The Design and Application of Quantum Well Film Based Modules

J. C. Bass, S. Ghamaty, D. Allen, V. Jovanovic and N. Hiller

Hi-Z Technology, Inc.

San Diego, CA

Presented to

High Efficiency Thermoelectric Workshop

Coronado, California

February 18, 2004

Areas Covered

- Applications and Examples
  - Automotive
  - Military
  - Aerospace
  - Civilian
- Module Construction
- QW Cooler Applications and Performance
- Conclusions

Automotive Applications of Quantum Well Thermoelectrics

- Exhaust Driven Generators
  - 1 kW Cars and Light Trucks
  - 5 kW Trucks and Busses
  - 10 kW Military Vehicles
- Auxiliary Generators
  - Hotel Power and Heat
  - Refrigeration

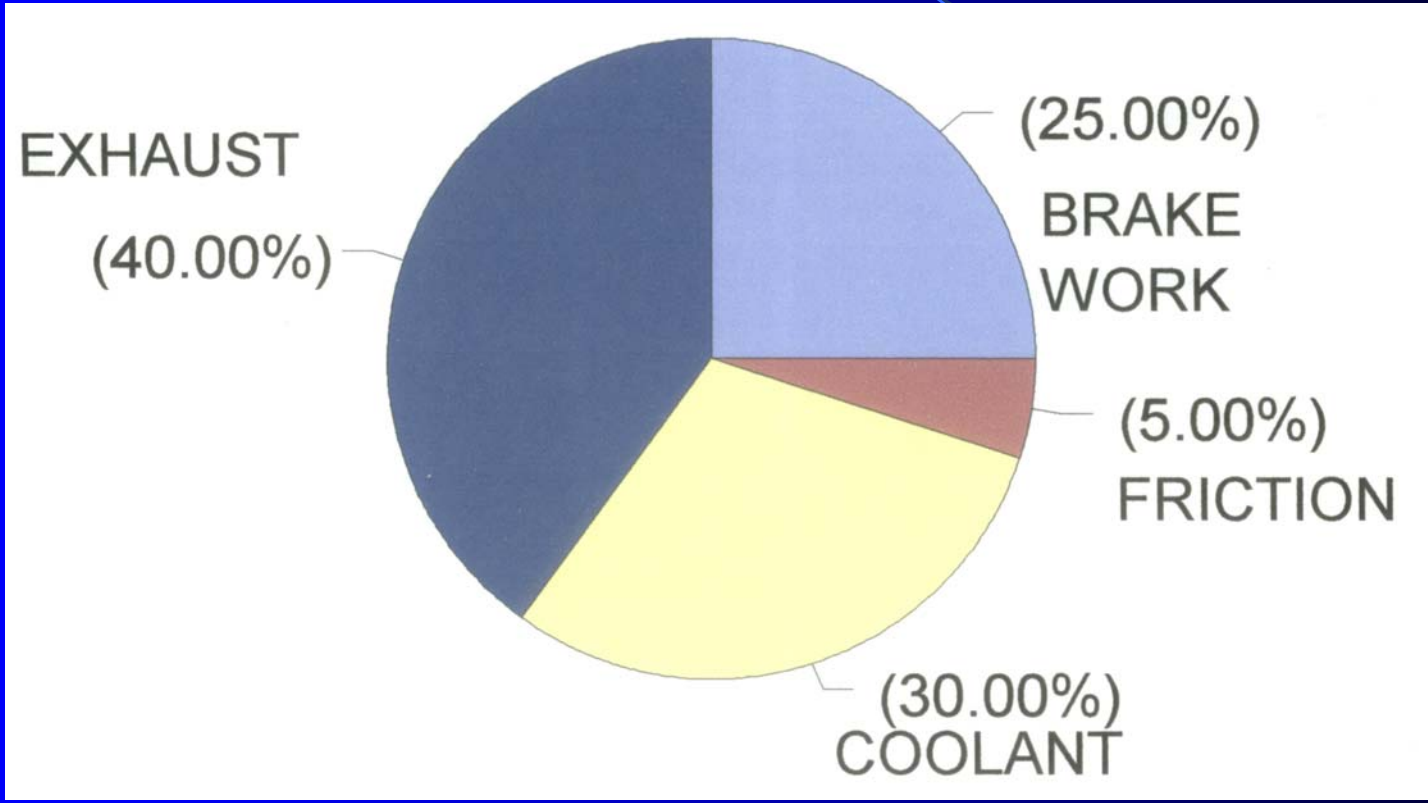
Hi-Z TECHNOLOGY, INC.

Automotive Applications of QW Thermoelectrics (contd)

- Self-Powered Fans
  - Powered by Radiator Heat
- Electric Air Conditioning
  - Quick Cooling
  - Modulated Power
- Prime Power for HYBRIDS
  - Multi Fueled, External Combustion
  - Low NOx
  - Competitive Efficiency

Hi-Z TECHNOLOGY, INC.

Gasoline I.C. Engine Energy Distribution



Military Applications of Quantum Well Thermoelectrics

- Man Portable Power Supplies for Battery Charging
  - Diesel Fueled
- Auxiliary Power Supplies
  - Diesel Fueled
- Vehicle Exhaust Driven Generators
- Wireless Instrumentation Power Supplies Using Energy Harvesting
  - Navy RSVP

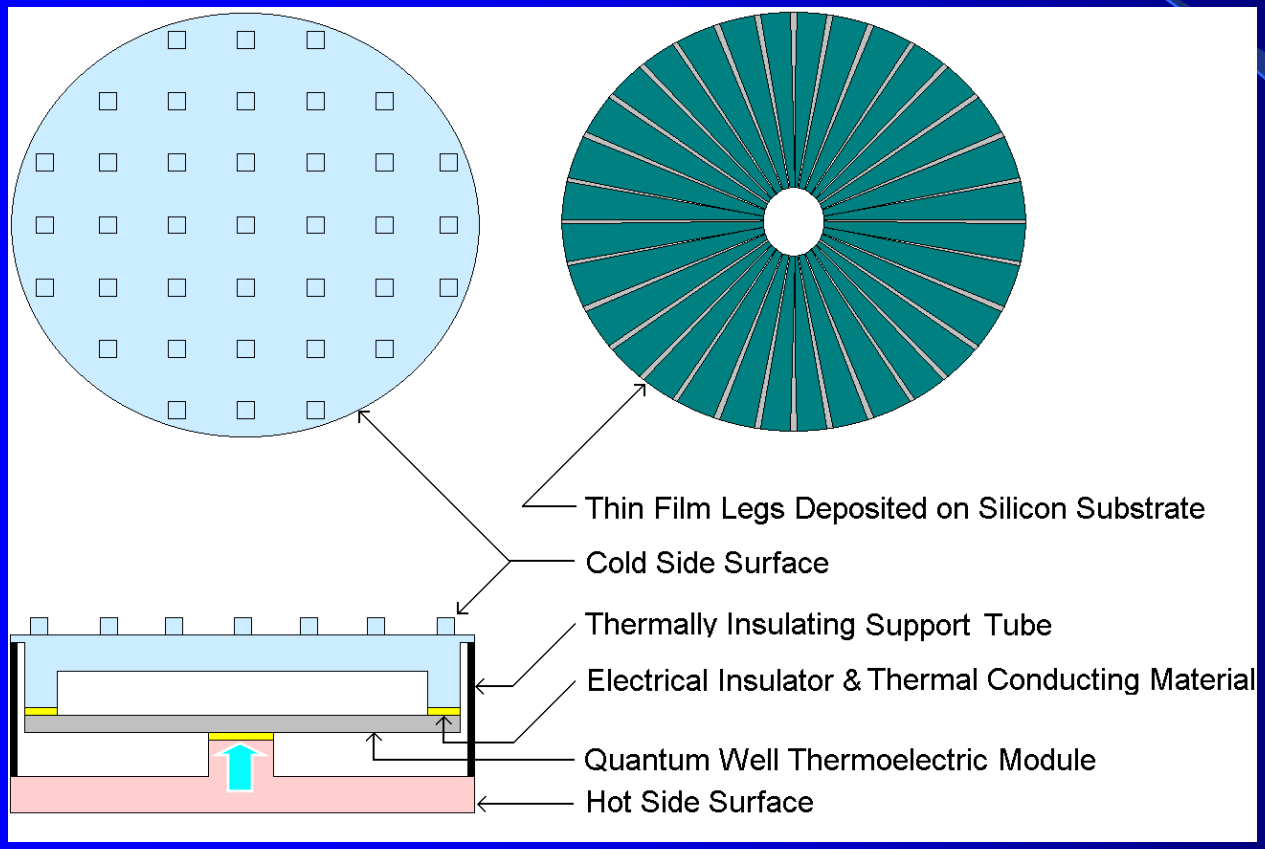
Hi-Z TECHNOLOGY, INC.

Military Application of Quantum Well Thermoelectrics (contd)

- Personal Coolers
- Self Powered Heaters
- Electronic Coolers
- Power Supplies for Computers
- Coolers for Night Vision
- Gun Sites
- Remotely Powered Power Supplies

Power Harvesting QW TEG Concept for Navy Shipboard Wireless Sensors

SBIR N02-124



Small size (1 in^3) requirement satisfied using QW TEG

Provides power for wireless sensors: 5 mW at 3 V using 41°C ΔT from ship interior thermal environment

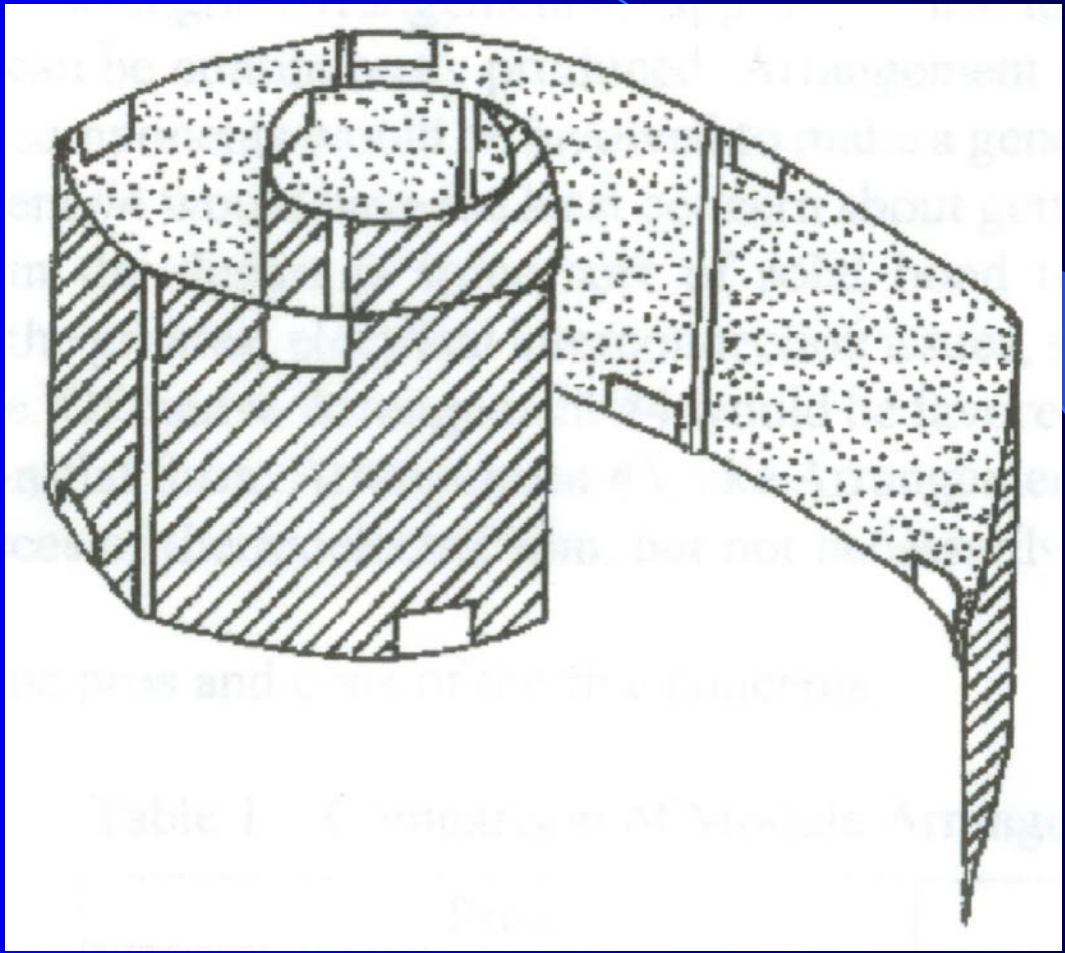
Generator dimensions: 1 in^2 footprint, ½ cm height

Aerospace Applications of Quantum Well Thermoelectrics

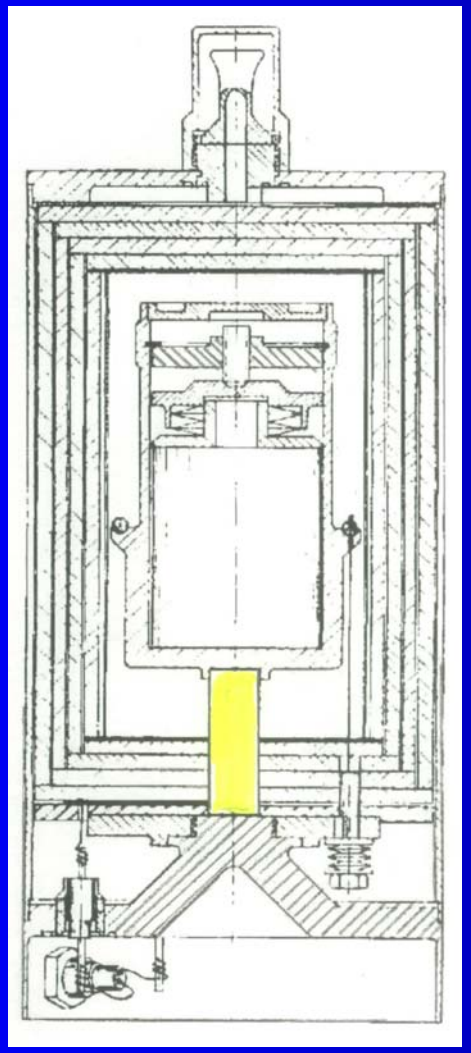
- Small RTG
  - 100 to 1000 mW Using RHU
- Large RTG
  - 10 W to kW Level Using GPHS
- Electric Power for Missiles and Rockets
  - Using Motor Radiation Heat
  - Using Reentry Heat
- Solar Power Systems
  - Mirror or Lens Systems
    - High Efficiency

Hi-Z TECHNOLOGY, INC.

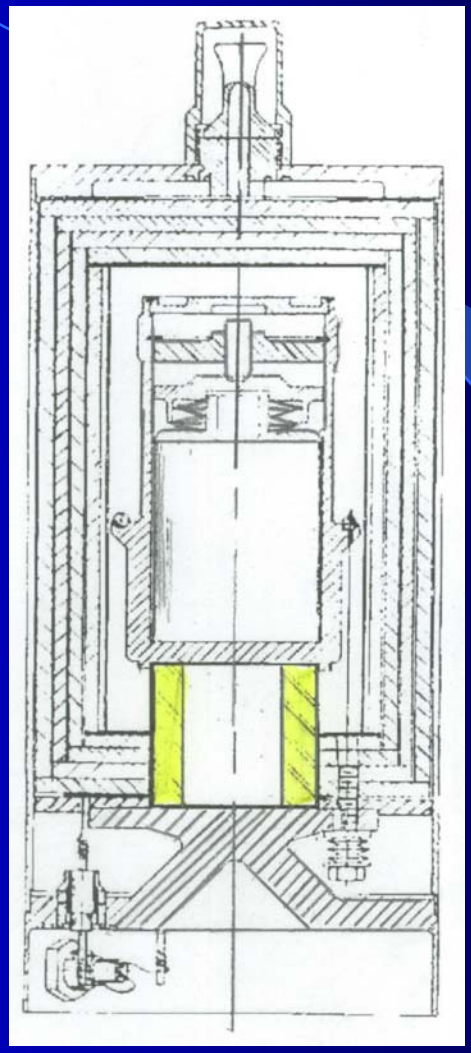
Strip Module for MillliWatt RTG



Comparison of MilliWatt Modules



40 mW RTG



200-300 mW RTG

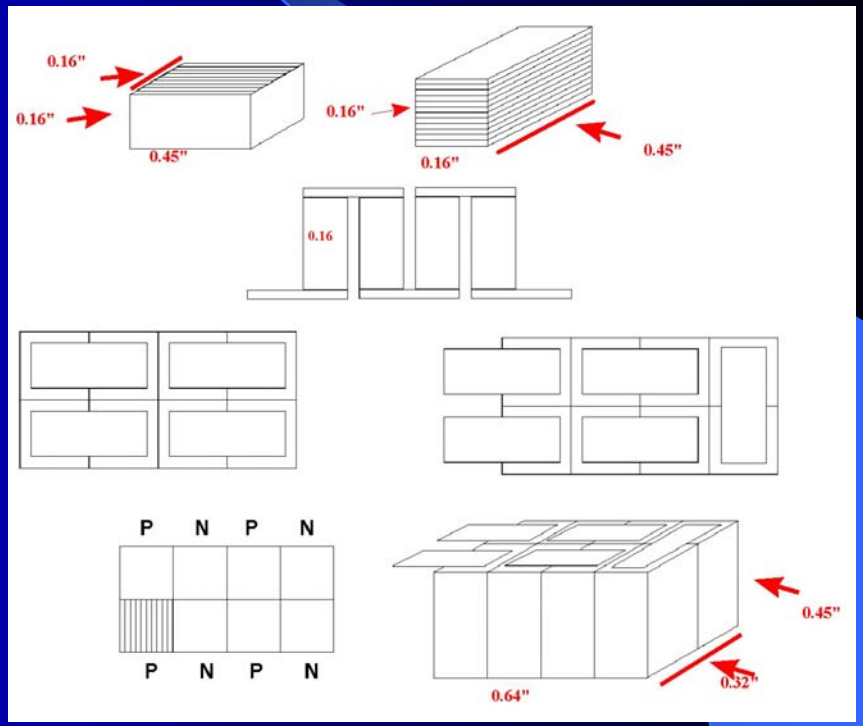
Watt Level RTG (Not Optimized)

- 1 GPHS Fuel Pellet
  - 62 Watt (t)
  - Encased in 5.31 cm dia. x 9.37 cm long Aeroshell
- Radiation Coupled
  - Capsule Temp. 996K
  - Element T_H 973K
  - Radiator 394K
- QW Material
  - P B_4C/B_9C on Si
  - N Si/SiC on Si
- Power 20 W
- Estimated Specific Power 6.32 W/Kg

Civilian Applications for Quantum Well Thermocouples

- Self-Powered Appliances
  - Furnaces
  - Hydronic Heaters
  - Fans, Gas and Wood Stoves
  - Pellet Stoves
  - Auxiliary Power Supplies, mW to kW
  - Wireless Sensor Power Supplies
    - Utilities
    - Oil and Gas Fields
- Cooling
  - HVAC Systems
  - Portable Coolers
  - Refrigeration

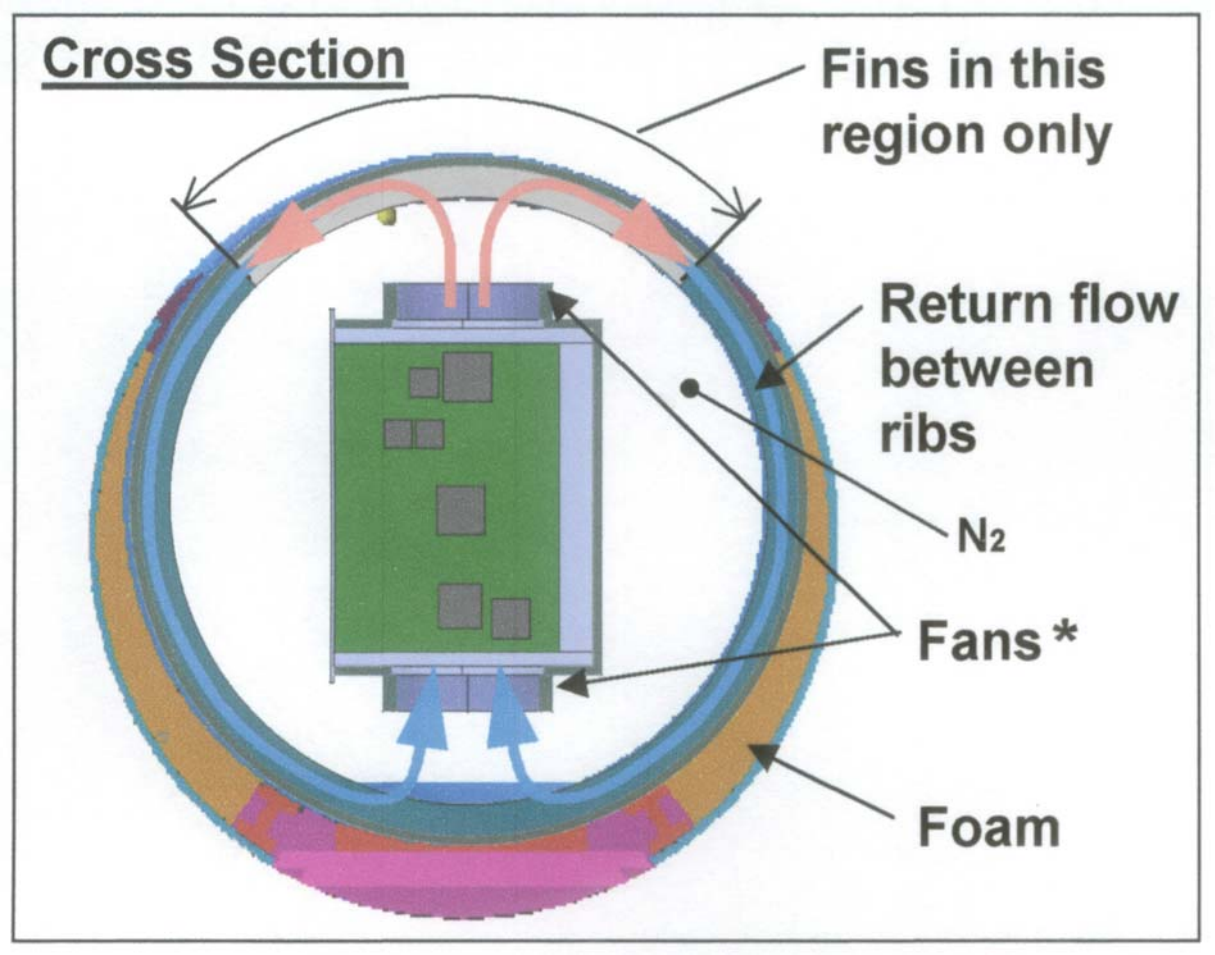
2.5 Watt QW Module In Progress



QW Cooler Applications

- HVAC
- Electronic Cooling
- Refrigeration
- Cryogenics
  - Multiple Stage Coolers to LN_2

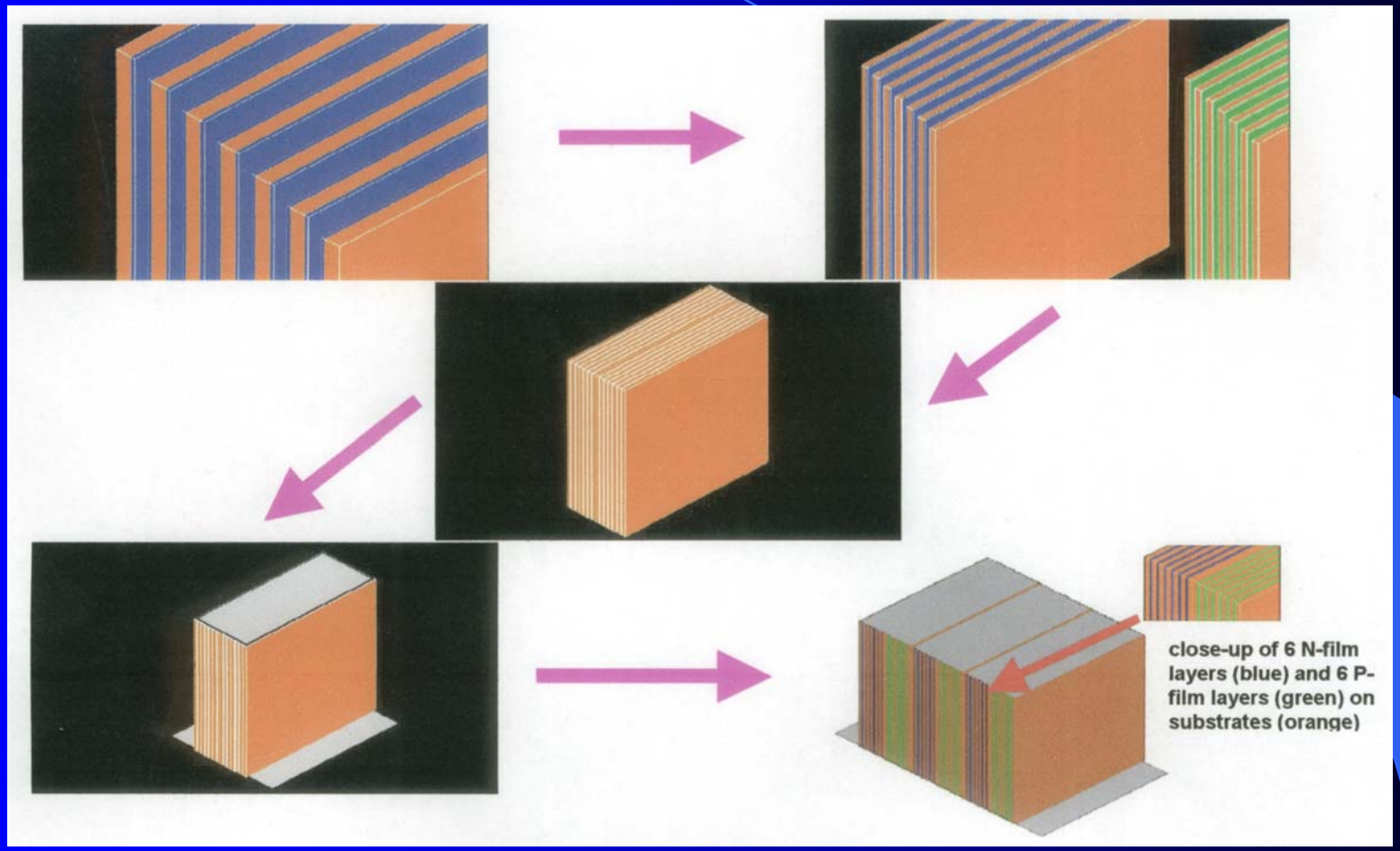
Electronic Cooling of UUV



Cooling Module Design

- Material 11 µm Si/SiGe on 0.0025 cm Kapton
- Temperature Difference: 30C Degrees
- Number of Films/Element: 83
- Number of Couples: 128 (16 x 16 array)
- Module Size: 4.9 cm x 4.9 cm x 0.25 cm
- Module Voltage: 12.85
- Module Current: 2.8 amps
- Pumping Power: 102 Watts
- COP: 2.85
- Area of QW Film/Module: 198 in^2

Quantum Well Arrangement

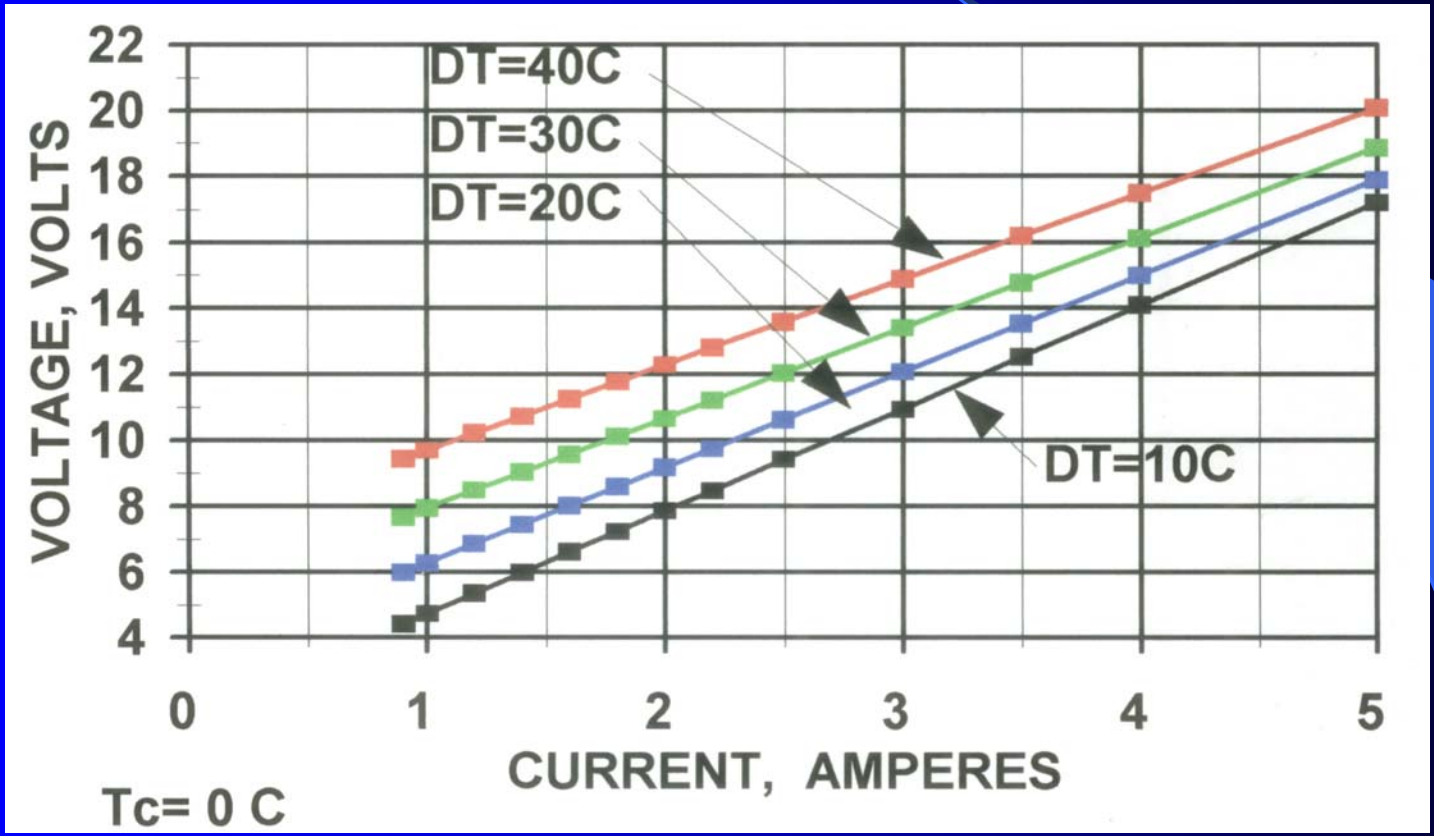


Cooler Modules Investigated

- 11 µm Si/SiGe QW on 5 µm Si Substrate
  - Same Use in QW Test Couple N Leg
  - Si Provides High Thermal Bypass
- 11 µm Si/SiGe QW on 0.0025 cm Kapton
  - SiGe on Kapton Sample Fabricated
  - Kapton Low Thermal K
- Other Substrates Possible

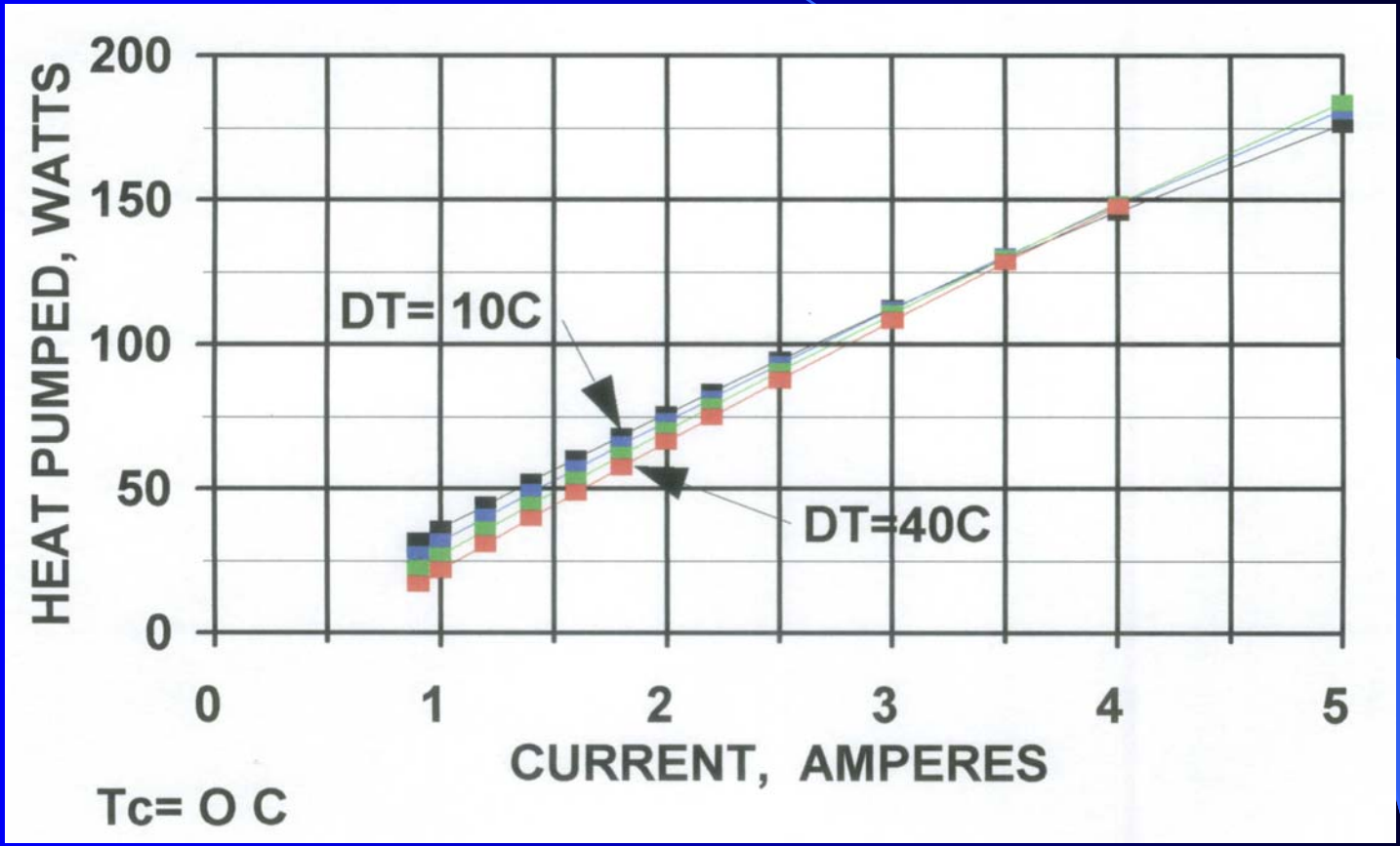
QW Cooler Volts *vs* Current

11 μm SiGe QW on 0.00254 cm Kapton



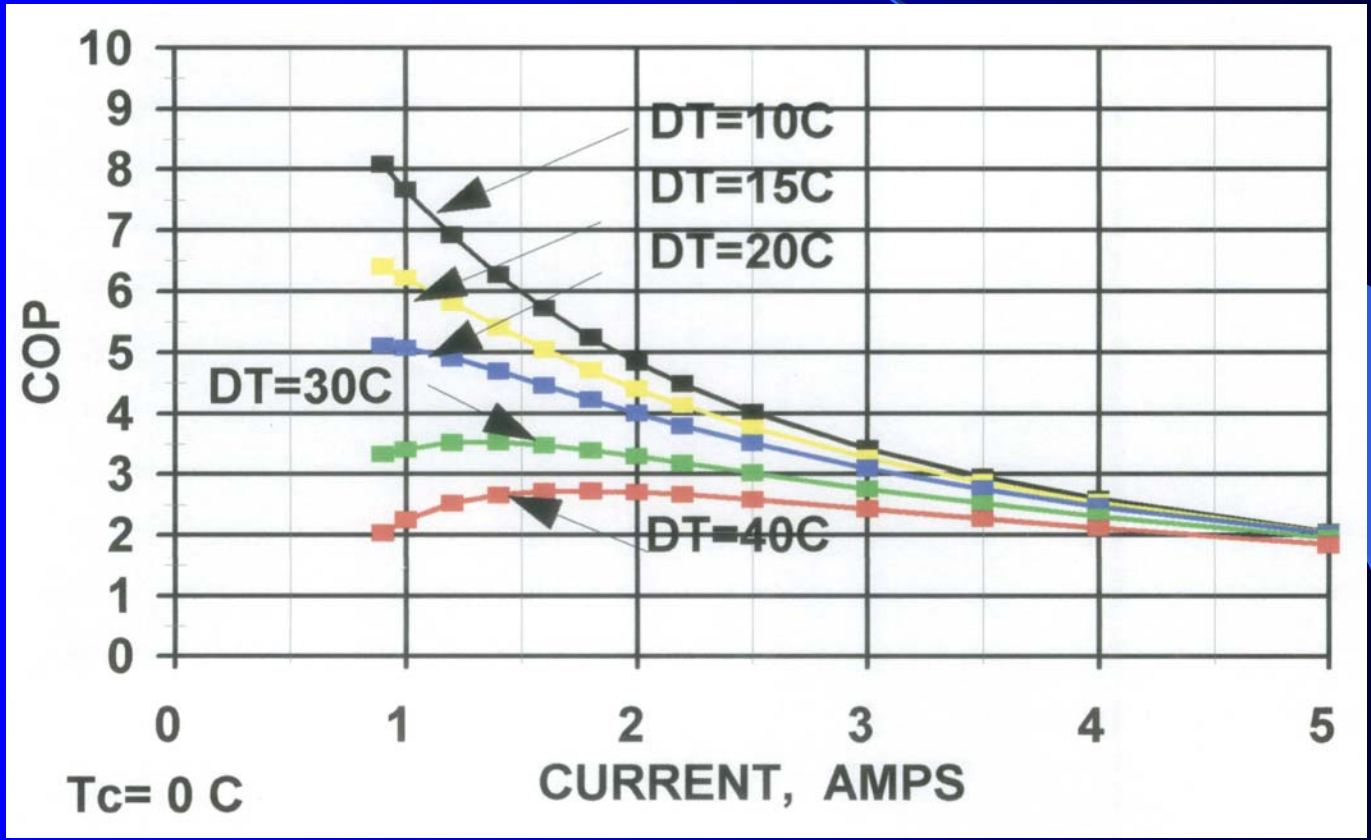
QW Cooler Heat Pumped *vs* Current

11 μm SiGe QW on 0.00254 cm Kapton



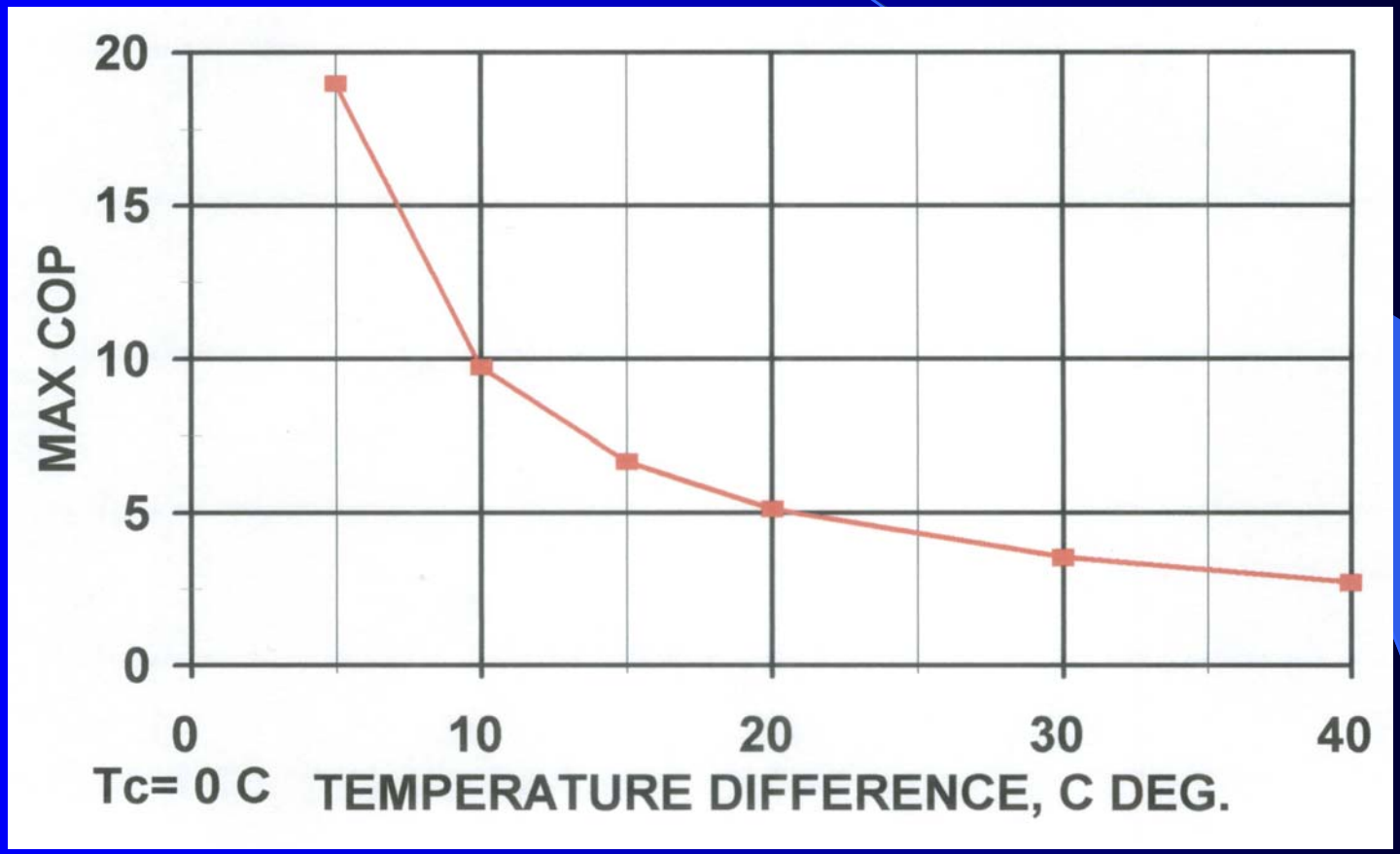
QW Cooler COP *vs* Current

11 μm SiGe QW on 0.00254 cm Kapton



Max. COP *vs* Temperature Difference

11 μm SiGe QW on 0.00254 cm Kapton



Conclusions

- Quantum Well Thermoelectrics
  - Much Higher Efficiency
  - Cooling Matches Mechanical
- Large Number of Applications in All Fields
- Progress is Being Made
  - Test Couple
  - 2 ½ Module Under Way
  - MilliWatt Flat Module Under Way
  - Fabrication Capability Increased