Thermoelectrics Interests and Research: ARL and TARDEC

DoE Thermoelectrics Applications Workshop: Mar. 2012

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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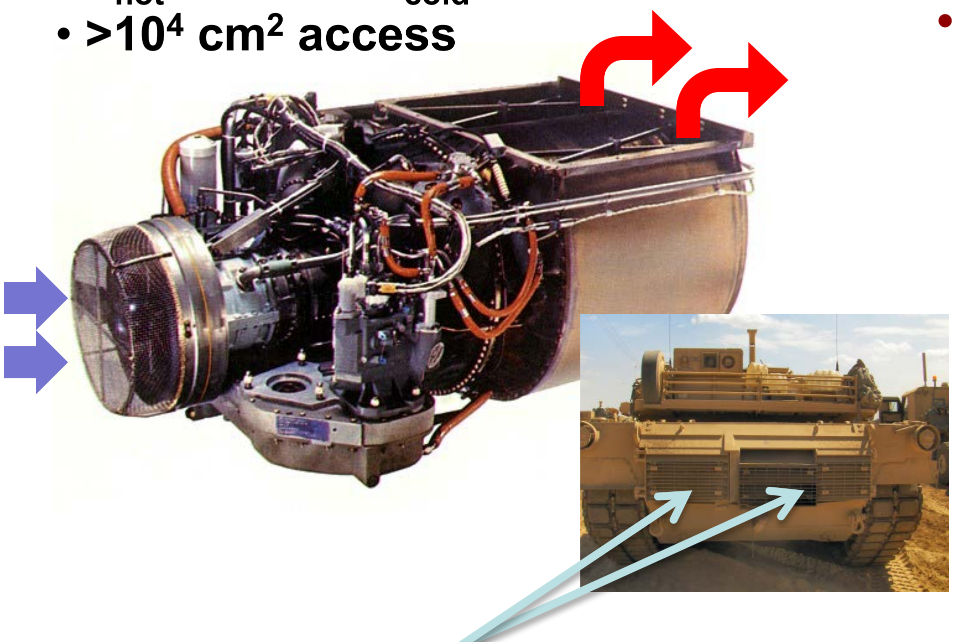
Outline

- **Army Application:**
  - **M1A2**
- **Accurate Measurements:**
  - **Seebeck Coefficient**
  - **Thermal Conductivity**
  - **Comparison to device**
- **Parasitics of Devices:**
  - **Controlling Contact Resistivity**
- **Field Emission:**
  - **Approach**
  - **Etch-release layers have been demonstrated**

Army Application

- **M1A2:**
  - Crew of four soldiers max
  - Issues/Opportunities:

- **Fuel Util./Waste-Heat Recovery:**
  - AGT1500 turbine
  - > 1MW heat
  - T_{hot} ~ 400º C T_{cold} ~ 80º C
  - >10^4 cm^2 access



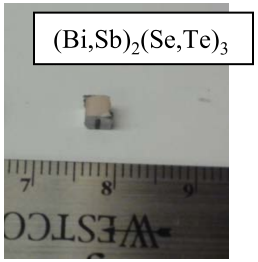
Exhaust

- **Cabin temperature/TE cooling:**
  - more electronics → more heat
  - desert, cramped space

- Thermoelectrics is a key enabler
  - Solid-state, rugged, confined-space, low amortized cost, abundant heat, limited # platforms
  - Works!

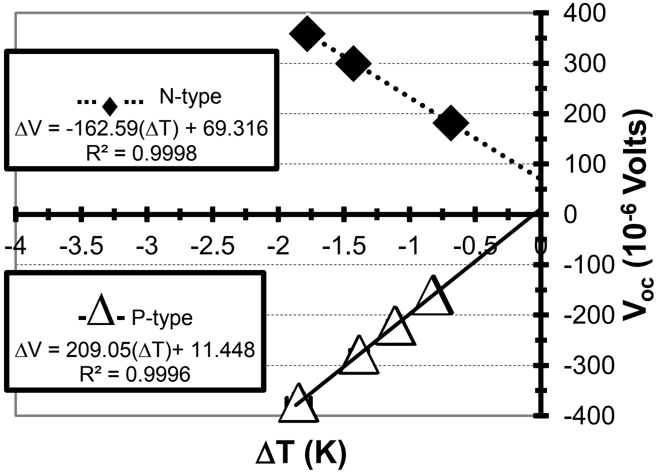
- ARL activities – Broaden Scope and Acceptance:
  - Thermal Conductivity: Improved Accuracy
  - Efficiency and Validation – TE cooling

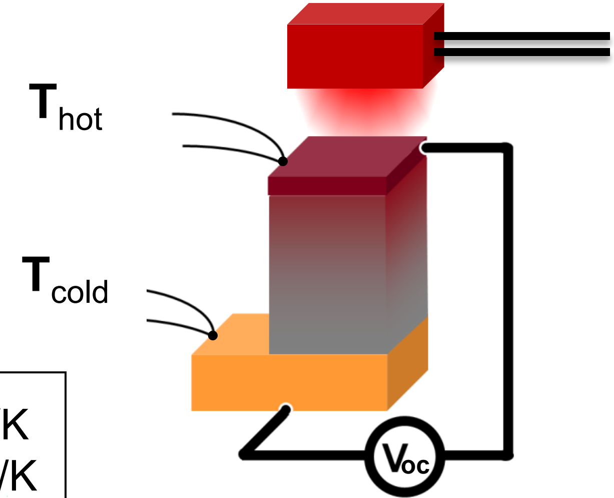
- Case Study:
  - P-type, N-type, individual measurements
  - Fabricate device
  - Efficiency: Does it agree with theory?
  - Validation: Compare to Device



Accurate Measurements

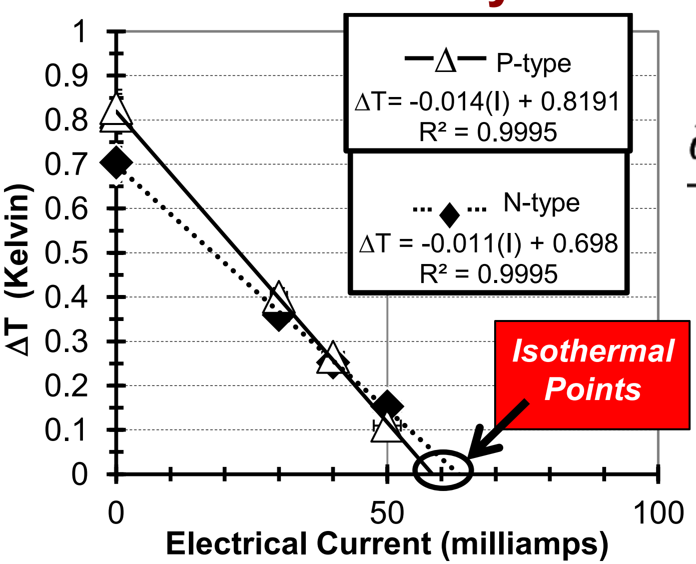
- **Seebeck Coefficient:**



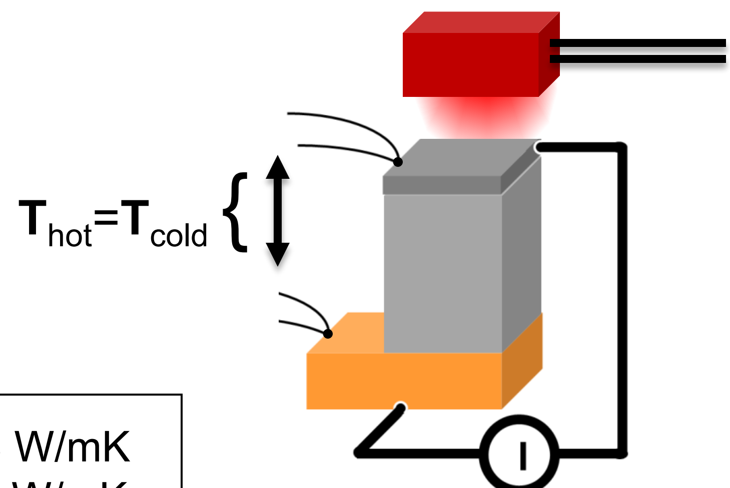


N: -163.8 μV/K
P: +207.2 μV/K

- **Thermal Conductivity**



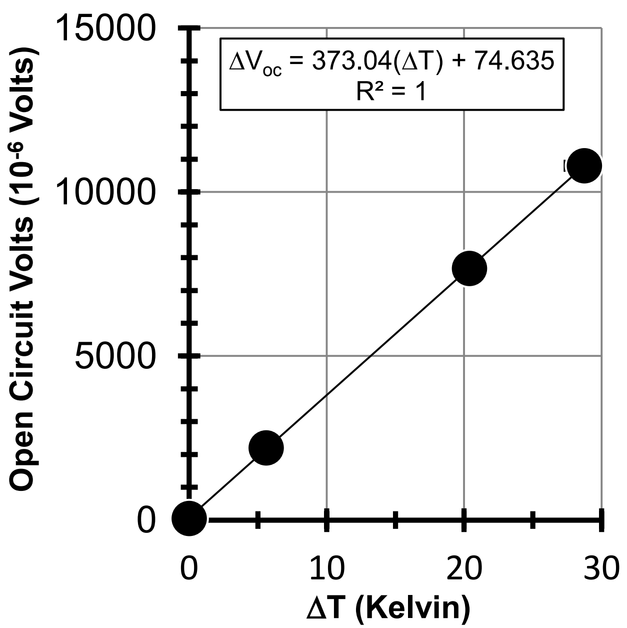
$$\frac{\partial \Delta T}{\partial I} = \frac{\propto T}{\kappa\left(\frac{A}{\ell}\right)}$$



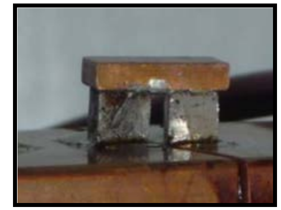
N: 1.48 W/mK
P: 1.47 W/mK

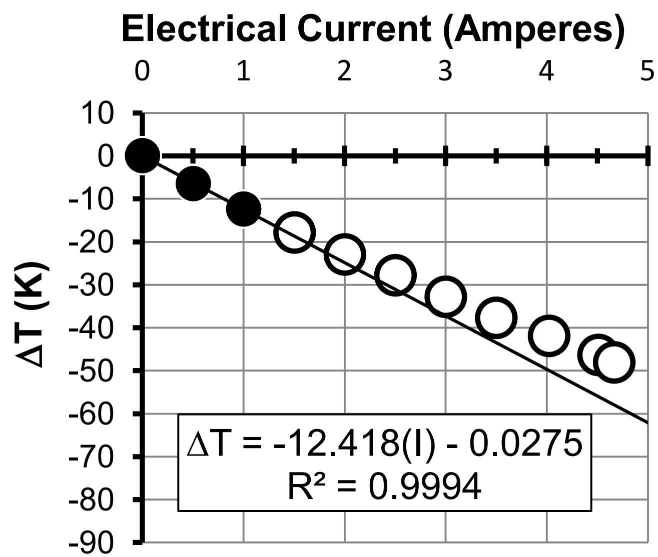
Accurate Measurements

- **Validation by Device:**



$$\frac{\partial \Delta V_{oc}}{\partial \Delta T} = \propto_{sum}$$



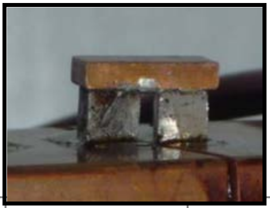


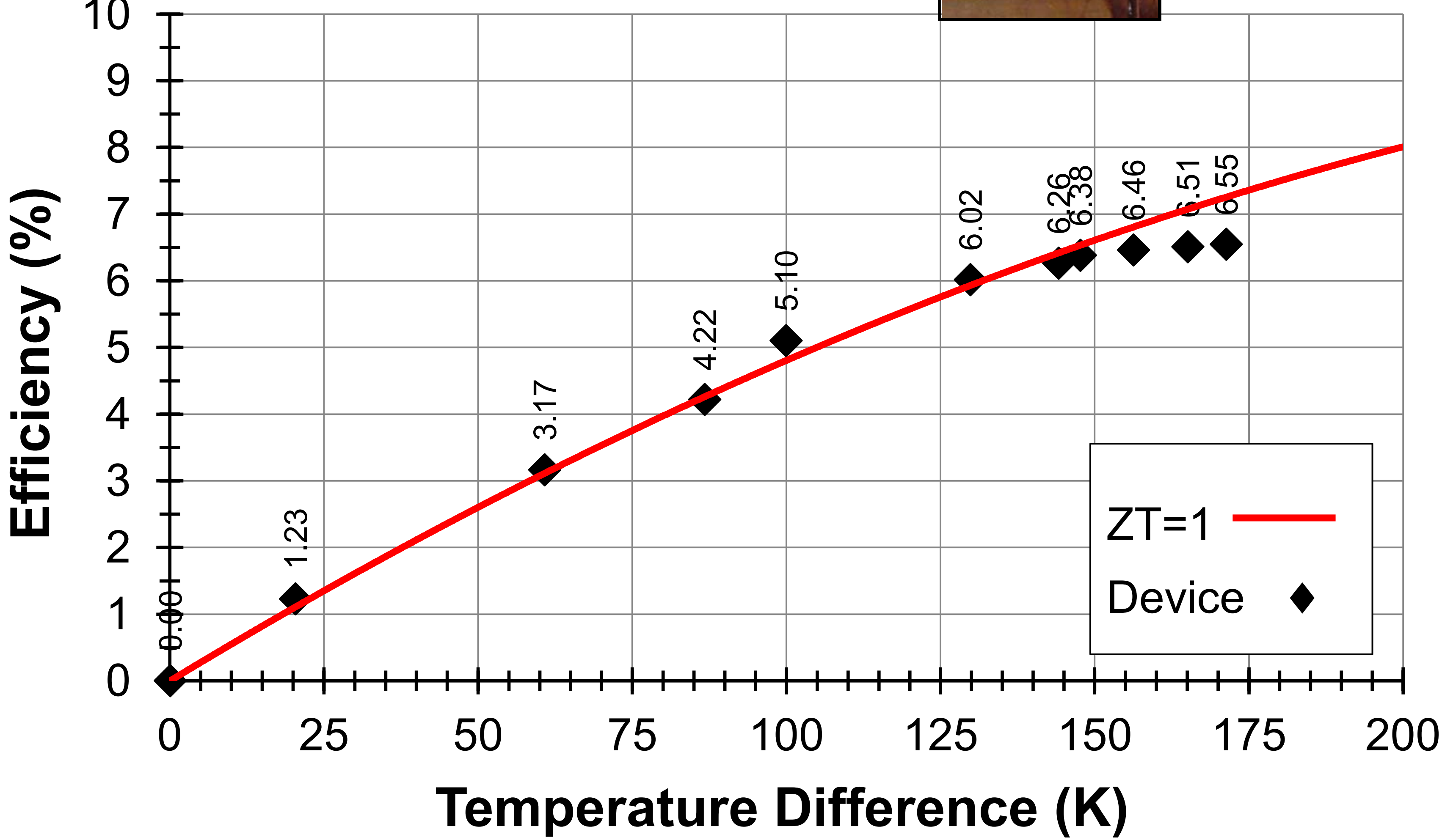
$$\frac{\partial \Delta T}{\partial I} = \frac{\propto_{sum} T_{cold}}{\kappa_{sum} \left(\frac{A}{\ell}\right)}$$

Physical Property	Individually Measured	Extracted from Device	Agreement
Thermal Conductivity (sum)	2.95 W/mK	2.90 W/mK	1.70%
Seebeck Coefficient (sum)	371.0 μV/K	373.0 μV/K	0.50%

Accurate Measurements

- **Validation by Device:**
  - ***should conform to ZT =1***

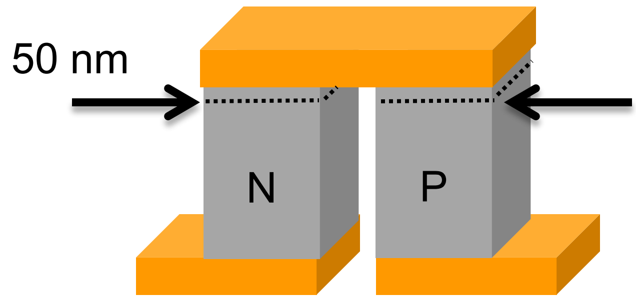


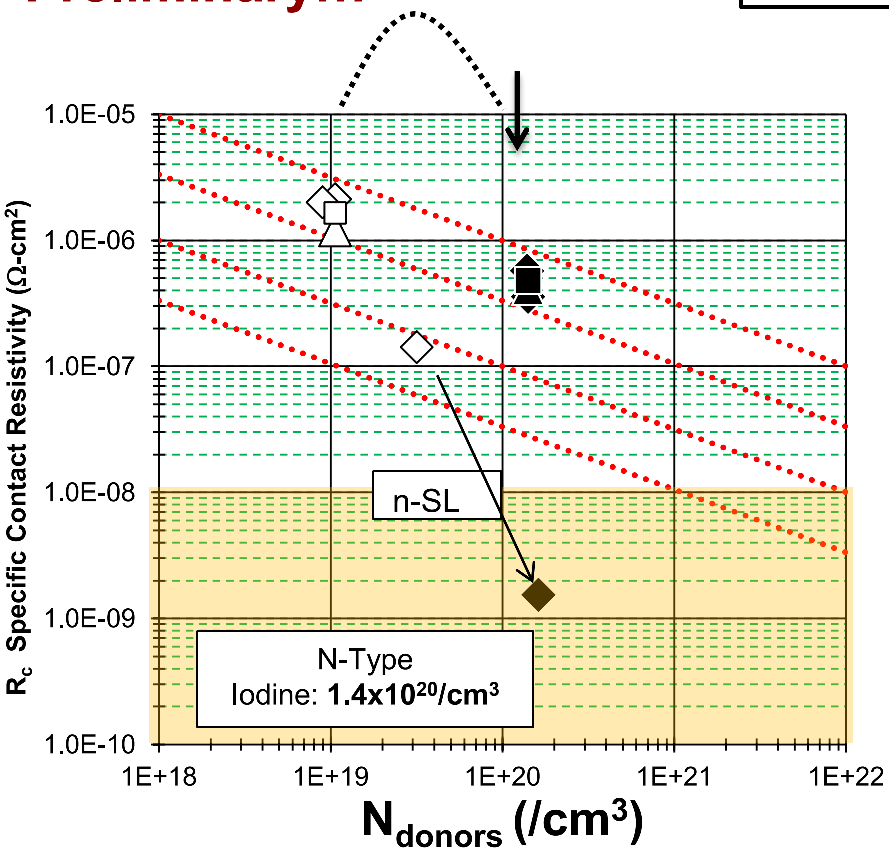


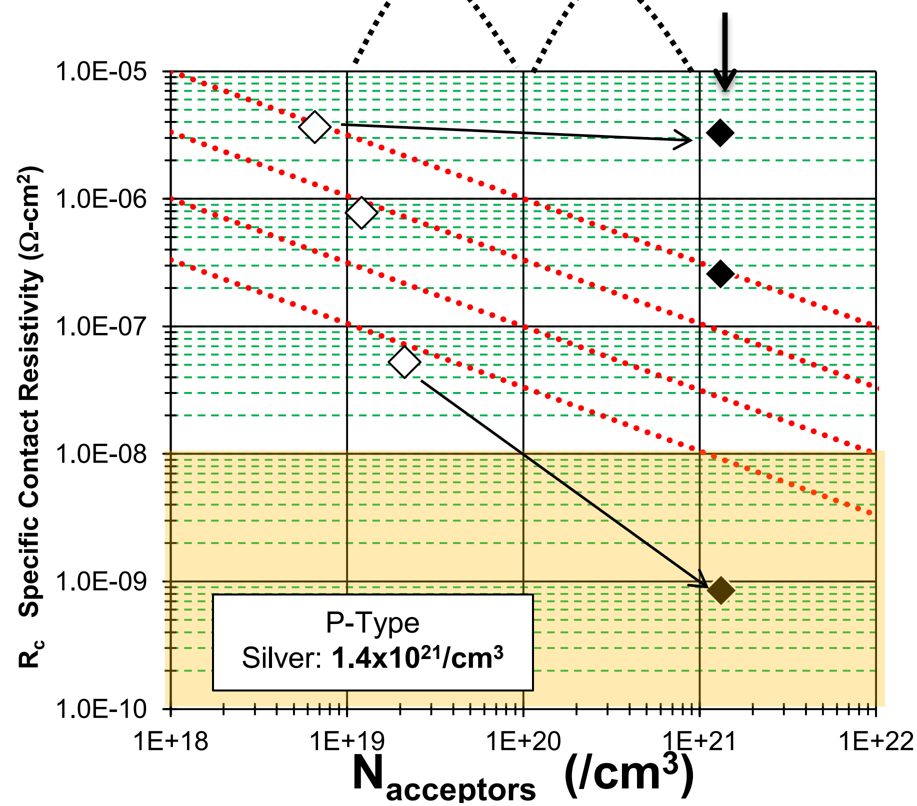
Controlling Contact Resistivity

- **Increase interface doping:**
  - *ion-implantation*
  - *benchmark – Ni metal*
- **Theoretical Prediction:**
- **Preliminary…**

$$R_c \propto \frac{1}{\sqrt{N_{d,a}}}$$



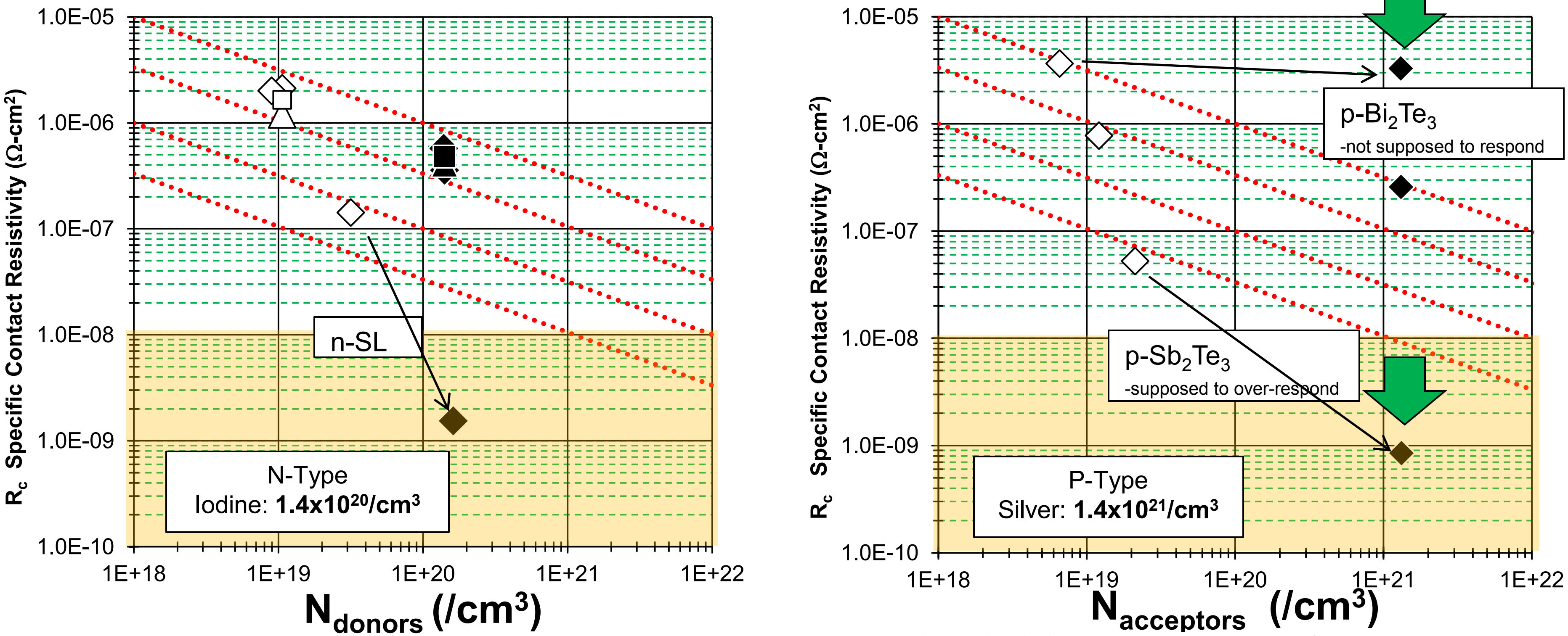




Controlling Contact Resistivity

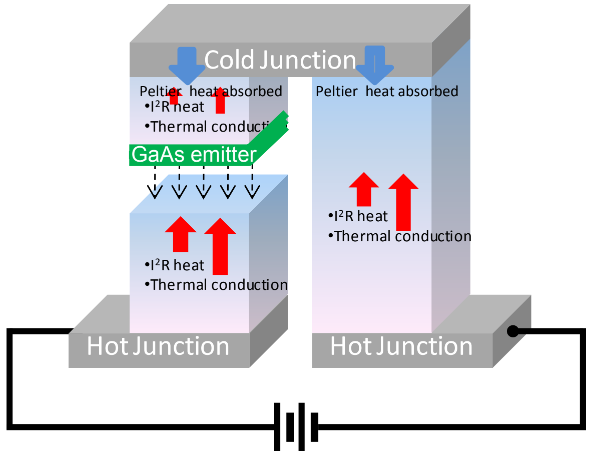
- **Iodine in Sb_2Te_3, Bi_2Te_3 is very well behaved w.r.t. theory**
  - **$I:Bi_2Te_3$** should be an n-type dopant, 1 electron per iodine
- **Silver is consistent with behavior in bulk:**
  - **$Ag:Bi_2Te_3$** should be an n-type dopant…J. Cui et. al. Journ. Sol. State Chem., Vol. 180 , p. 1158 (2007)
  - **$Ag:Sb_2Te_3$** generates 1.7 holes-per-Ag…J. Navratil, et. al. Journ. Sol. State Chem., Vol. 140 , p. 29 (1998)
- **Detection Limit**

For pure Bi_2Te_3, Ag is an n-type dopant

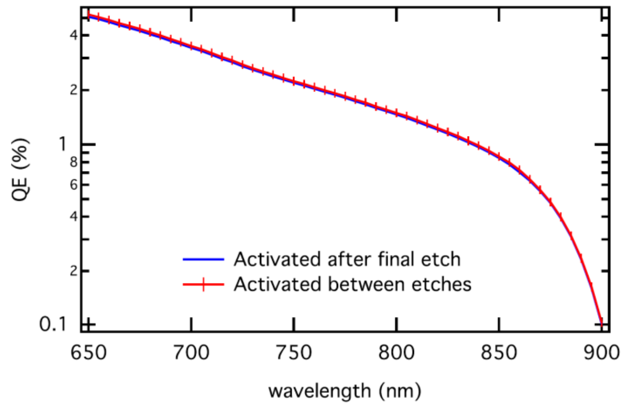


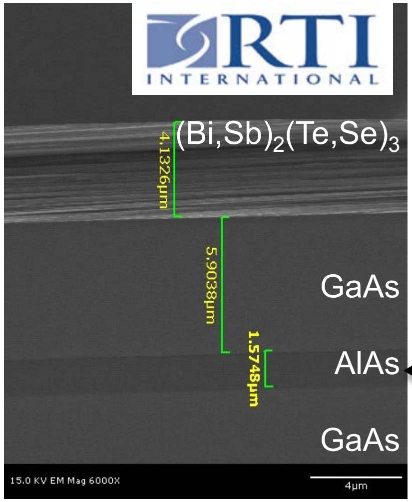
Field Emission

- **Conceptual Approach:**
  - Break physical continuity
  - Obviate thermal conduction
  - Electrical continuity by field-emission across gap



- **Experimental Progress:**
  - •Gary Bulman, Jonathan Pierce
    RTI International
  - •Gregory Mulhollan, John Bierman
    Saxet Surface Science
  - "quality" = photo-yield





Successfully grown $(Bi,Sb)_2(Te,Se)_3$ on GaAs/AlAs/GaAs etch-release structure

Etch/remove subst. (below)

-activated freed surface
-observed photo-emission

- **Continue to Develop (device)**

Summary

- **Army Application:** **M1A2**
- **Accurate Measurements:**
  - Seebeck Coefficient
  - Thermal Conductivity
  - Comparison to device
- **Parasitics of Devices:**
  - Increase interface doping drops R_c
  - Implantation is very reproducible.
  - Choose the right dopant
- **Field Emission:**
  - Approach
  - Etch-release layers have been demonstrated
- **ARL:** ***partner***