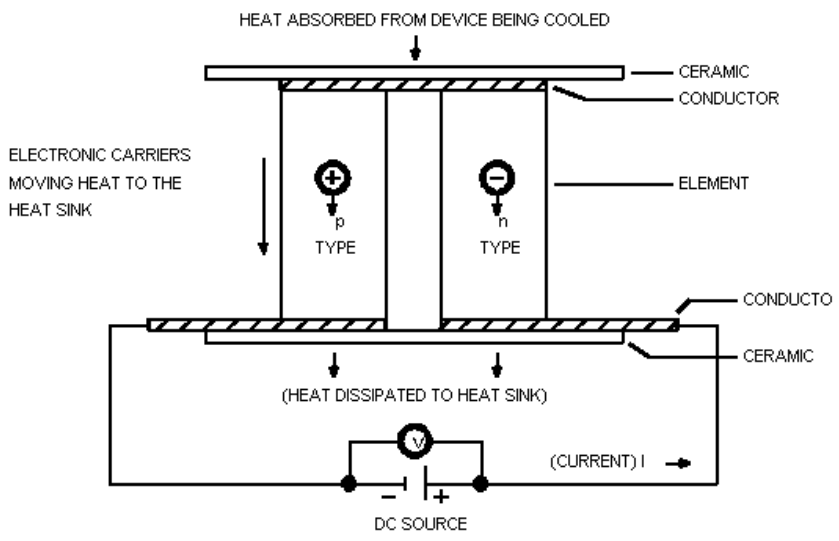
Hi-Z Technology
San Diego, California

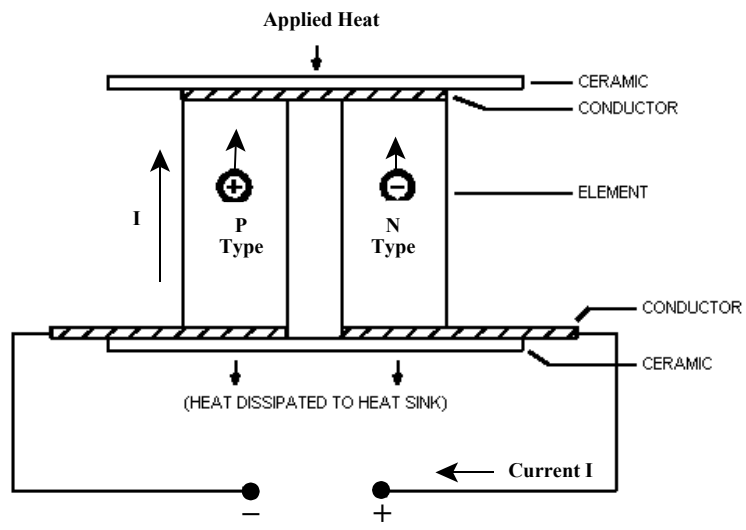
Department of Energy
High Efficiency Thermoelectric Workshop
March 24-27,2002
Loews Coronado Bay resort
San Diego, California

THEMOELECTRICITY (TE)

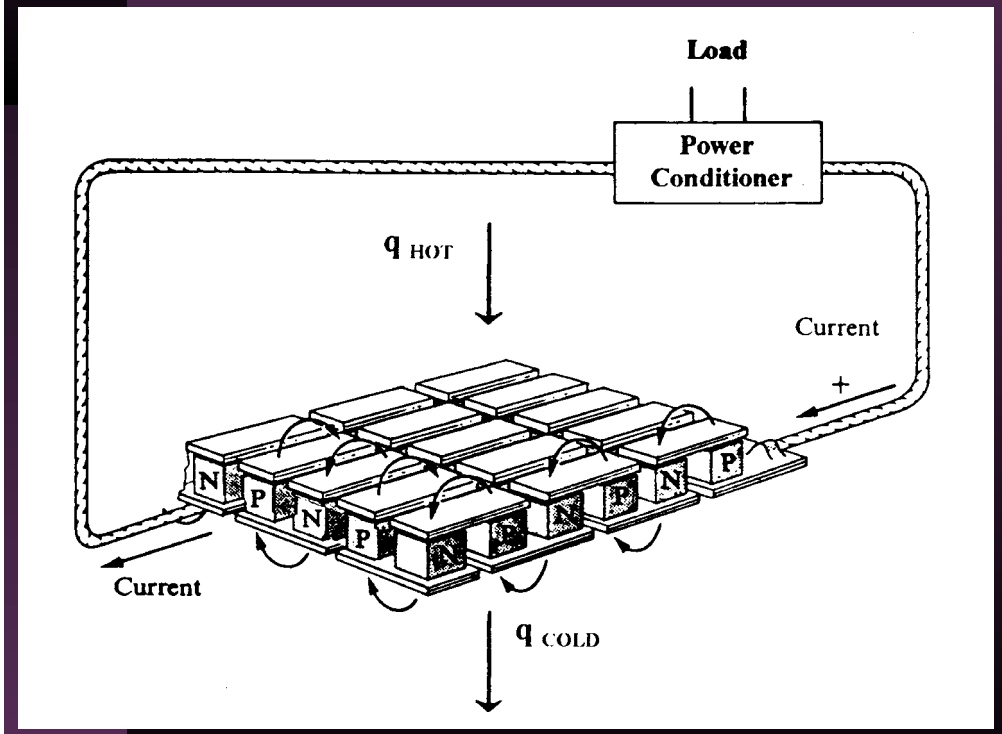
TE Cooling

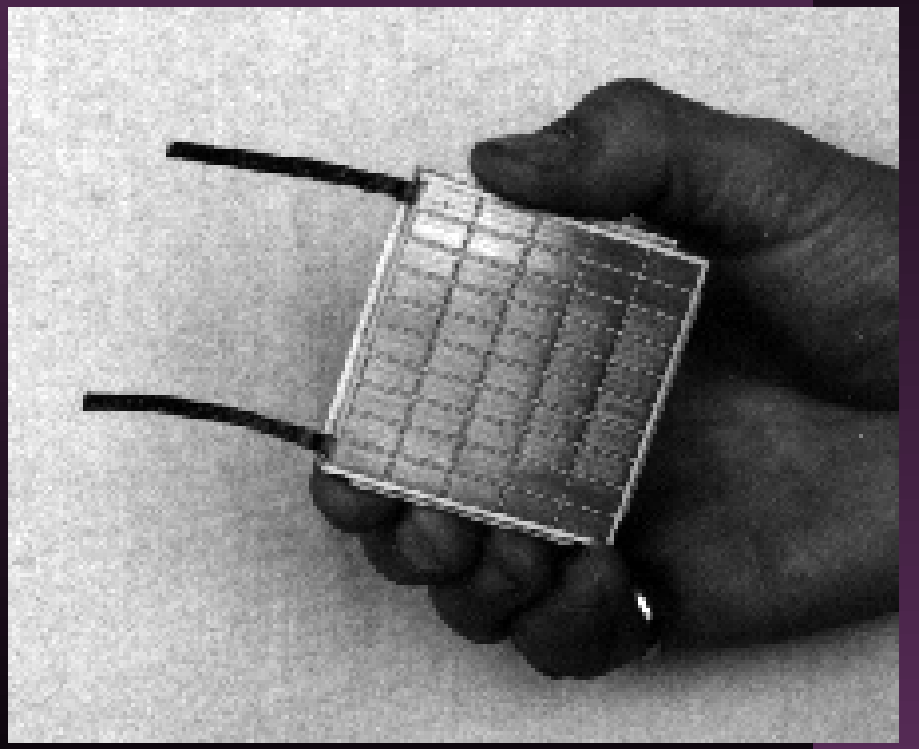


TE Power Generation



TE Module





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Quantum Well TE

Objective

Exploit the features of quantum well structures to obtain high efficiencies via high figure of merit TE materials **(Z):**

Z = "^{2}/(D.6)

where:

" = Seebeck Coefficient

D = Resistivity

6 = Thermal Conductivity

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Quantum Well TE

- Quantum-well confinement multilayer film by the adjacent barrier layers
- Active layer sandwiched between materials with band offset to form a barrier for the charge carriers
- Improvement in Z from an increased Seebeck coefficient (") from an increase in the density of states
- Significant reduction on resistivity (D) because of quantum confinement
- Significant reduction on thermal conductivity (6)
- Quantum-well (QW) effects become significant the thickness of layer < 200D

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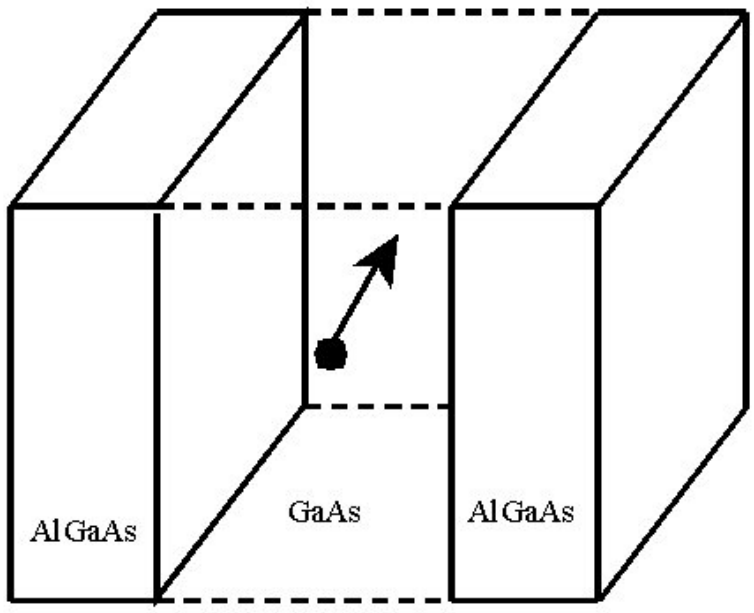
Quantum Well TE



From www.bell-labs.com

Applications

Energy conversion with high efficiency for

- Small Power Supplies
- Self Power Appliances
- Waste Heat Recovery
- Low Temperature Detector Cooling
- Environmentally Benign Systems (non CFC/HCFC cooling).
- Space Power: Solar or Isotopic
- Self Power IC
- Electronic Cooling
- Price

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Impact

- Discovery of new TE materials with high energy conversion efficiency (>20%).
- Verified that 2-dimensional QW improve TE properties.
- Verifies that ZT enhancement is possible and values much higher than 1 have been obtained.

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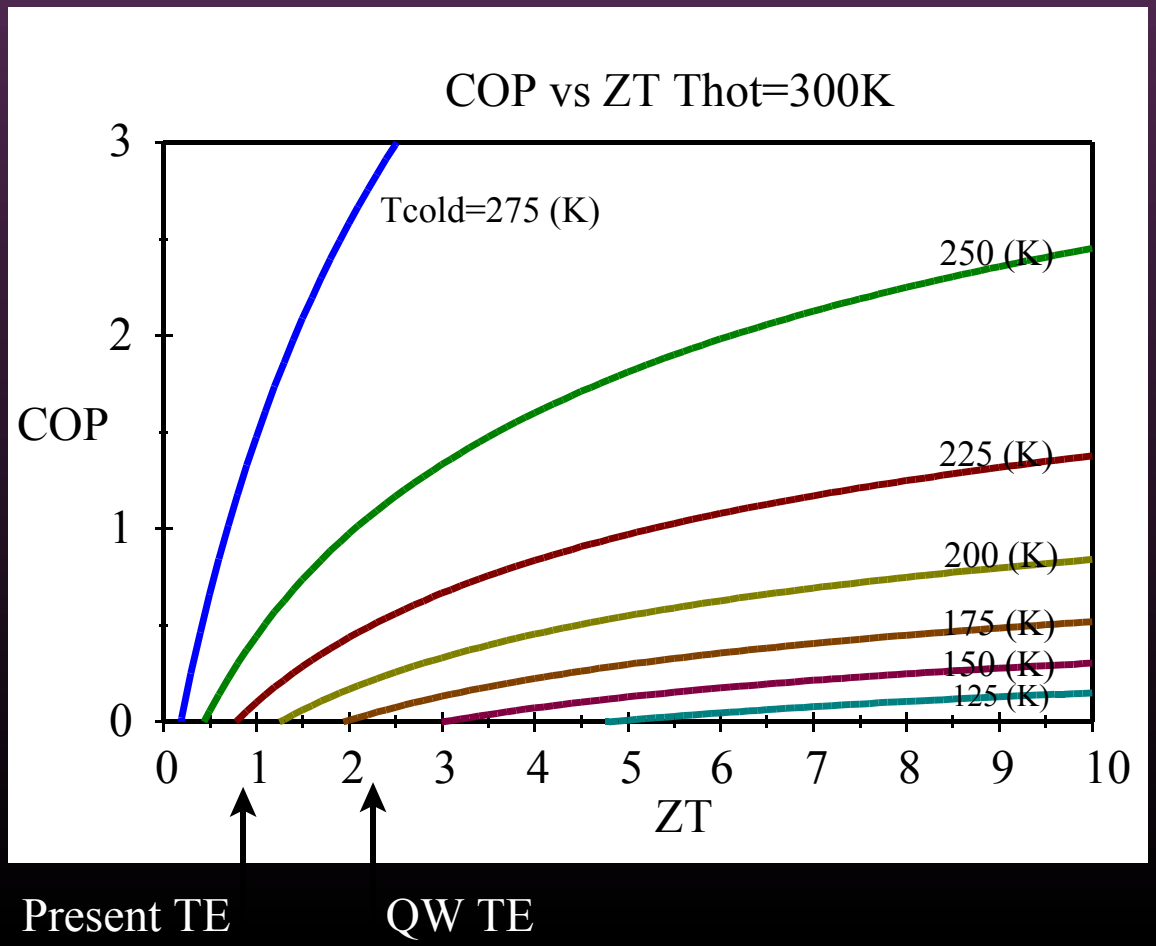
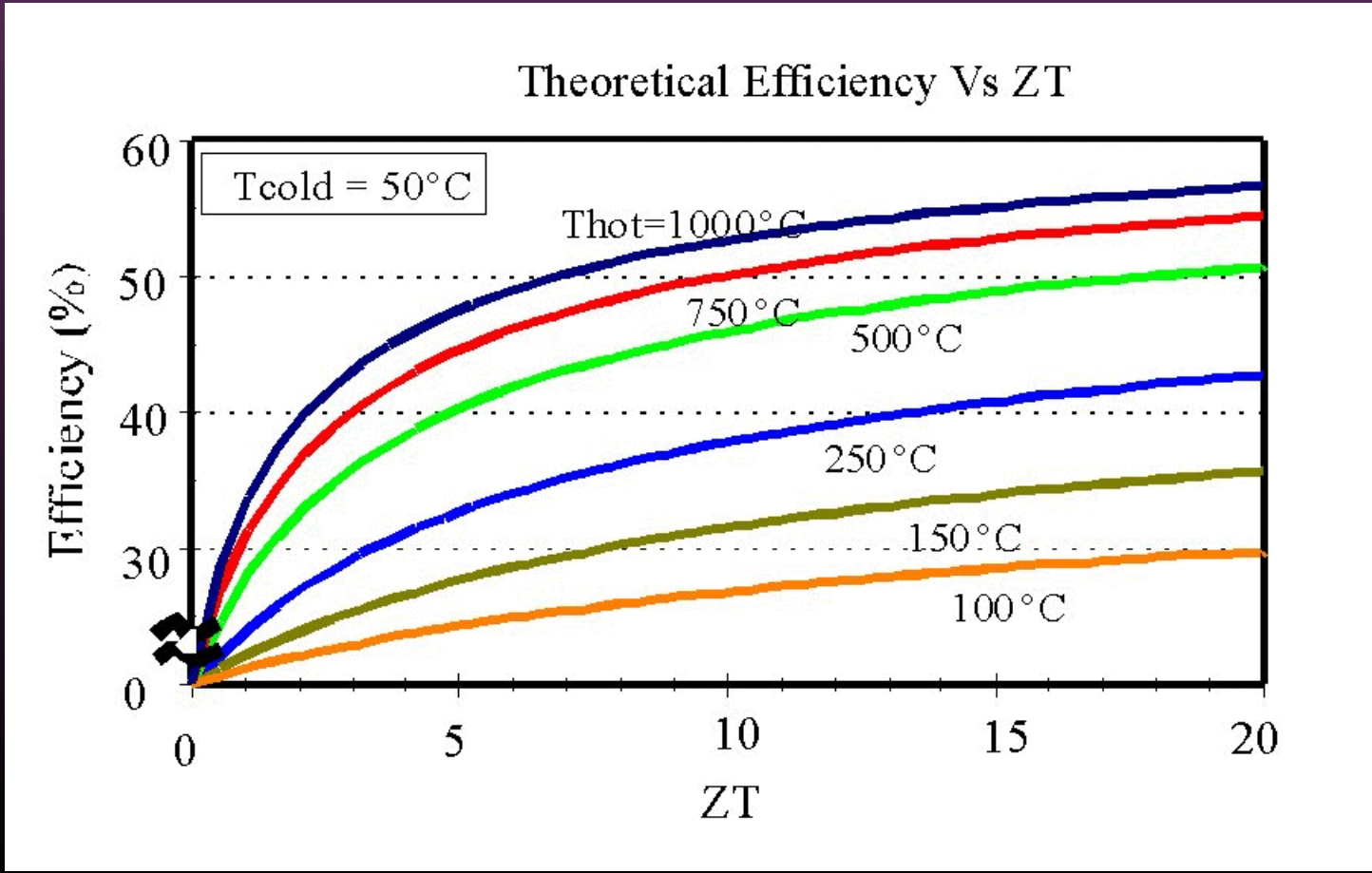
Why Large Z?

Thermoelectric Cooling



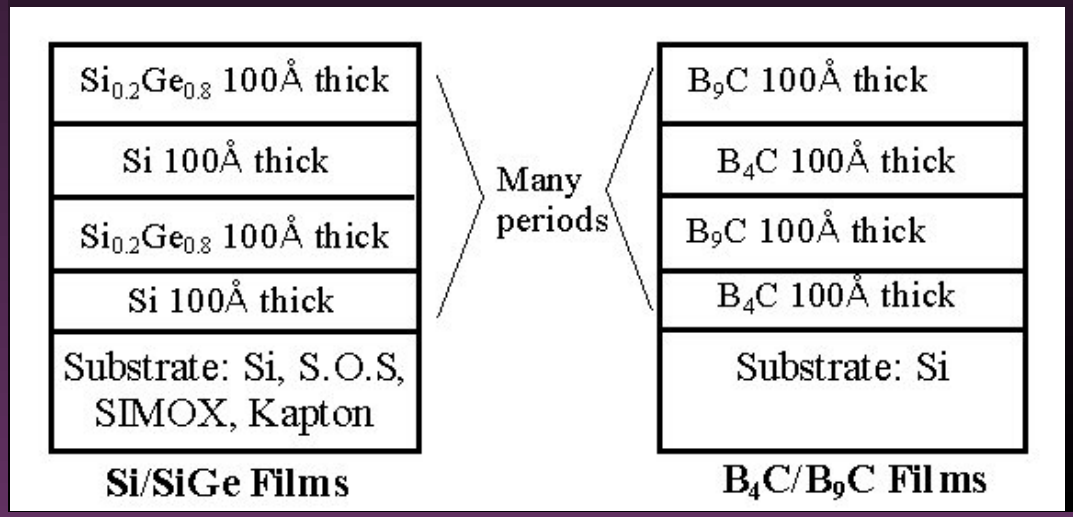
Why Large Z?

Generation of Power

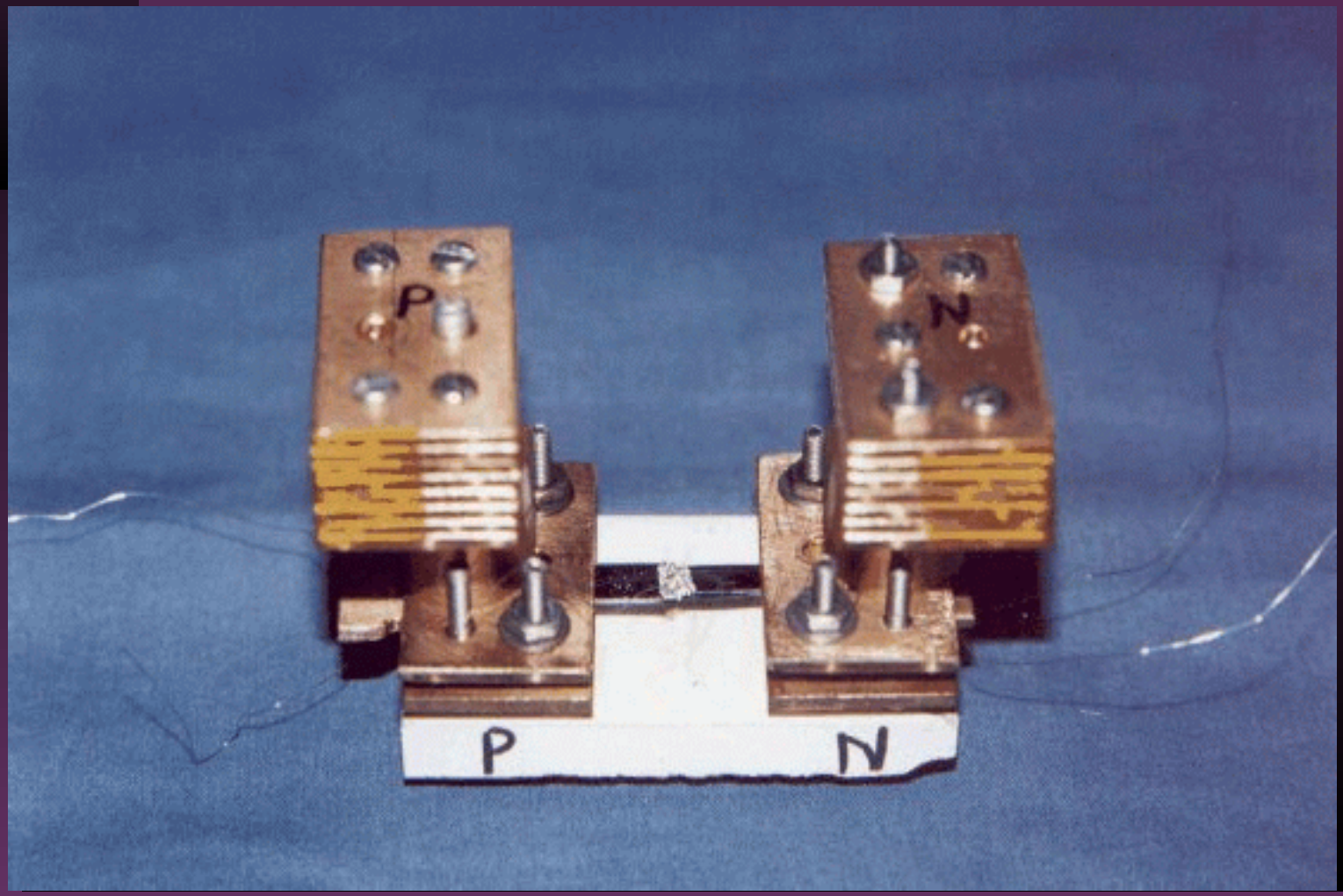


Quantum Well (QW) Programs at Hi-Z

- Si/SiGe: Multi-Layer Quantum Well Film Thermoelectrics.
- P-type B_4C/B_9C: High Temperature Thermally Stable Multilayer Quantum Well Films.
- Funded by the DOE SBIR.
- MURI-ONR Program funded by DOD



QW Experimental Couple



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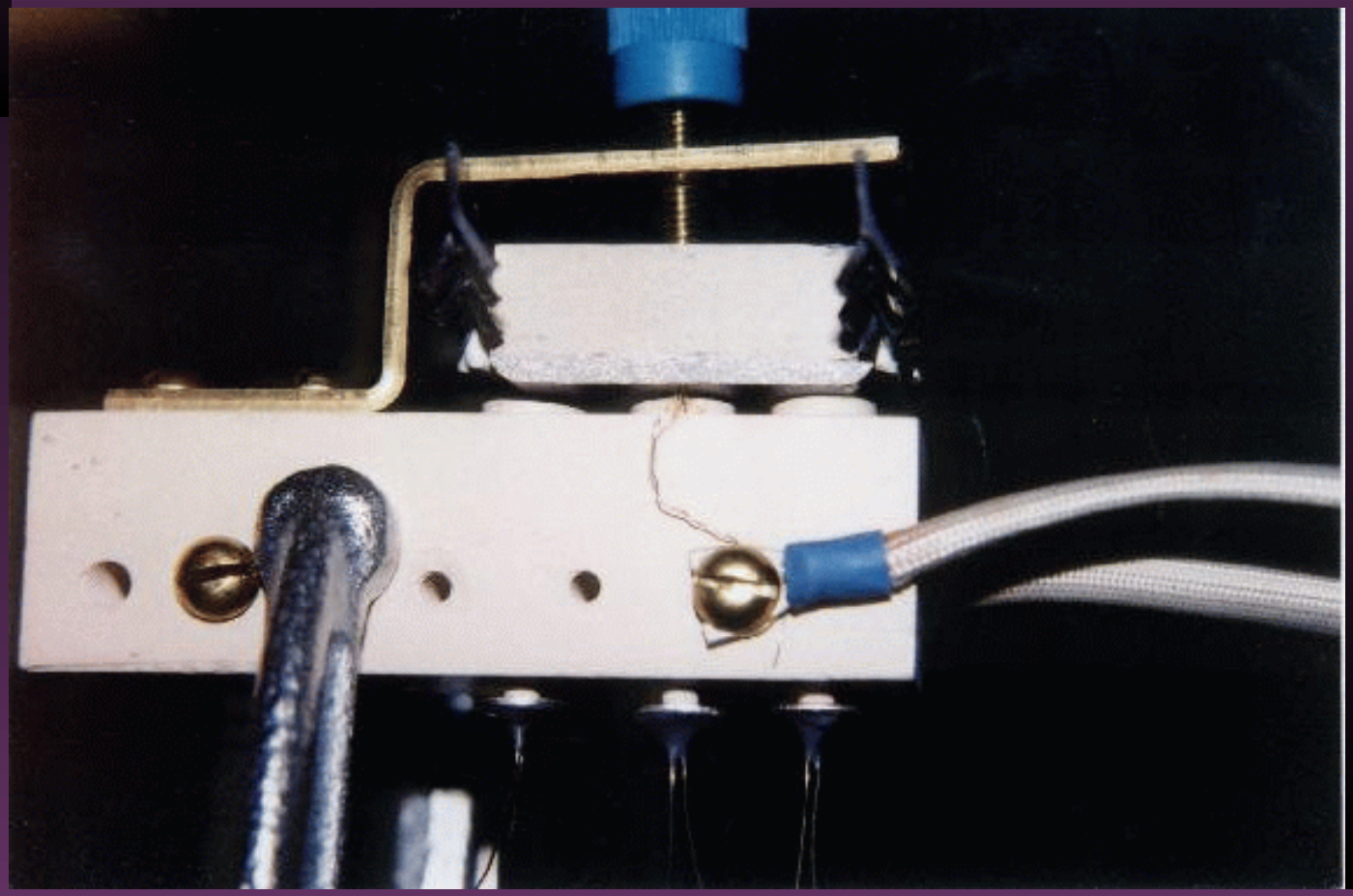
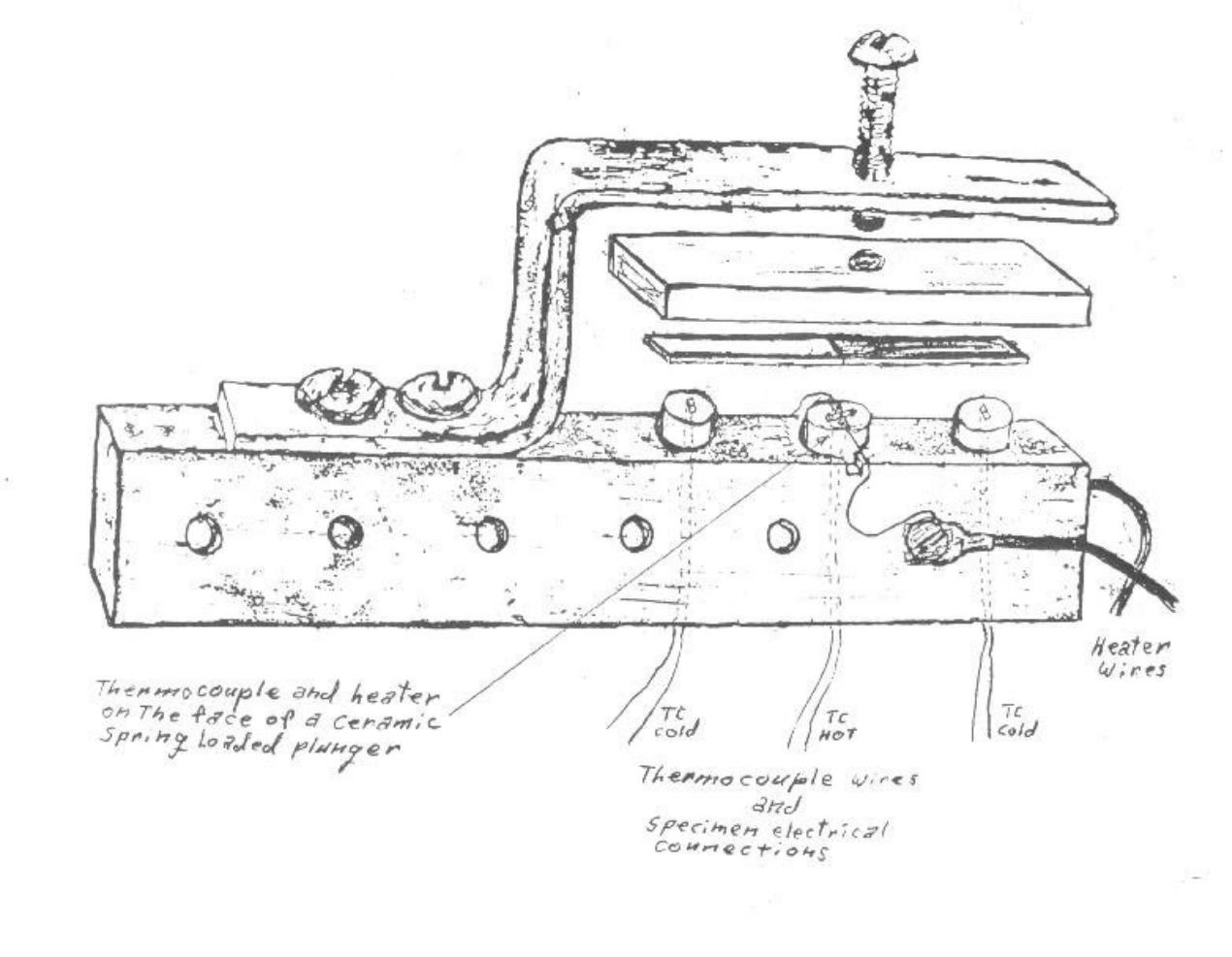
Experiment Setup

- Thick film N and P coulples



Experiment Setup (con't)



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Power and Efficiency Measurements

Power Measurements:	Current and voltage
Efficiency Measurements:	Straight power-in and power out no correction
	Power-in: heater power
	Power-out: QW device power

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QW Device Power Data

T_{Cold}~70°C T_{Hot}~250°C		
Devices on ~5 : m Si Substrate	Film Thickness	Experimental Power (: W)
B_4C/B_9C-Si/SiGe P-N Device	1 : m	1.63
B_4C/B_9C-Si/SiGe P-N Device	**11 : m (0.433mil)**	**16.21**
Bulk Bi_2Te_3 Device	NA	0.13*
Bulk B_9C-SiGe	NA	0.05*
*Published data		

QW Device Efficiency Data

T_{Cold}~70°C T_{Hot}~250°C		
Devices on ~5 : m Si Substrate	Film Thickness	Experimental Efficiency (%)
B_4C/B_9C-Si/SiGe P-N Device	1 : m	<2
B_4C/B_9C-Si/SiGe P-N Device	**11 : m (0.433mil)**	**14**
Bulk Bi_2Te_3 Device	NA	~5*
Bulk B_9C-SiGe	NA	<1*
*Published data		

QW Film FOM Data

	T~450°K	
Films	Film Thickness	Figure of Merit ($10^{-3}K^{-1}$)
B_4C/B_9C	11 : m	9.1
Bulk Bi_2Te_3	NA	2.8*
Bulk B_9C-SiGe	NA	~0.2*
*Published data		

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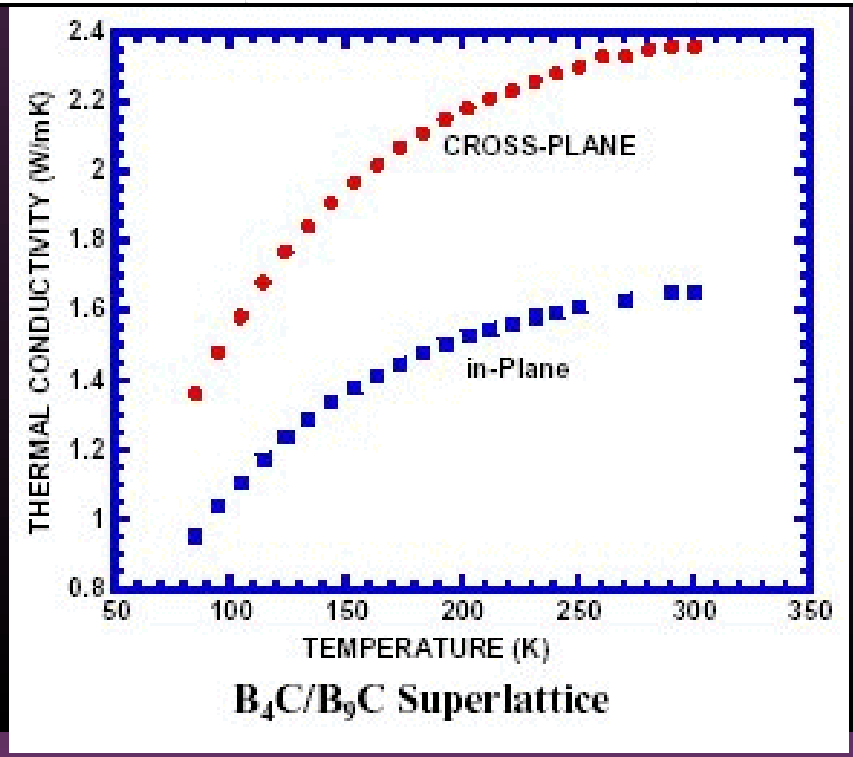
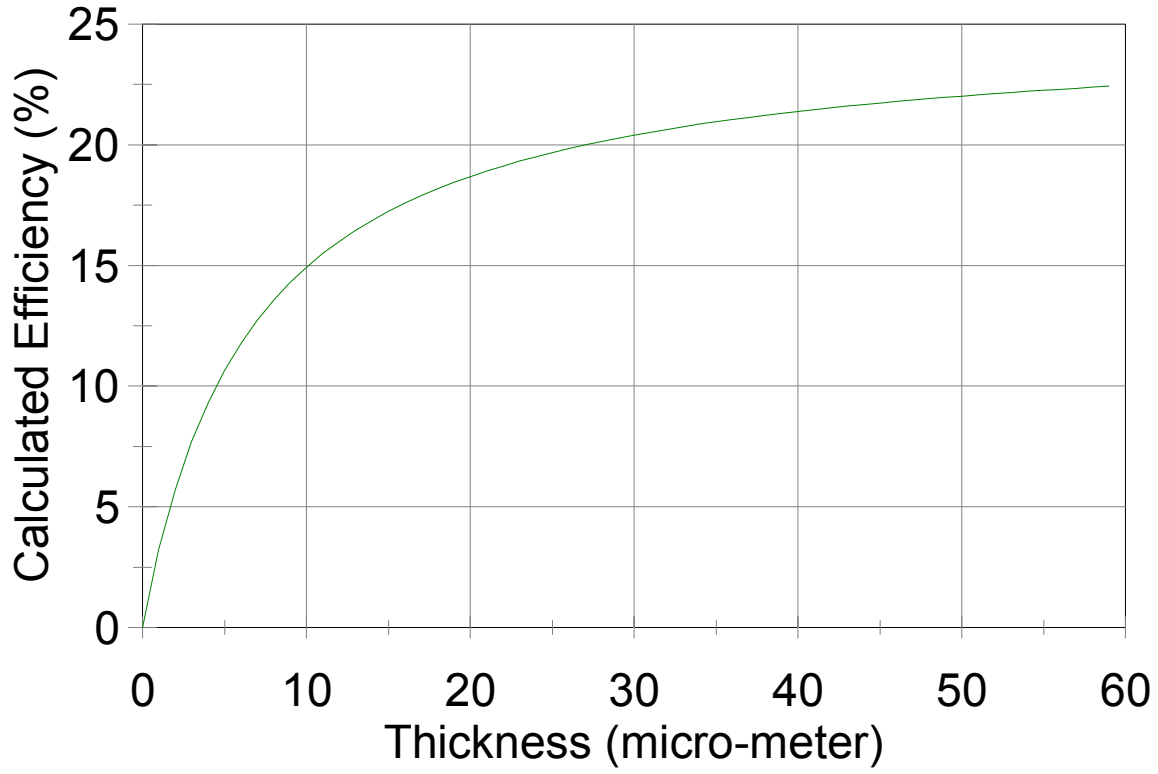
QW Film Thermal Conductivity

	T~450°K	
Film	Thermal k	Thermal k
B_4C/B_9C	From Efficiency 1.5W/mK	Direct Measurement 1.7W/mK



Efficiency Versus Thickness



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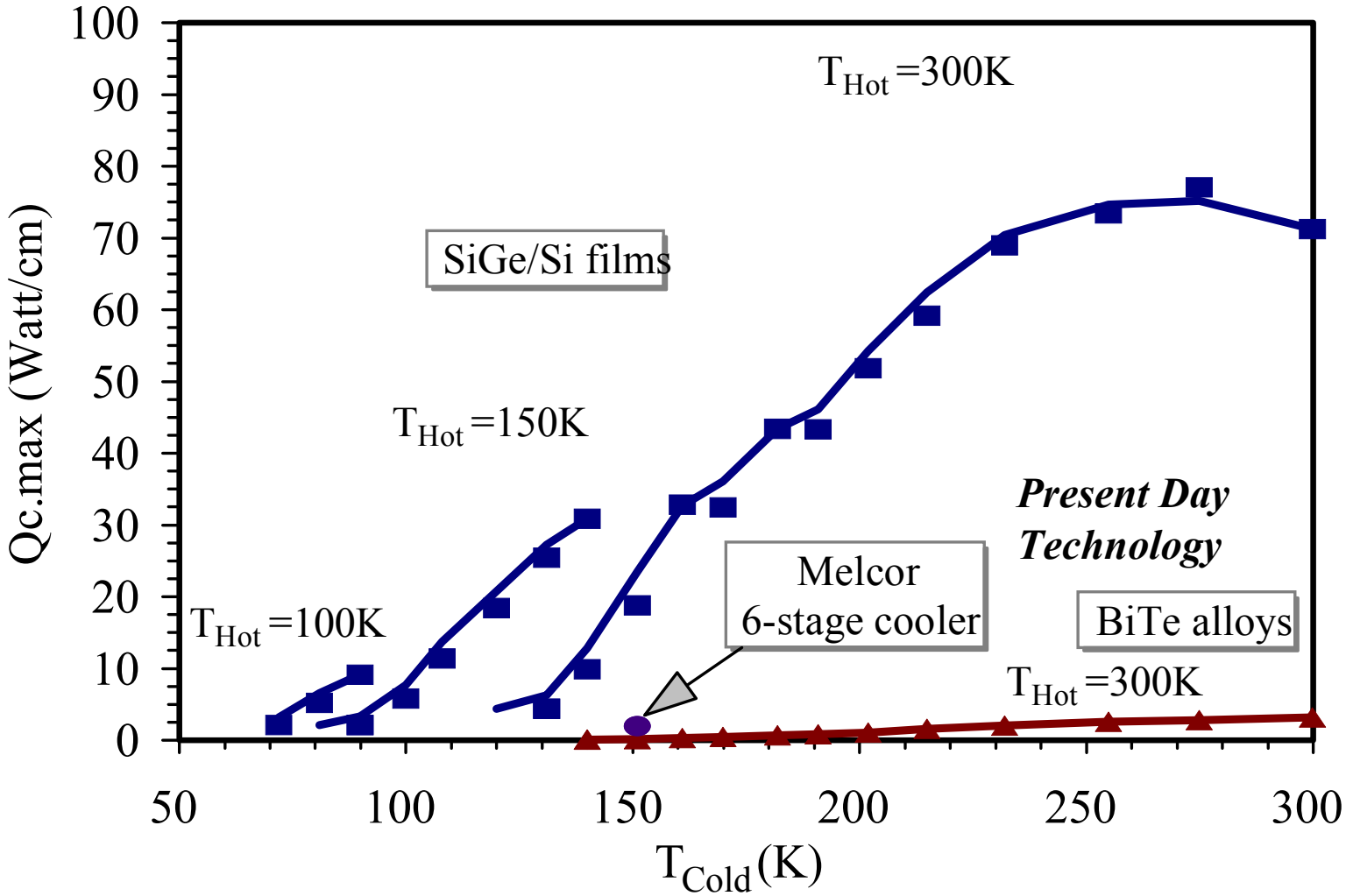
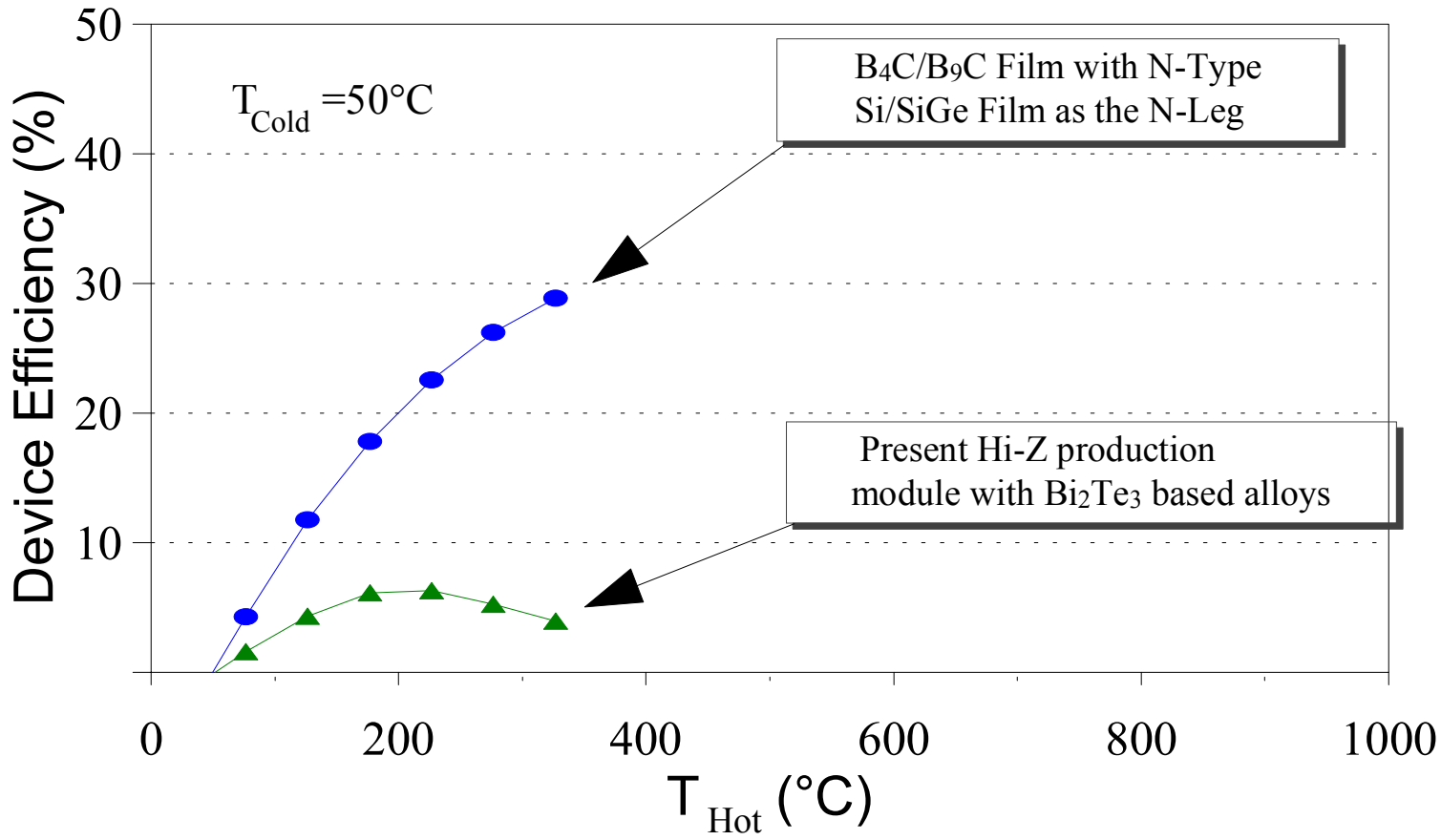
Maximum Heat Pumping Rate



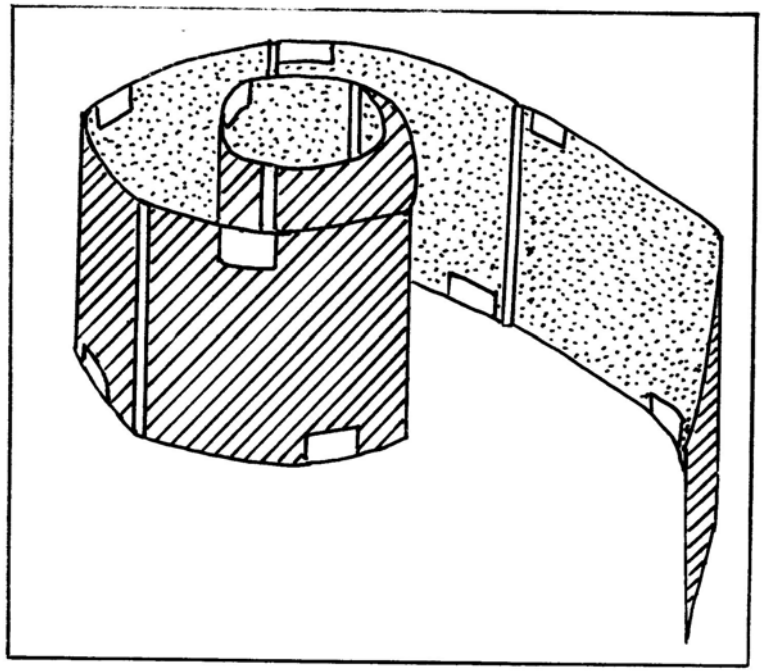
Theoretical Qc.max (Maximum Heat Pumping Rate from the cold side/unit length) of SiGe/Si film vs. Bulk BiTe alloys.

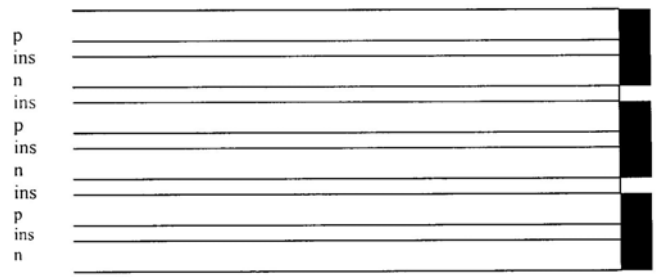
Efficiency of B_4C/B_9C Multilayer Films

Comparison of presently fabricated module and potential modules incorporating QWs

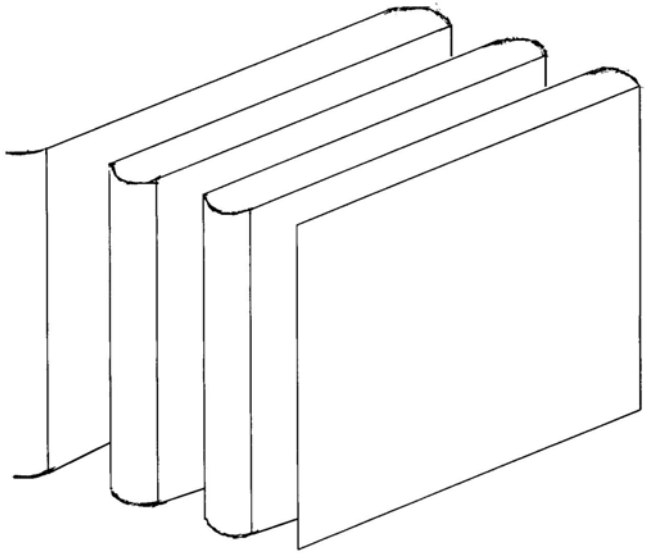


20 W QW Module (con't)



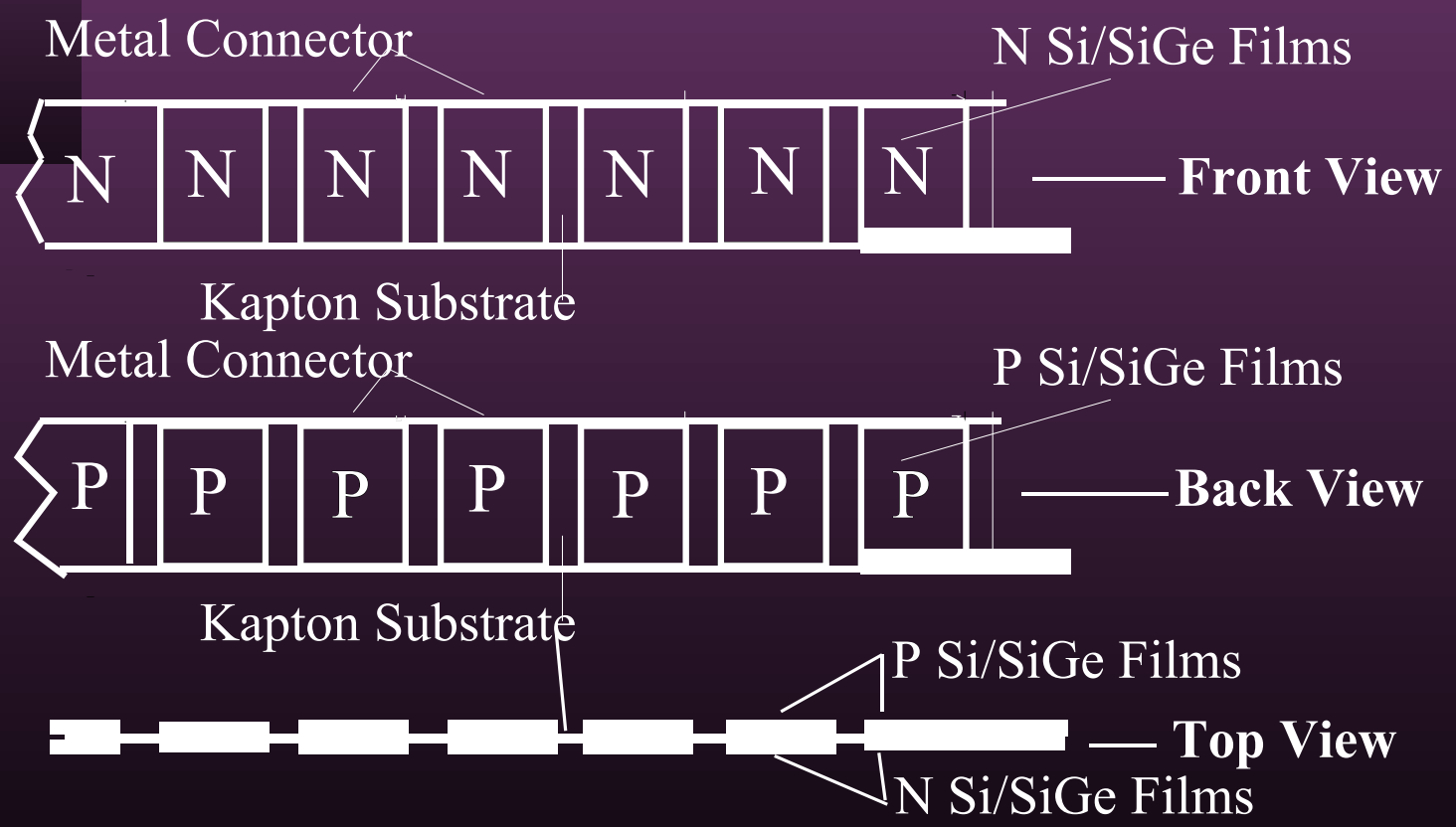


Hot junction

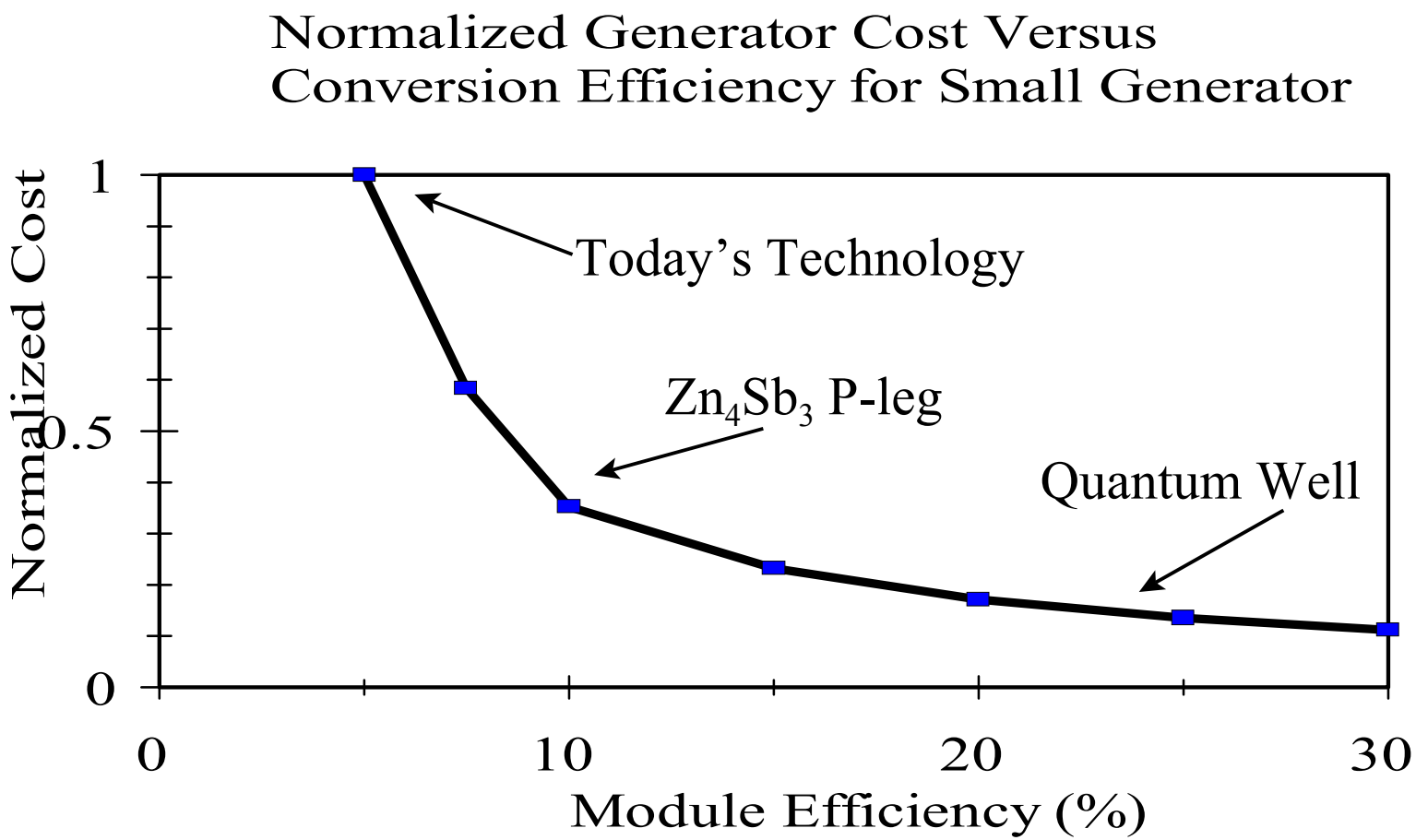


Cold junction

MULTI-COUPLE DEVICES



- N&P Si/SiGe Films are deposited first and then the metal connectors

- Substrate: Kapton, 0.5 mils (.0005") thick

QW Thermoelectric Device Cost