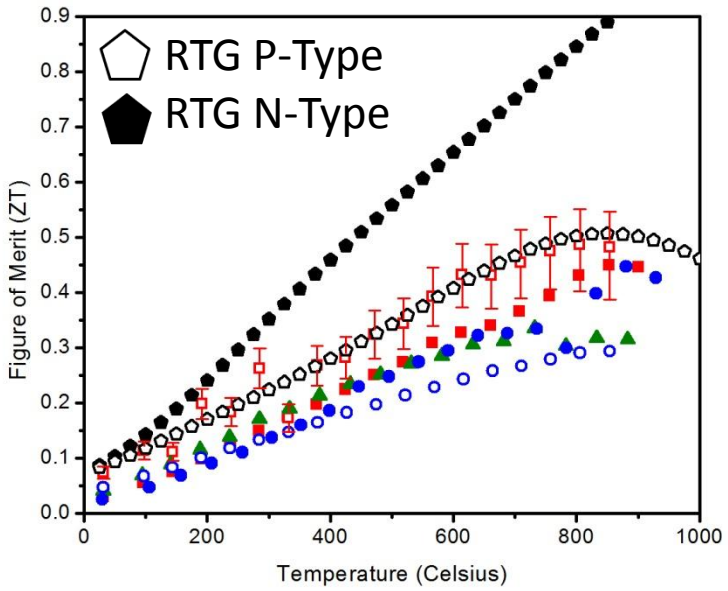
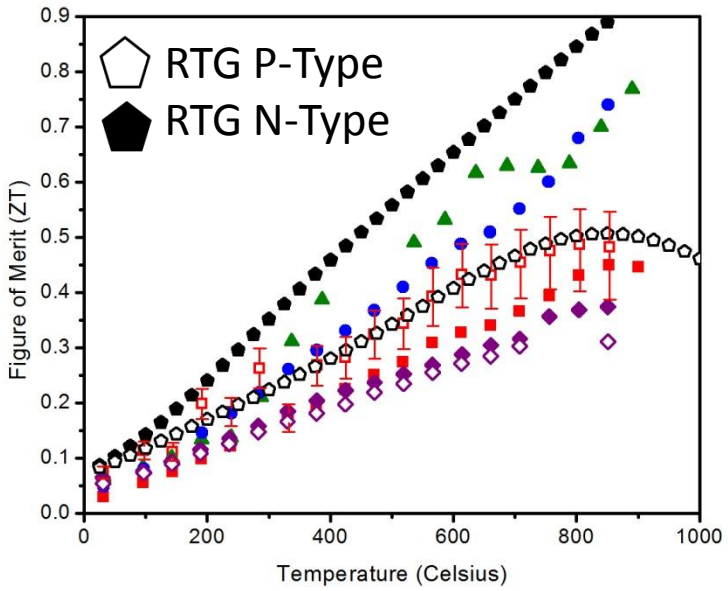

Ge
Si
W
100 um





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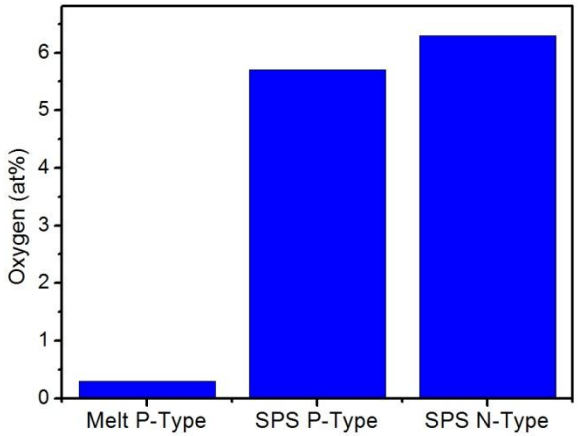

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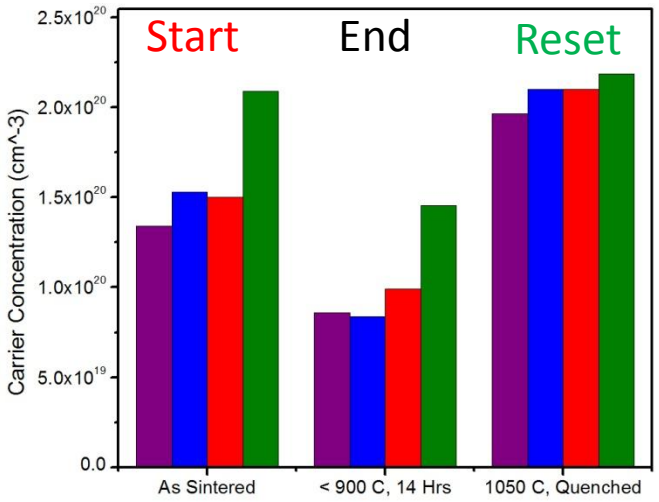

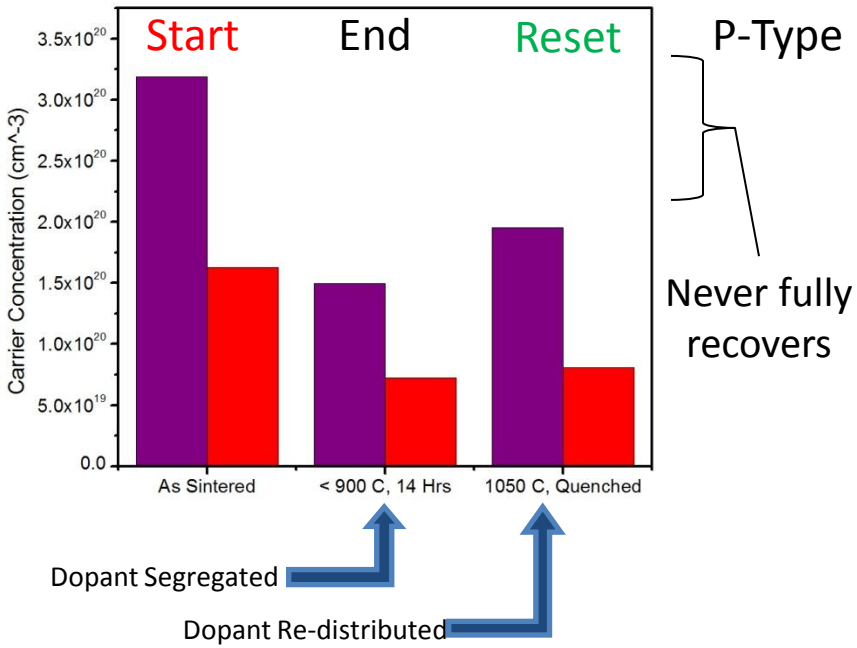

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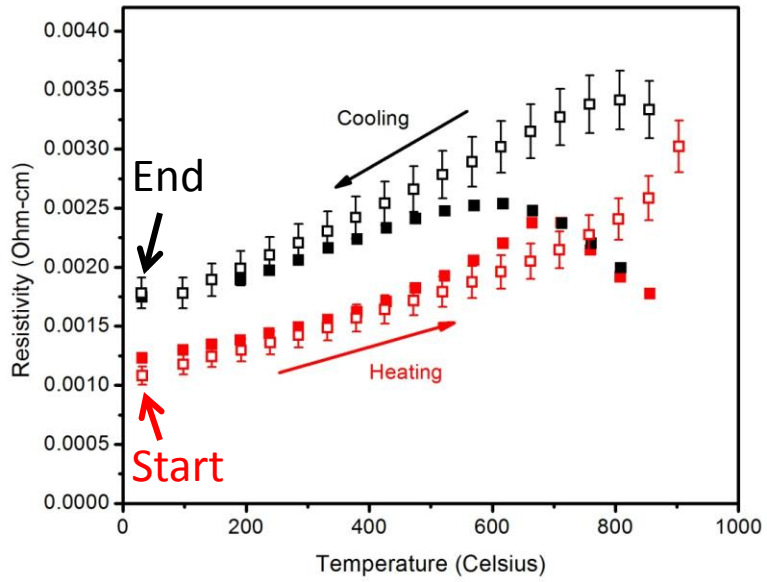

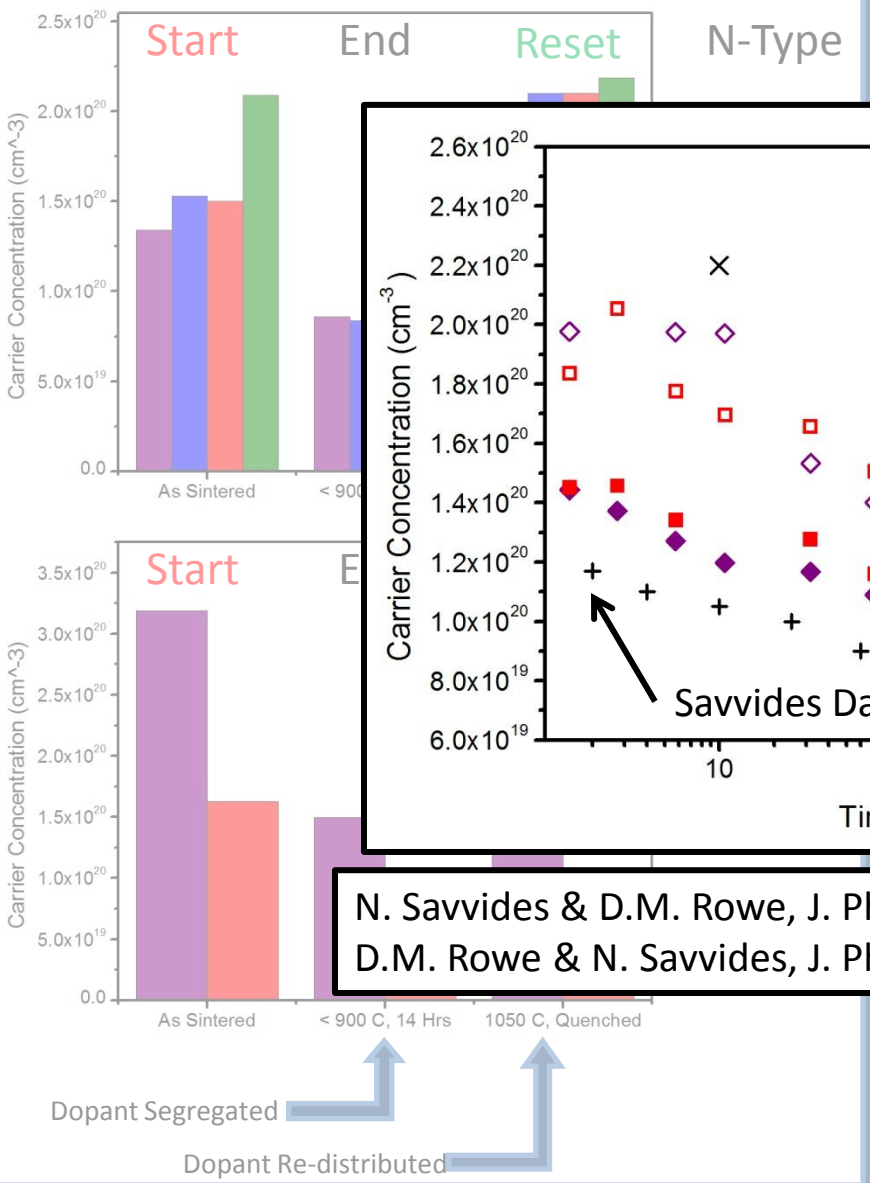

N. Savvides & D.M. Rowe, J. Phys. D: Appl. Phys. **14** (1981)
D.M. Rowe & N. Savvides, J. Phys. D: Appl. Phys. **12** (1979)

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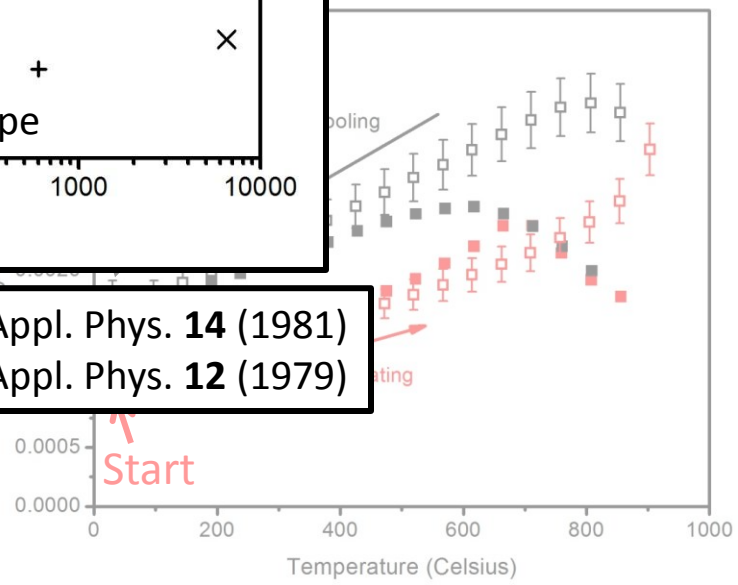
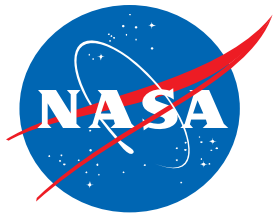


Conclusion

- Silicide phase successfully reduces lattice thermal conductivity.
- Increased ZT for silicide composites as compared to baseline Si/Ge.
  - Need to control oxygen contamination to match baseline Si/Ge to RTG.
- Tungsten silicide phase offers tuning of carrier concentration.
- Silicide phase does not hinder thermal stability.



The University of Akron

Case Western Reserve University EST. 1826
think beyond the possible

Acknowledgements

Tom Sabo, Ray Babuder, Ben Kowalski, Clayton Cross
NASA Glenn Research Center

Dr. Michael Cinibulk
AFRL Wright Patterson Air Force Base

Dr. Sabah Bux, Dr. Jean-Pierre Fleurial
JPL

NASA Cooperative Agreement: NNX08AB43A