Performance Improvement of Thin-Film Thermoelectric Devices for Energy Harvesting and Cooling Applications

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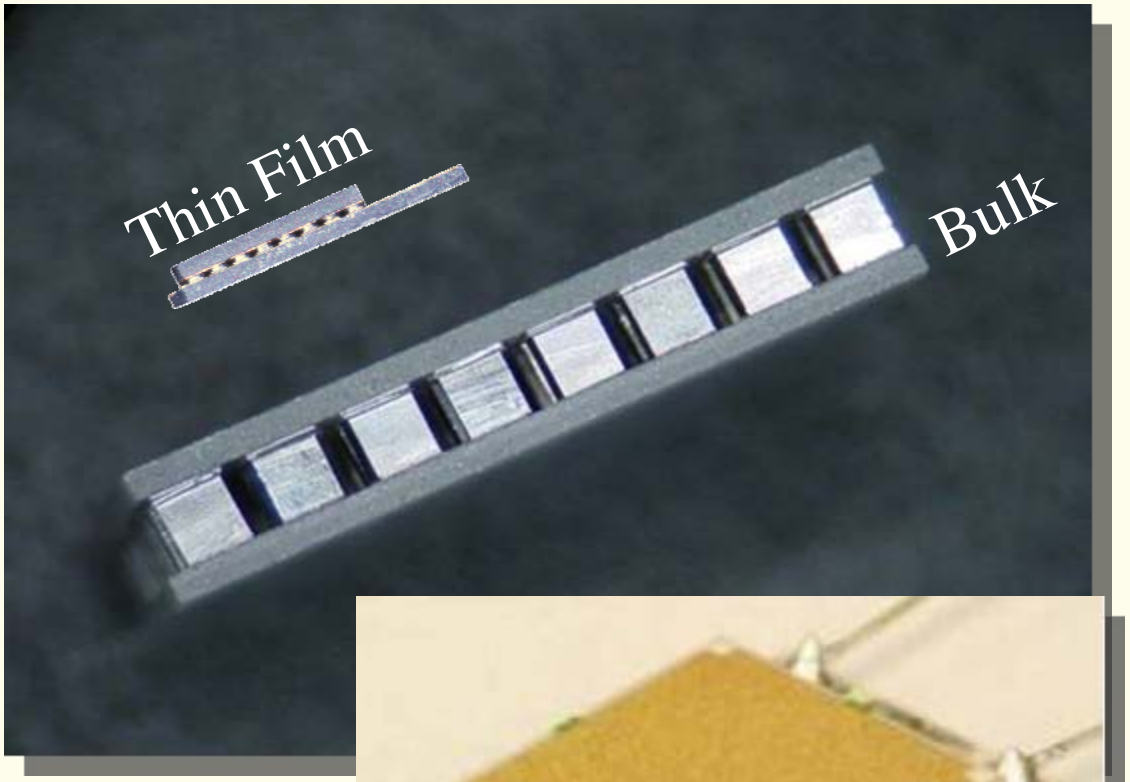
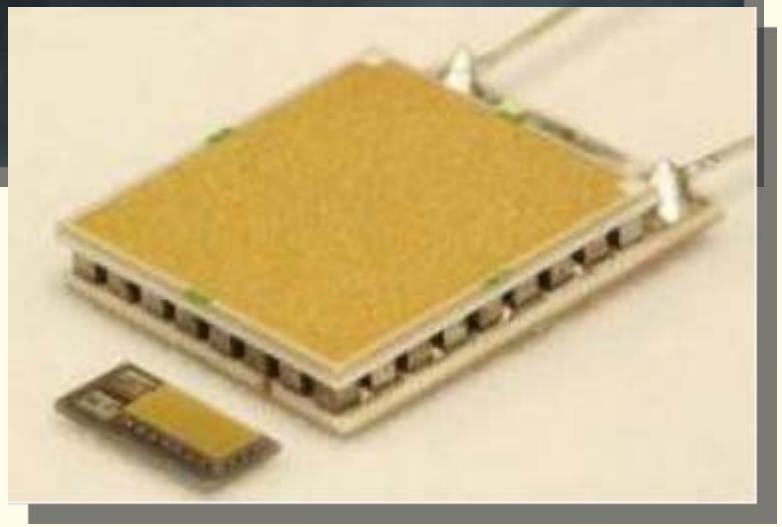
Introduction to Nextreme Thermal Solutions

- Founded December, 2004
  - Spin-off from RTI International, a $600M nonprofit research organization, http://www.rti.org
- Financing
  - Series A Venture Financing: $14M
  - Series B Venture Financing : $13M (July '08)
    - Chart Ventures, RedShift Ventures, Harris & Harris, In-Q-Tel, RTI, Itochu Corporation, Itochu Technology Ventures
  - Two Strategic Investments: $8M ('09)
- 35 employees
- Located in Durham, NC

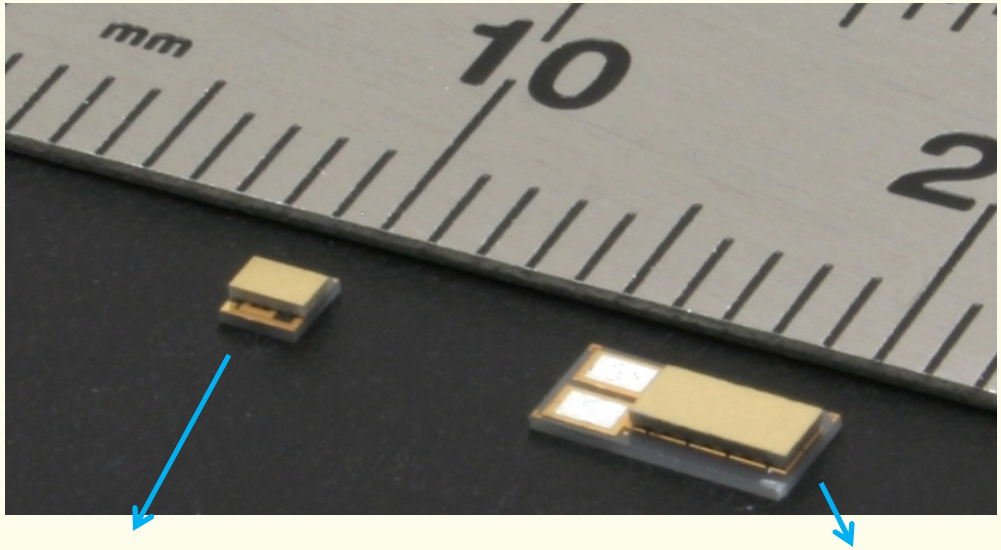
Why Thin-Film?

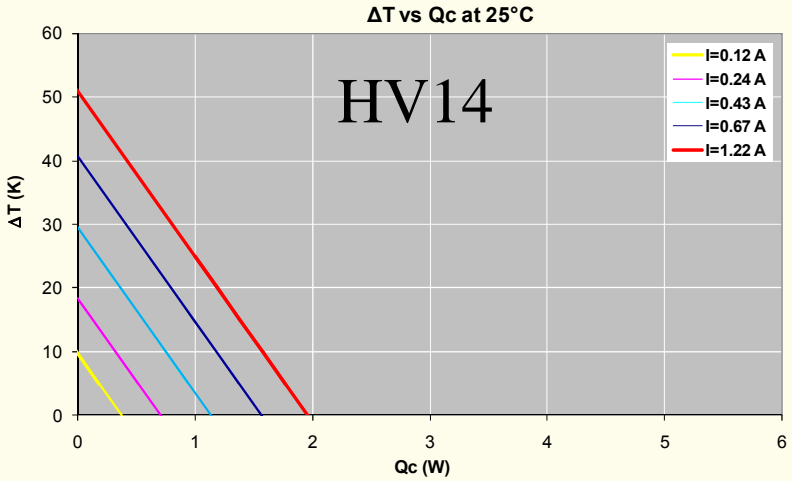


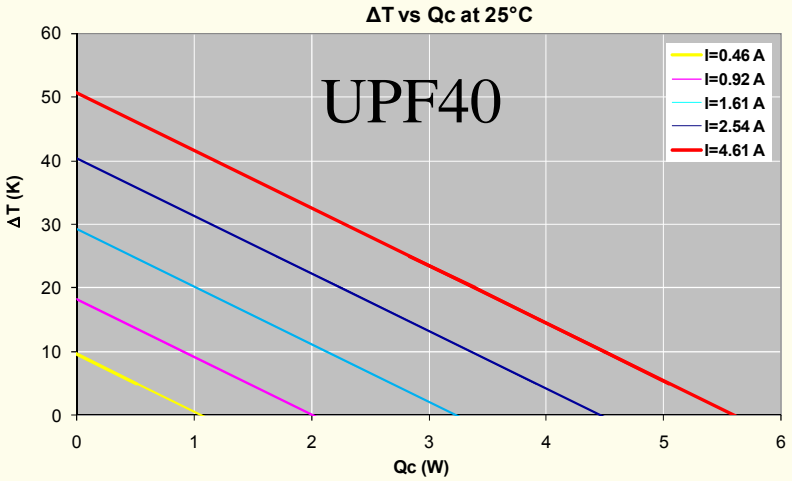


- Form Factor
  - Reduce thickness
  - Reduce footprint
  - Reduce weight
- Integration: directly into components
- Performance: pump more heat per unit area
- Cost:
  - Reduce manufacturing costs
  - Reduce use of TE material

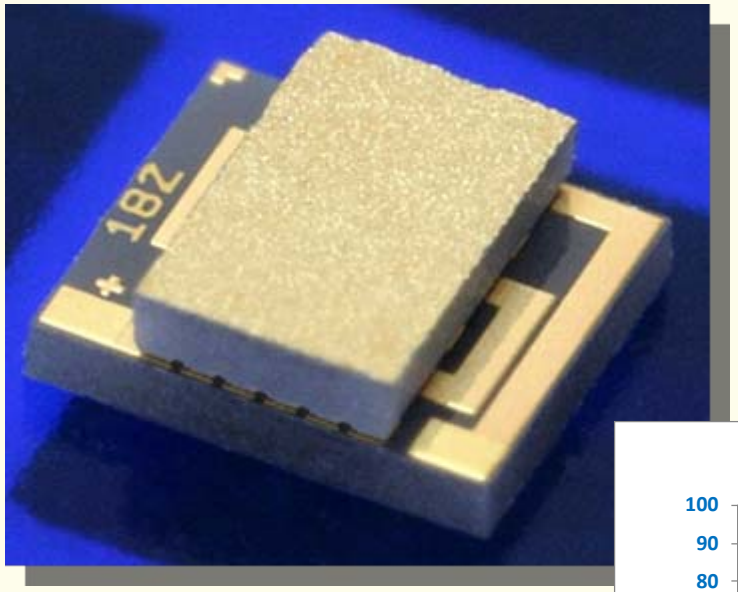
Today's Core Products Cooling Performance

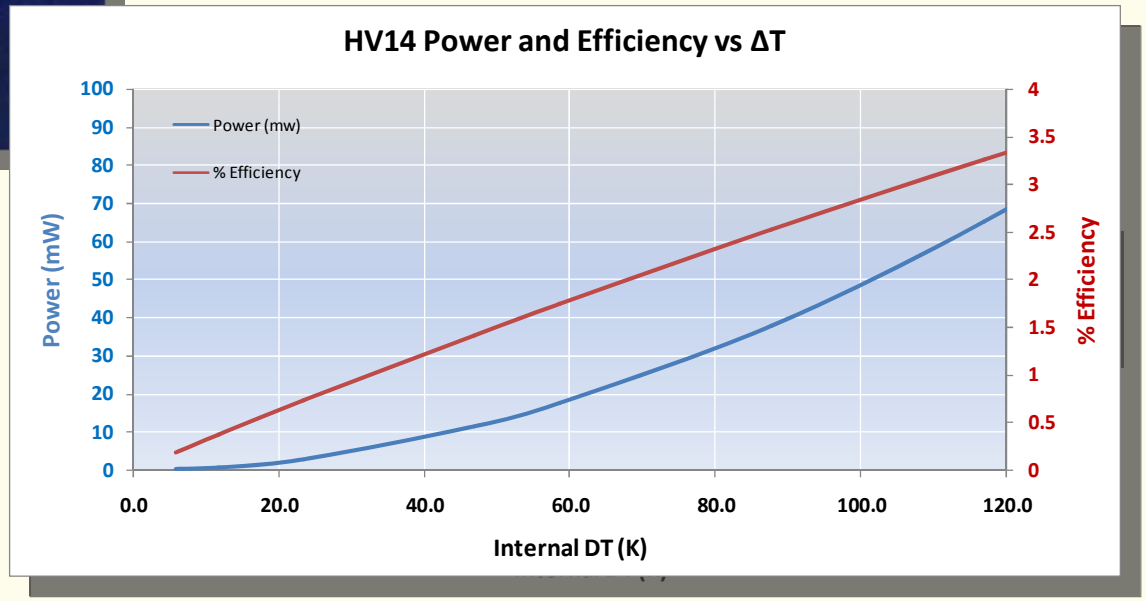






HV14 Thermoelectric Generator (TEG)

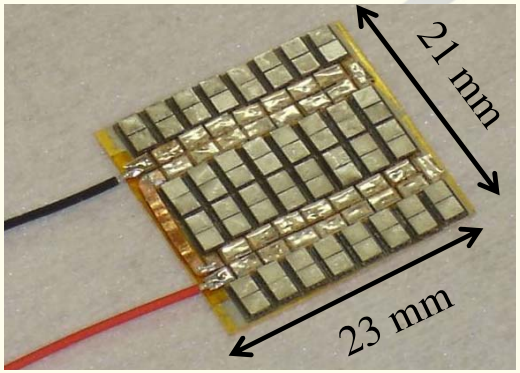




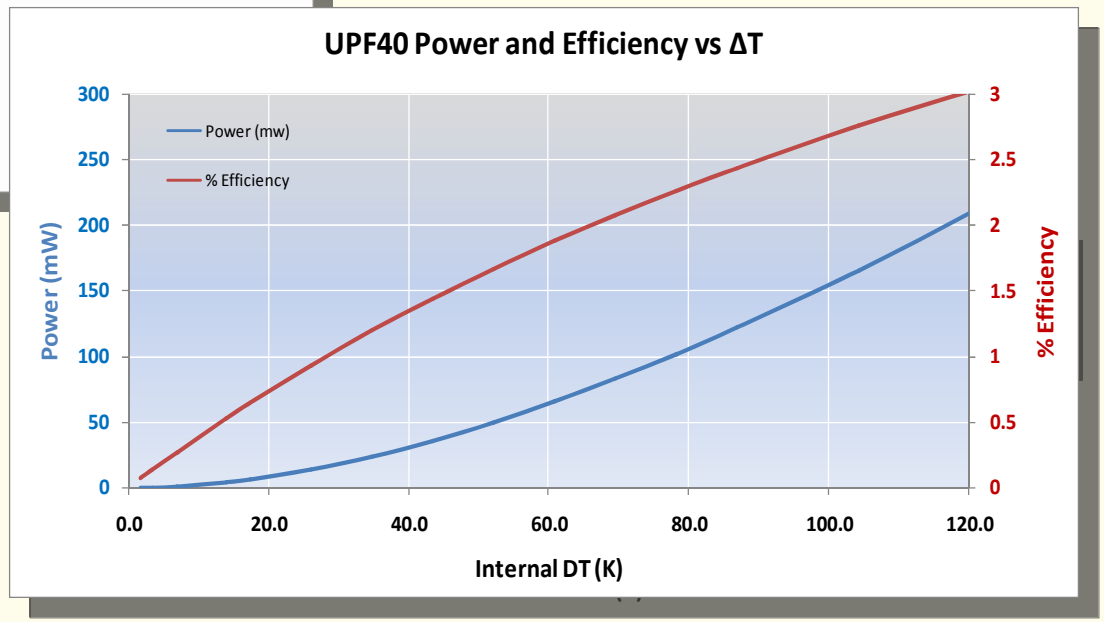
At 120°C DT

- **20 W/g**
- **2.6 W/cm^2**
- **43 W/cm^3**

UPF40 Thermoelectric Generator (TEG)



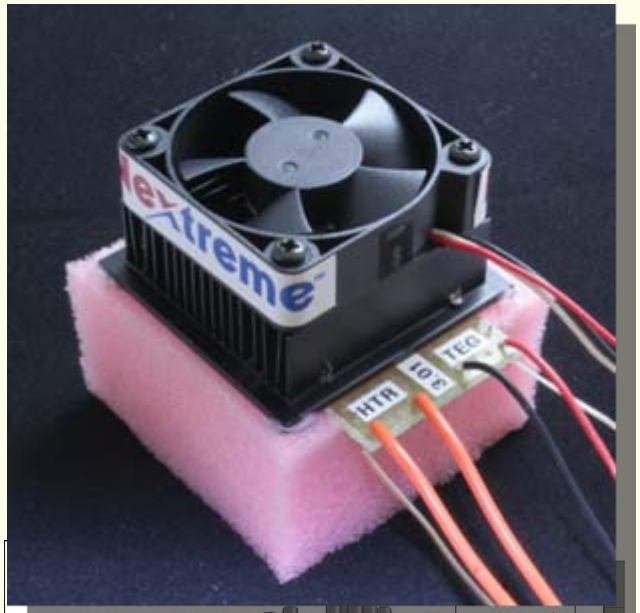
32 Unit Array

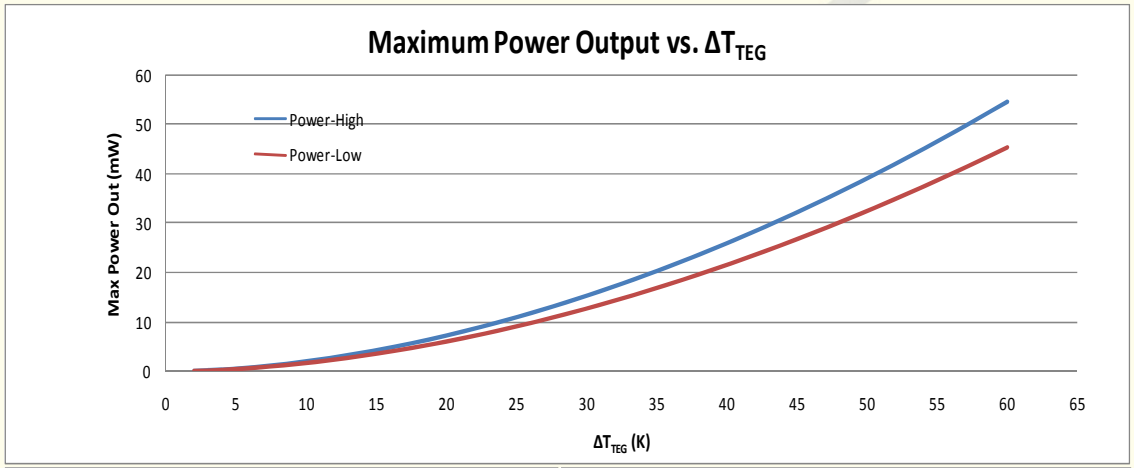


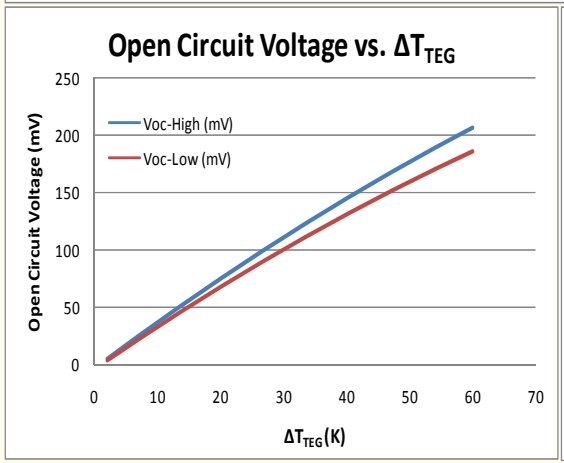
At 120°C DT

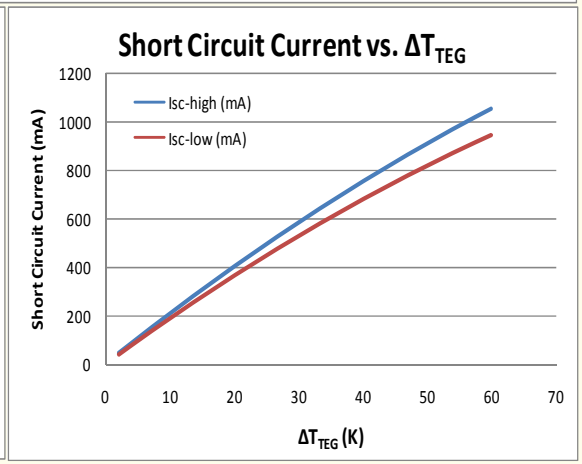
- **13 W/g**
- **1.6 W/cm^2**
- **27 W/cm^3**

UPF40 – TEG Evaluation Kit



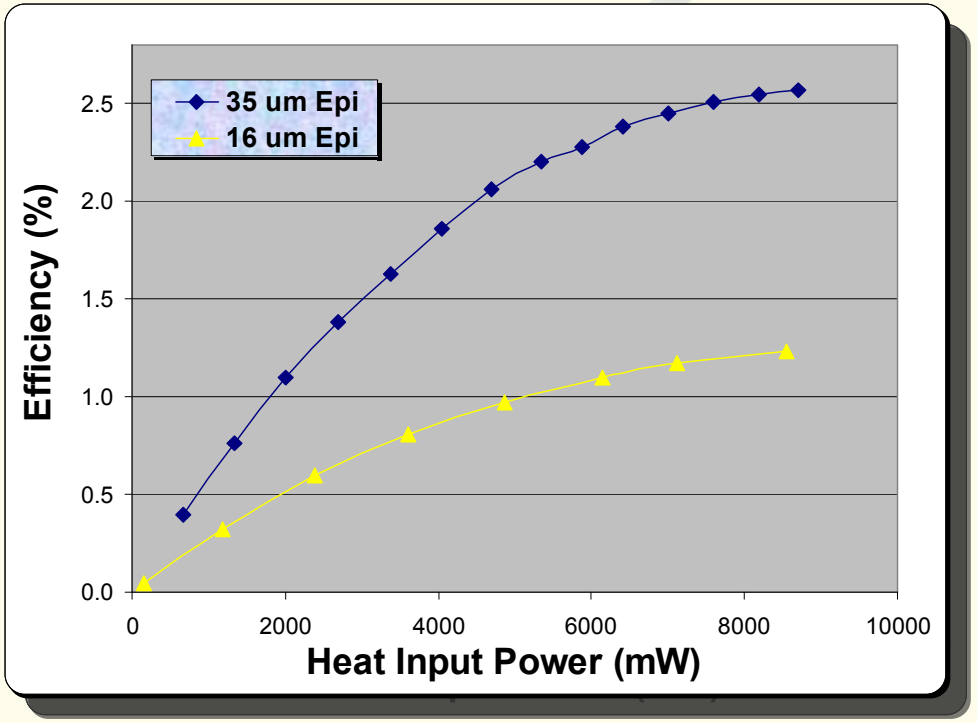




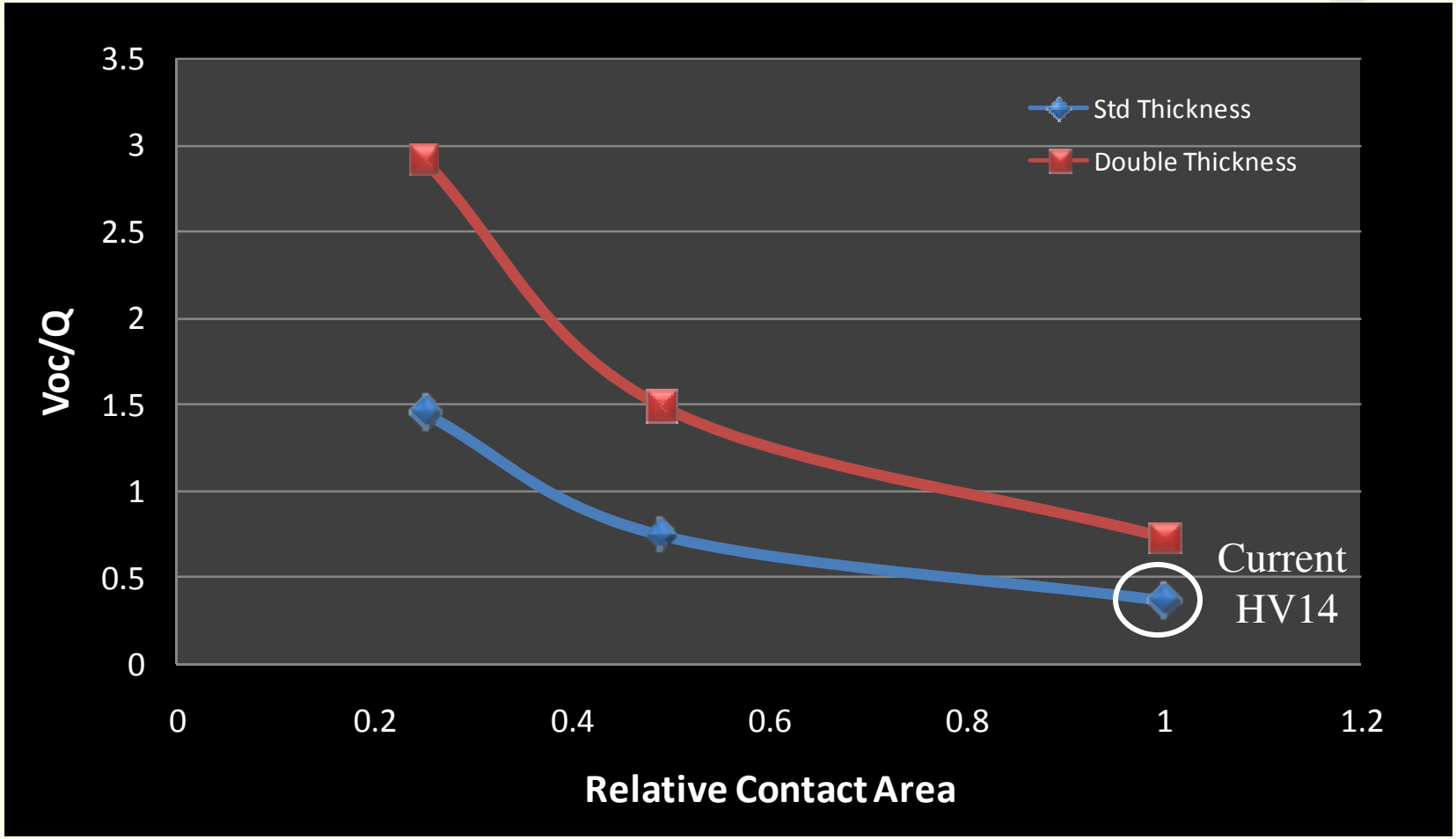


TEG Efficiency Improvement
North Carolina Green Business Fund

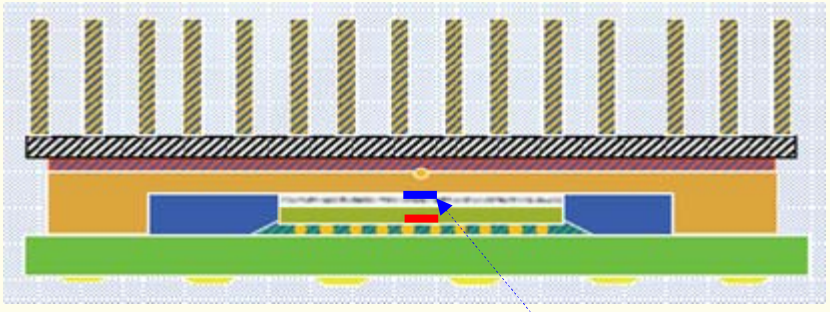
- Nextreme awarded one year program to improve TEG efficiency
- Synthesized n-type BiTeSe and p-type BiSbTe epitaxial films in excess of 30 um thick
  - Double typical thickness
  - Retained all material specifications
- Doubled conversion efficiency of baseline devices for given heat flux.

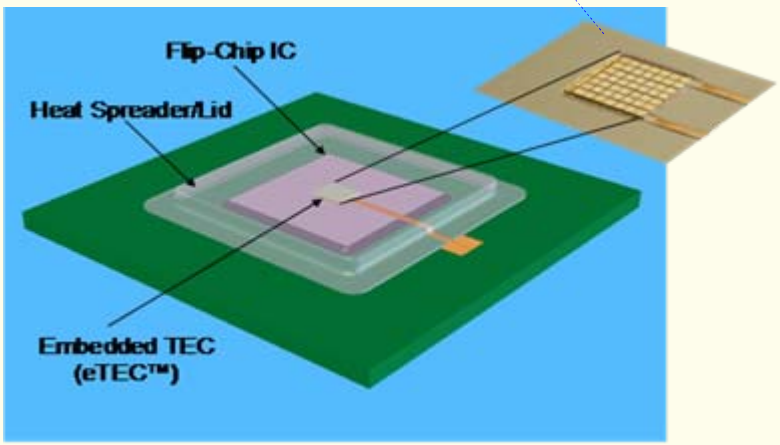


Improving Output Voltage
V_{oc}/Q vs Contact Area

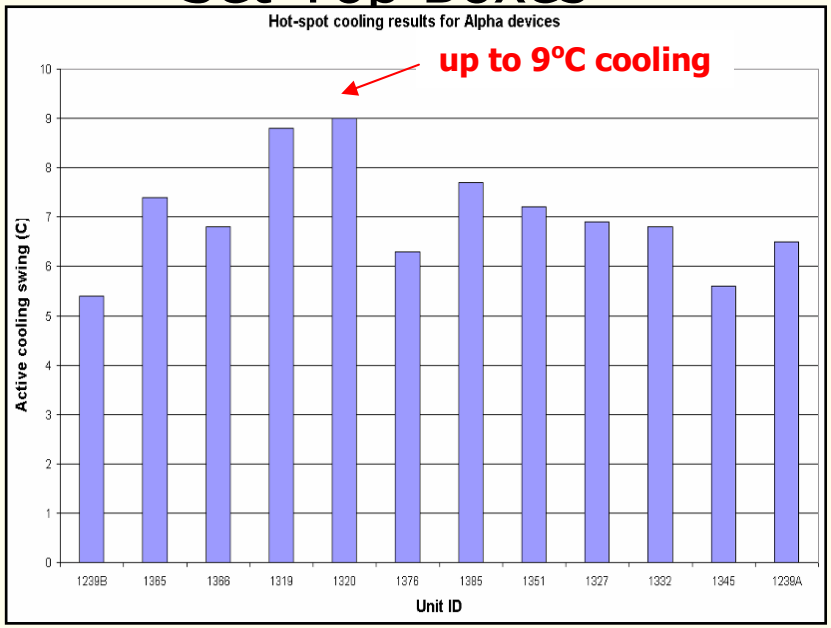


Applications
Semiconductor Hot-spot Cooling





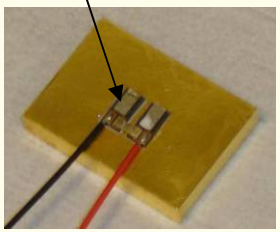
- Servers & Workstations
- High-performance PCs
- Cellular infrastructure
- Set-Top Boxes

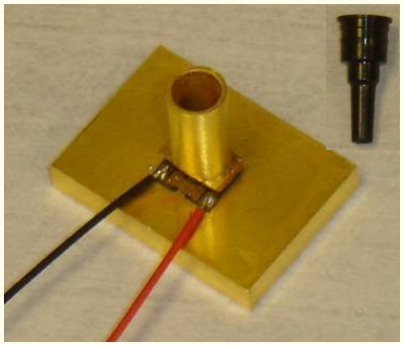


Intel validation (Saguaro TTV)

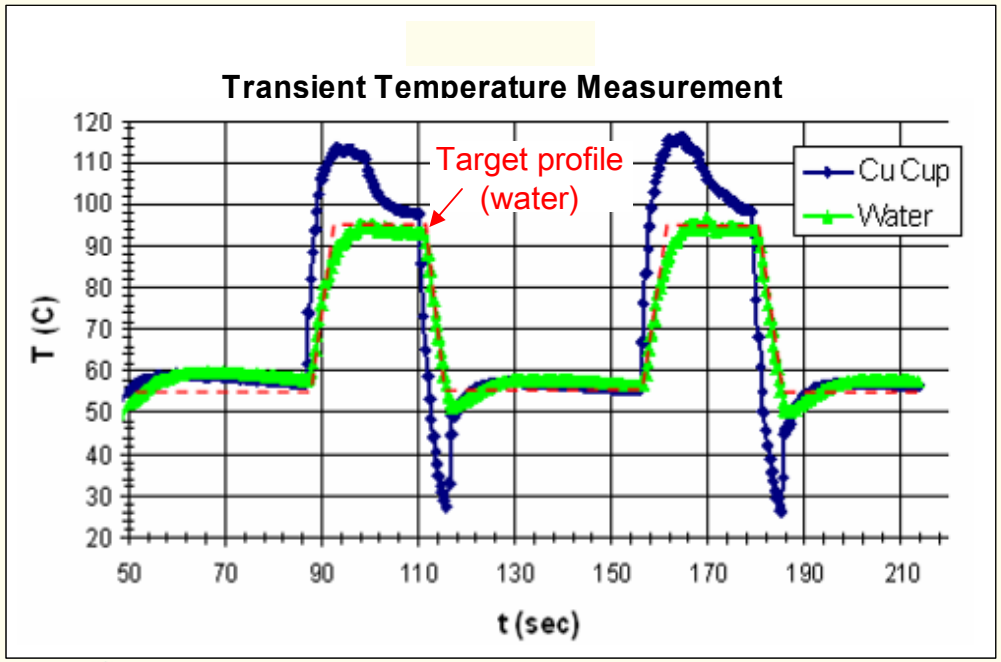
Applications: Industrial Equipment
Thermal Cycling--PCR

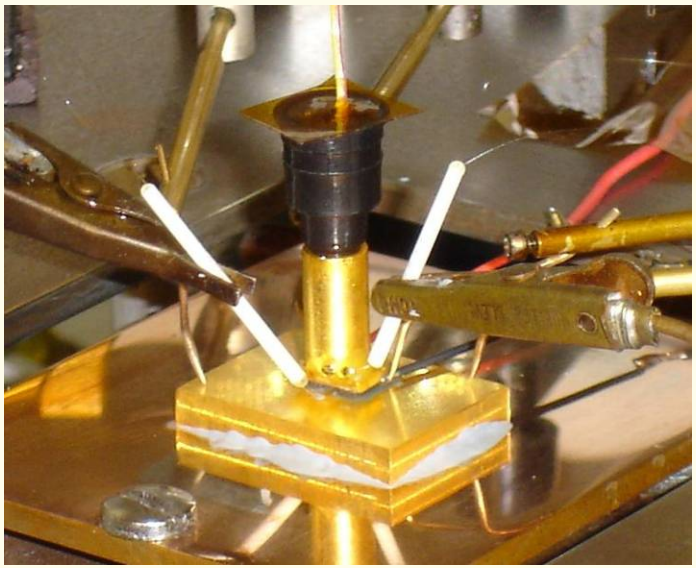
2 UPF 40s





– *Independent testing of thermal cycling showed TFTEC to be 9.5x more efficient & 2.5x faster than traditional solutions*



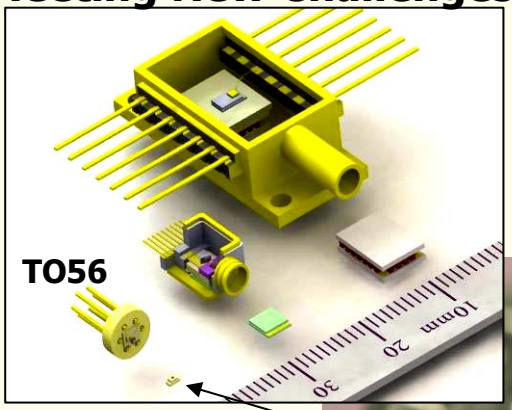


Test Set-up

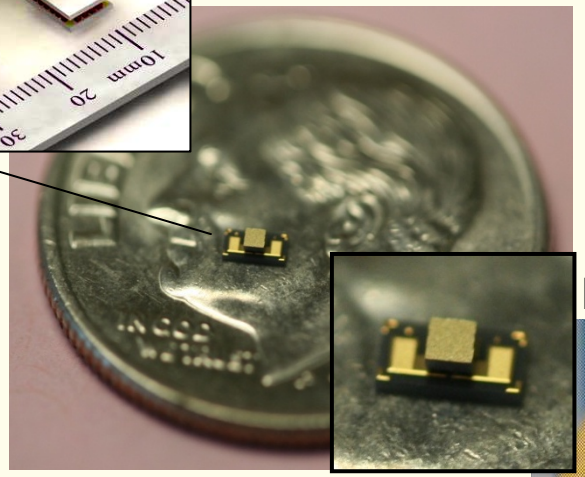
Applications: Photonics

Telecom—Laser Diode

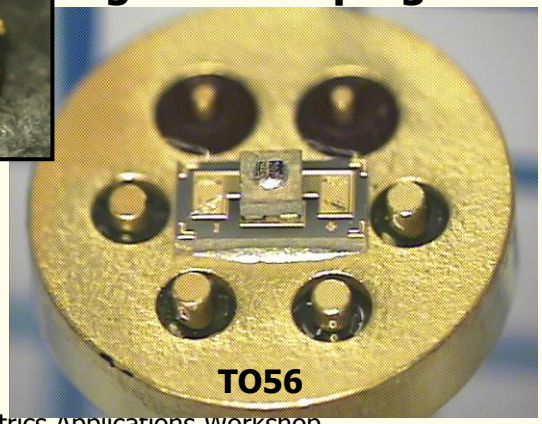
Meeting New Challenges



Smallest Size



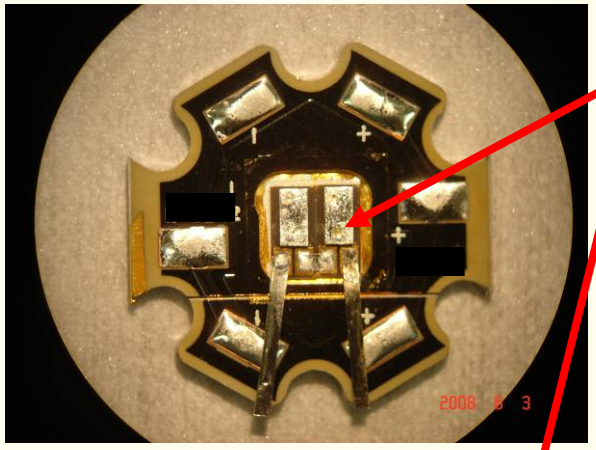
Highest Pumping Power



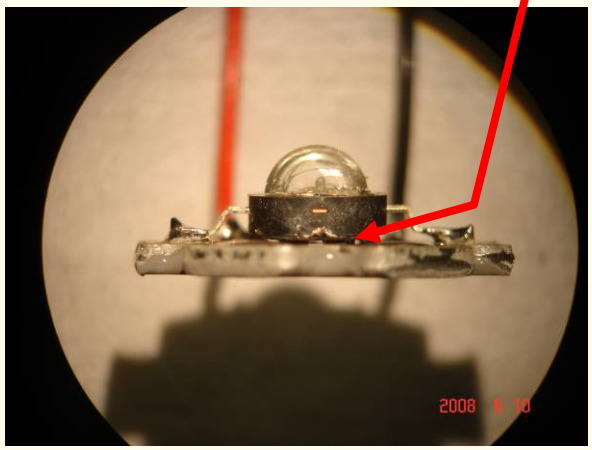
– Nextreme has demonstrated necessary size & performance as well as 4x efficiency in laser diode cooling

Applications: Photonics
LED Cooling

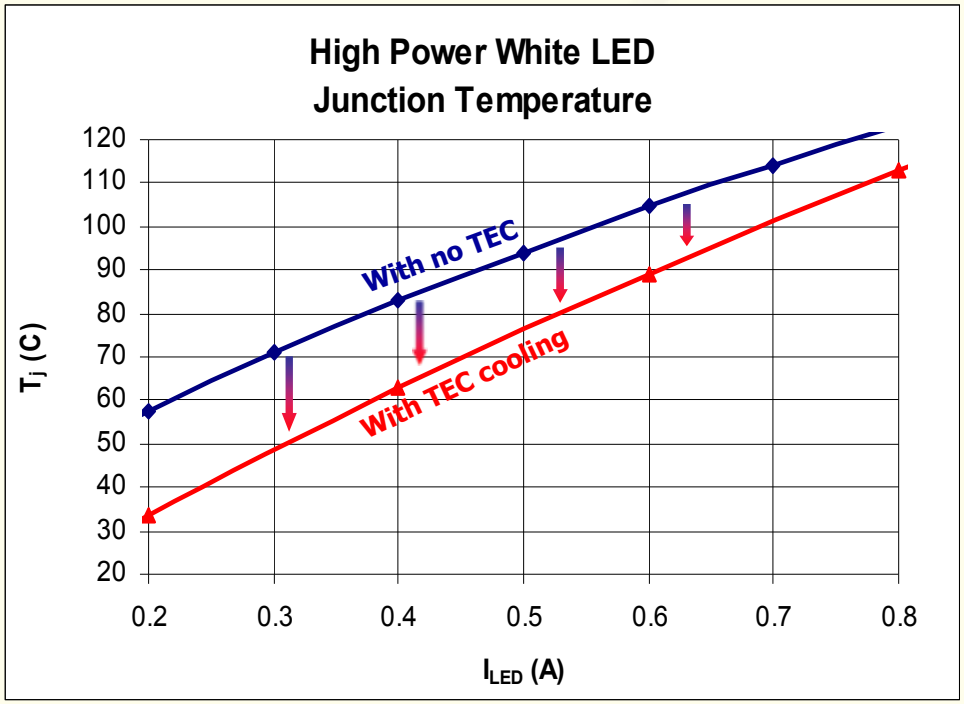
2 UPF40 Modules



Top view w/o LED



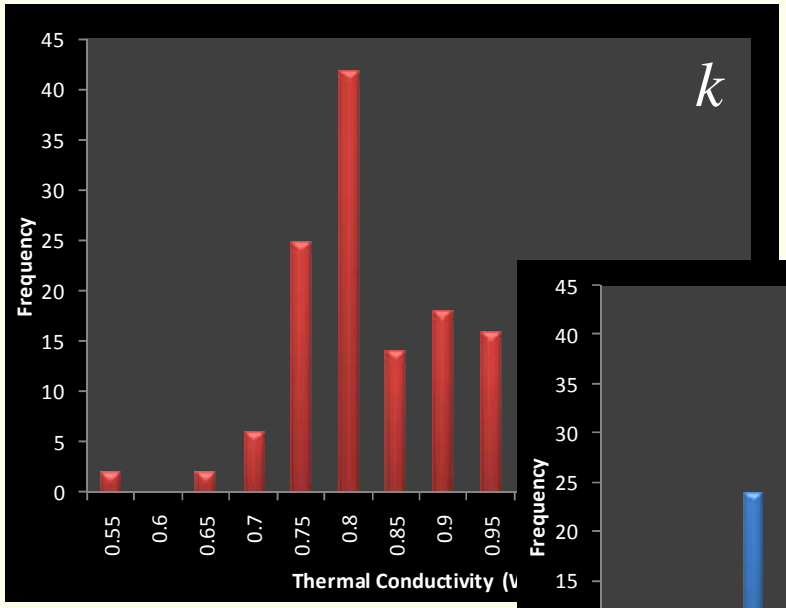
Side view of complete assembly

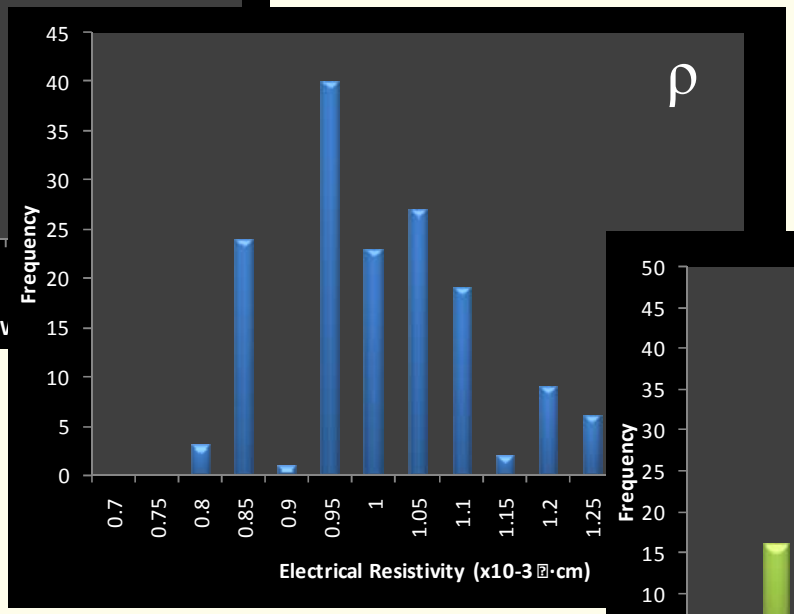


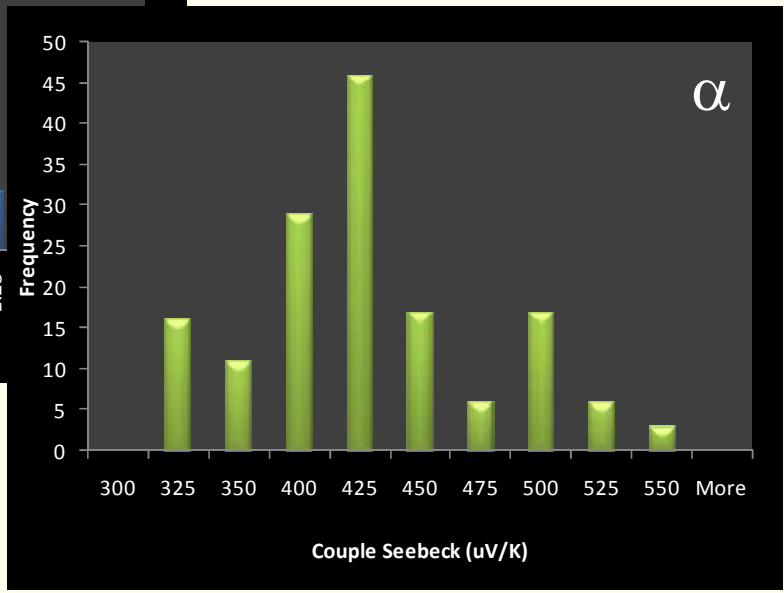
- TEC cooling lowers the LED junction temperature by ~20°C
  → Increased LED intensity and/or efficiency
  → Increased long-term reliability

Performance Headroom

Material Property Distributions from Module Extractions

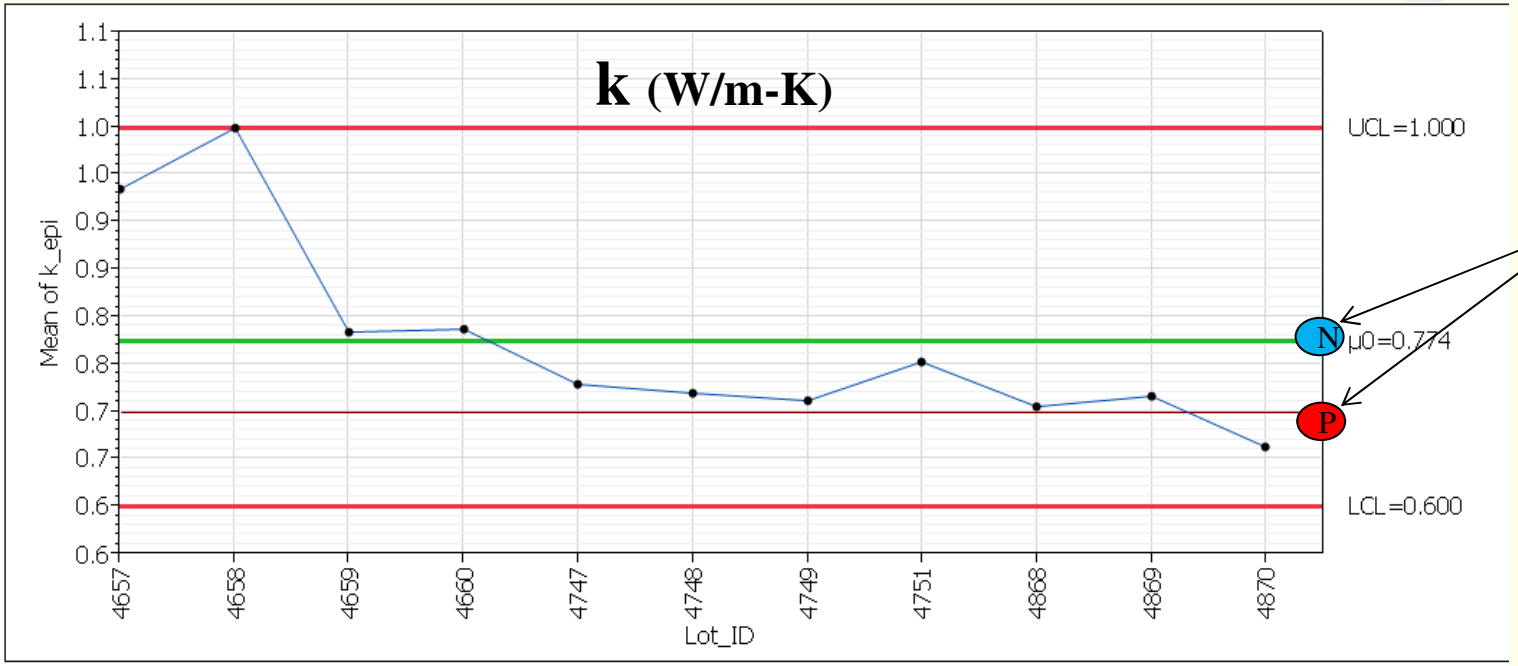






Thermal Conductivity Measurements

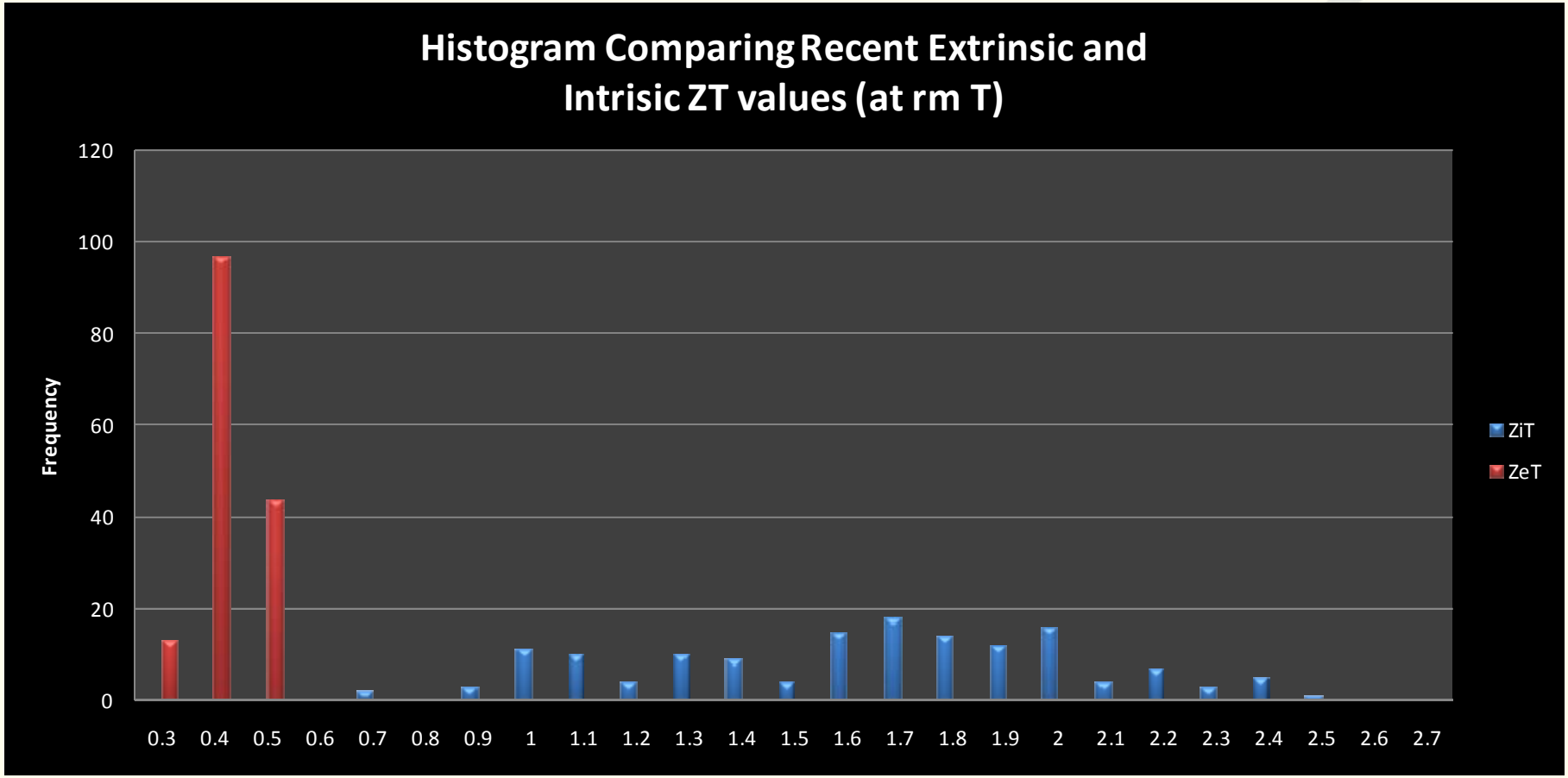
Data Extractions Corroborated by Through-Plane *k* Measurements



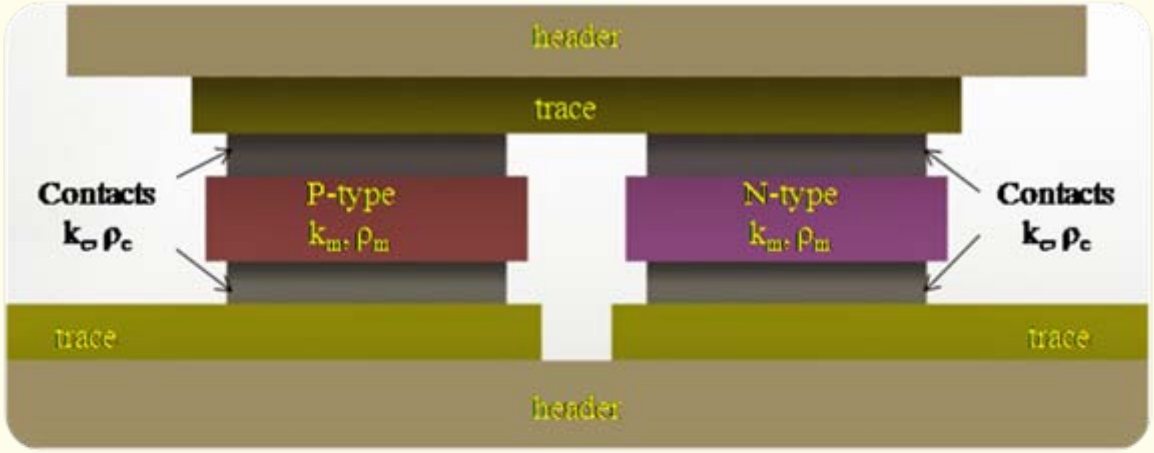
- Method: Time-resolved Thermoreflectance
- Conducted by Dr. David Cahill, University of Illinois, Urbana-Champaign

N-type thermal conductivity: 0.78 W/mK
P-type thermal conductivity: 0.68 W/mK

Extracted Intrinsic and Measured Extrinsic ZT



Effect of Parasitic Losses



$$Z_e T = \frac{Z_i T}{\left(1 + 2\frac{\rho_c}{L_m \rho_m}\right)\left(1 + 2\frac{L_c}{L_m}\frac{k_m}{k_c}\right)} = \frac{Z_i T}{(1+\Gamma_e)(1+\Gamma_t)} = \eta_e \cdot \eta_t \cdot Z_i T$$

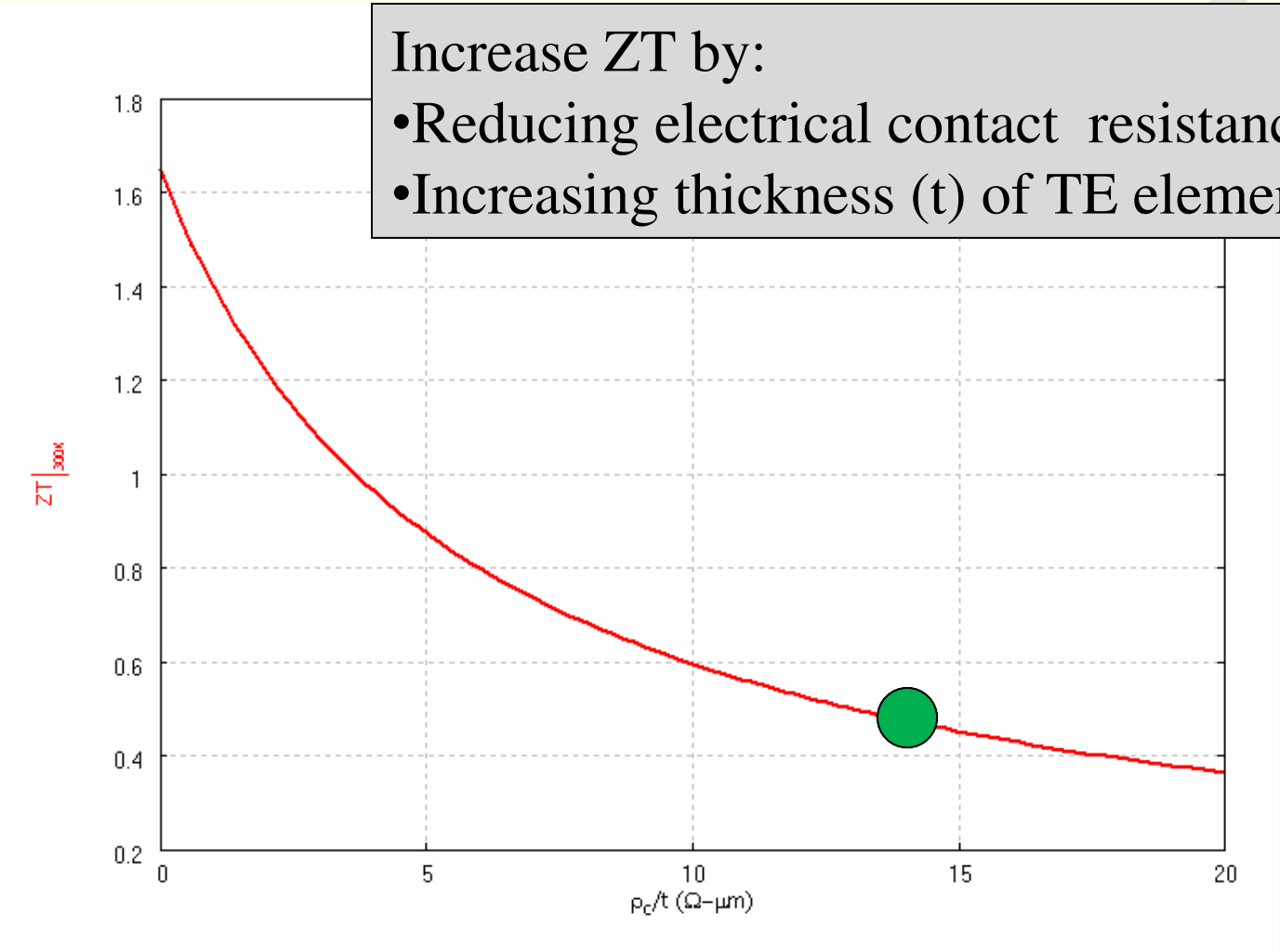
Thin film device performance is dominated by contacts to the device.

$\eta_t \sim 90\%$

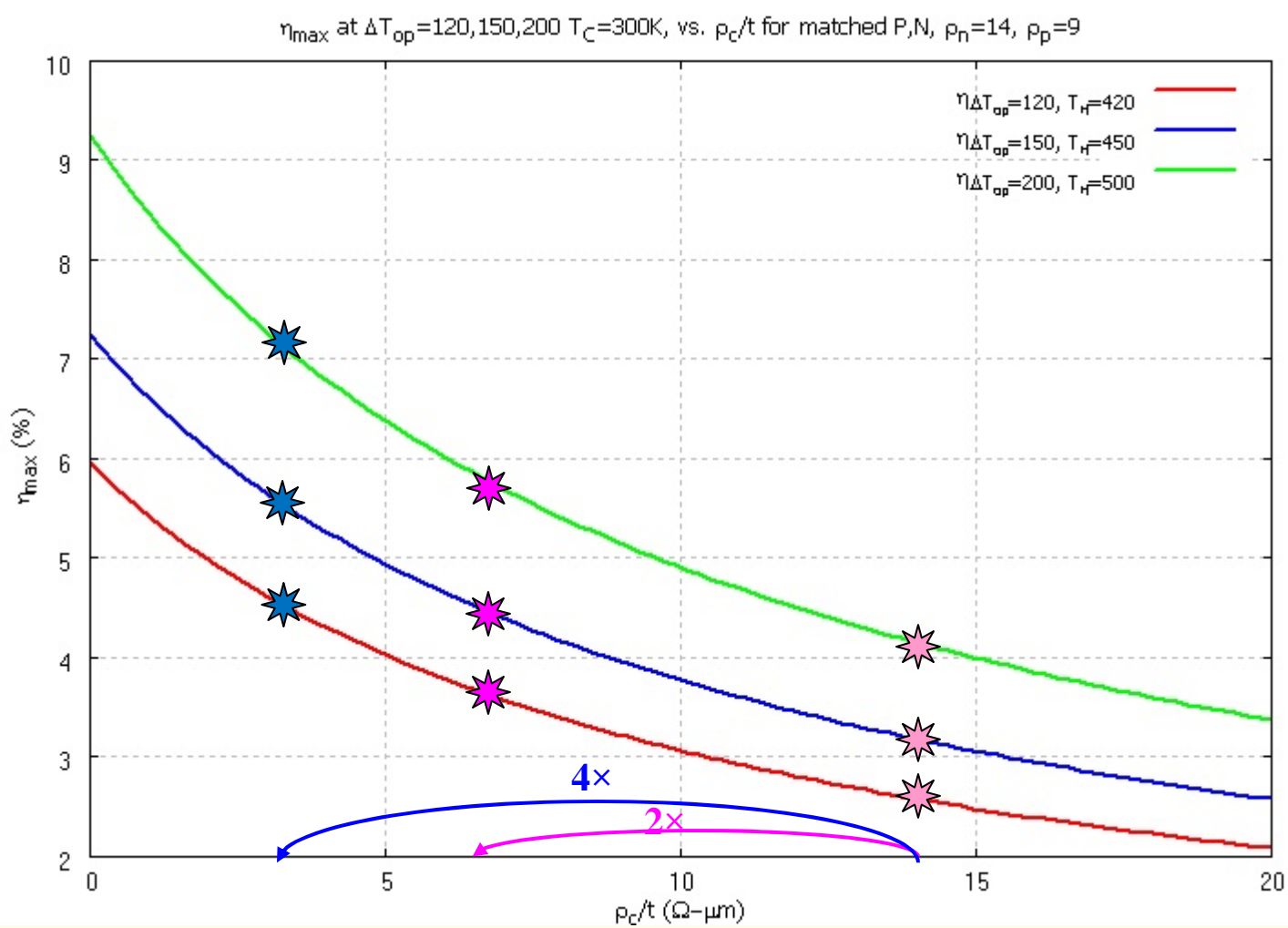
$\eta_e \sim 35\%$

Effect of Contact Resistance on Device ZT

Increase ZT by:
- Reducing electrical contact resistance ρ_c
- Increasing thickness (t) of TE elements



TEG Efficiency Improvements



Summary

- Thin film TE devices offer unique size, weight, performance and cost opportunities
- Applications vary widely
  - Micro-power
    - scalable to macro scale
  - Semiconductor hot spot cooling
  - Photonics cooling
- Improvements in performance being driven through
  - Contact resistance reduction
  - Film thickness increase
  - Contact area reduction

Thank You