Fabrication of A Quantum Well Based System for Truck HVAC

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Outline of Talk

- Measurement of Quantum Wells
- COP of Coolers
- Design Considerations
- Examples of Design
- HVAC System Design
- Construction of Module
- Present Status
- Conclusions

Property Measurement

- Measured by Outside Source
- Excellent Properties both Cooling and Power Production
- Material Measured Si/SiGe, B_4C/B_9C and Other Quantum Wells

Measured Data

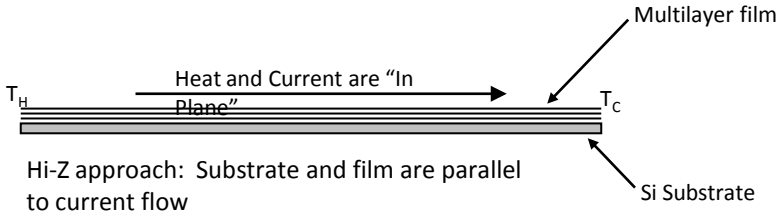
- Multi-Layer Films

  - Si/SiGe
    - Si Substrate
    - Kapton Substrate

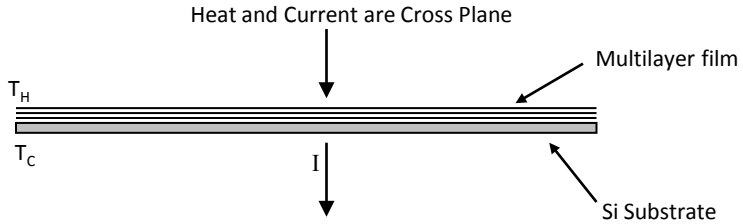
  - B_4C/B_9C
    - Si Substrate

  - B_4C/B_9C- Si/SiGe Couple
    - Si Substrate

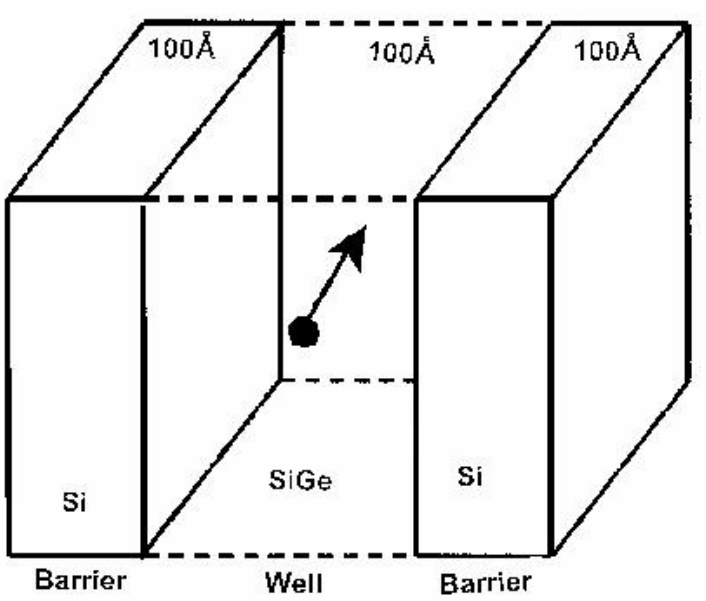
Hi-Z fabricates and uses the films "In Plane"



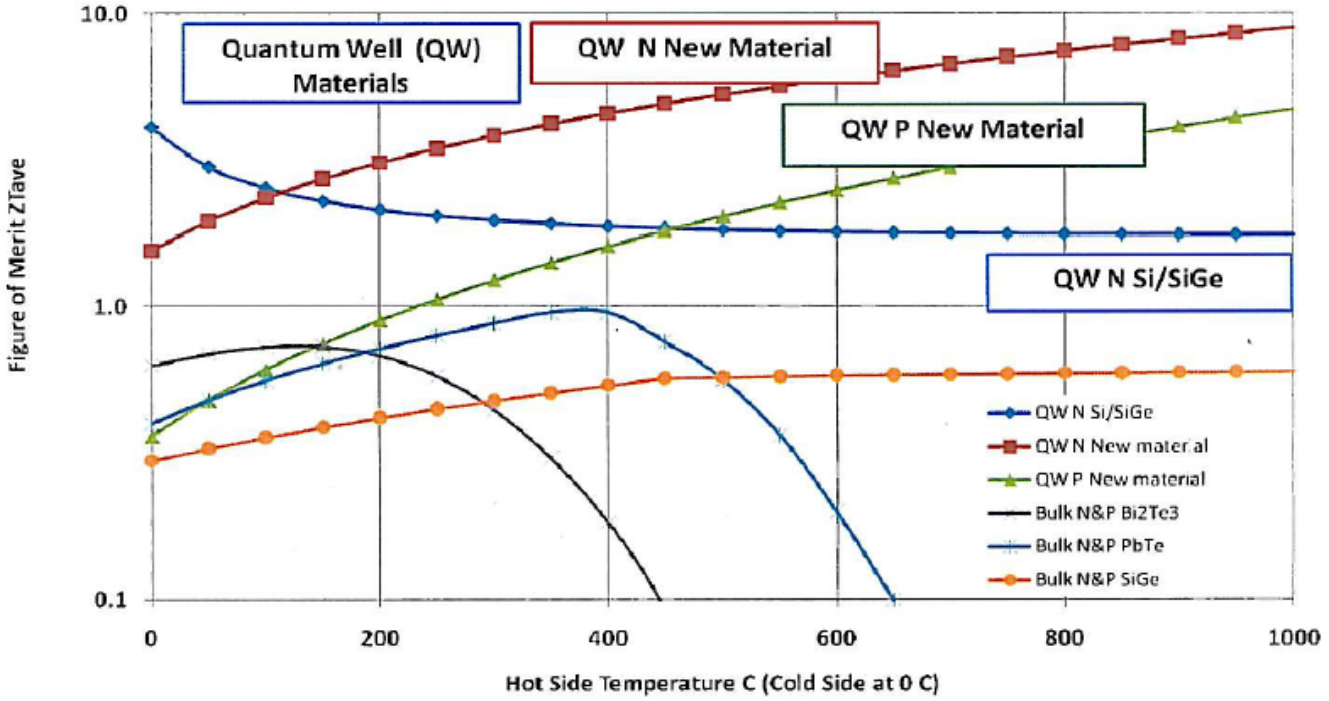
Hi-Z approach: Substrate and film are parallel to current flow



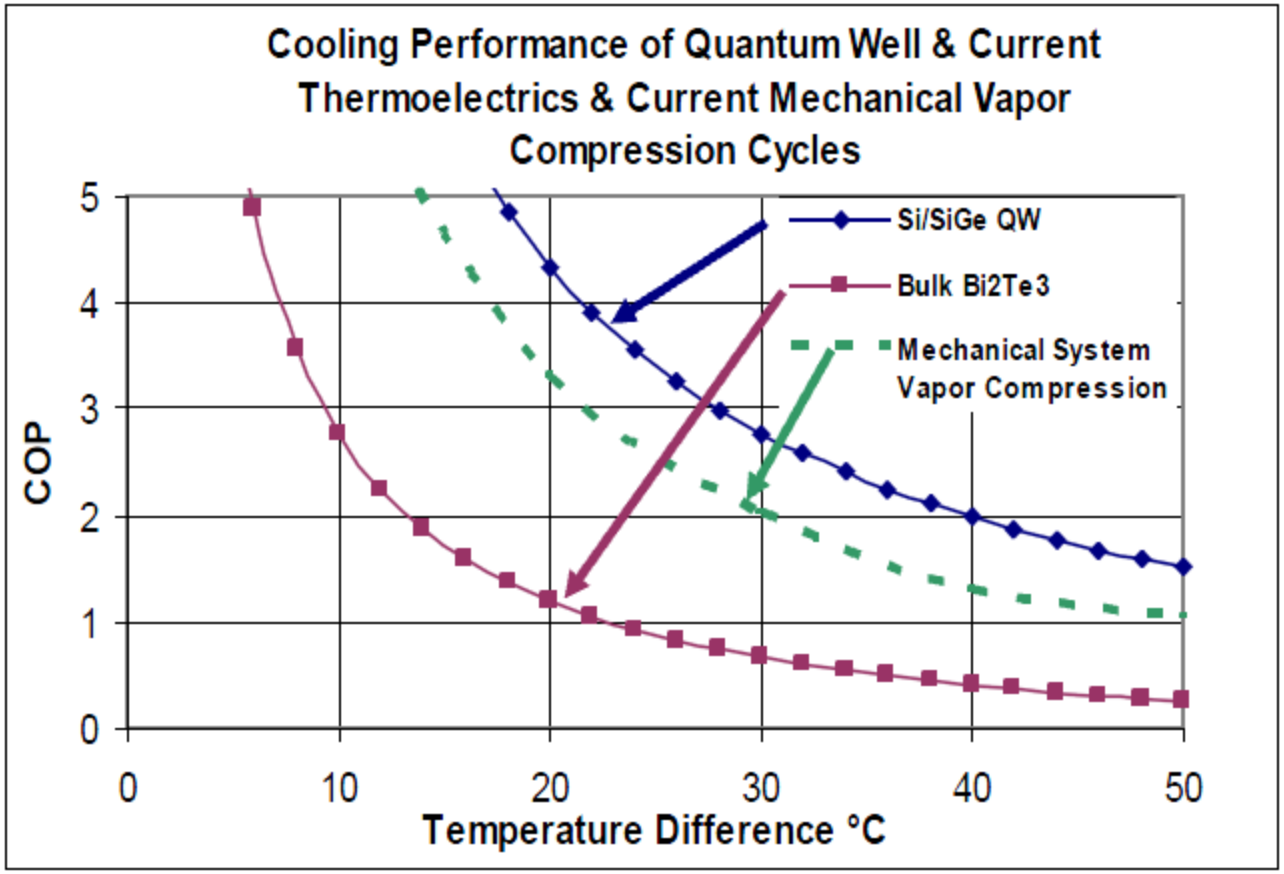
Substrate and film are perpendicular to current flow



Predicted QW TE Figure of Merit , ZT, as Function of Temperature and Compared with SOTA (Bulk) Thermoelectrics



Coefficient of Performance of QW and SOTA Thermoelectrics and SOTA Mechanical Vapor Compression Systems; COP as A Function of Cooler ΔT



Design Considerations

Substrates Selected Acts as Thermal Bypass

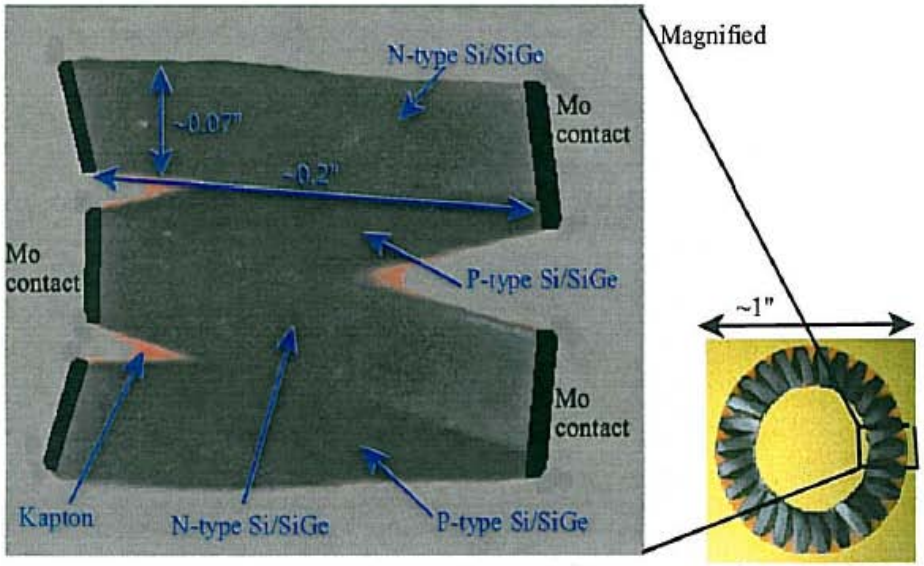
- Decreases overall efficiency
- Values of Thermal K Can Vary by 4 Orders of Magnitude
- Porous Si possible candidate
  - Low Thermal K
  - Expensive
  - Low Strength
- Glass or Kapton Can be Used, Low K

Ring Converter

Circular Device

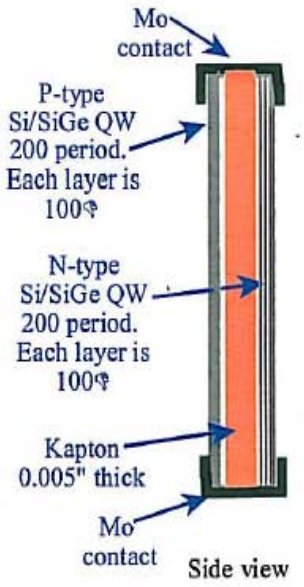
- **N** on one side **P** on other
- 26 Couples Deposited on Kapton
- Two Couples removed
  - Contacts deposited
  - Tested
- Numerous Applications
  - Power Supply for sensors
  - Possible use in mW RTG
  - Spot Cooler Applications

QW N- and P- Type Si/SiGe Two Couple Device on Kapton®. The Mo was deposited by an improved sputtering process yielding the first QW device on Kapton®.



Two couple device with N&P Si/SiGe QW on Kapton substrate

Complete 26 couple device



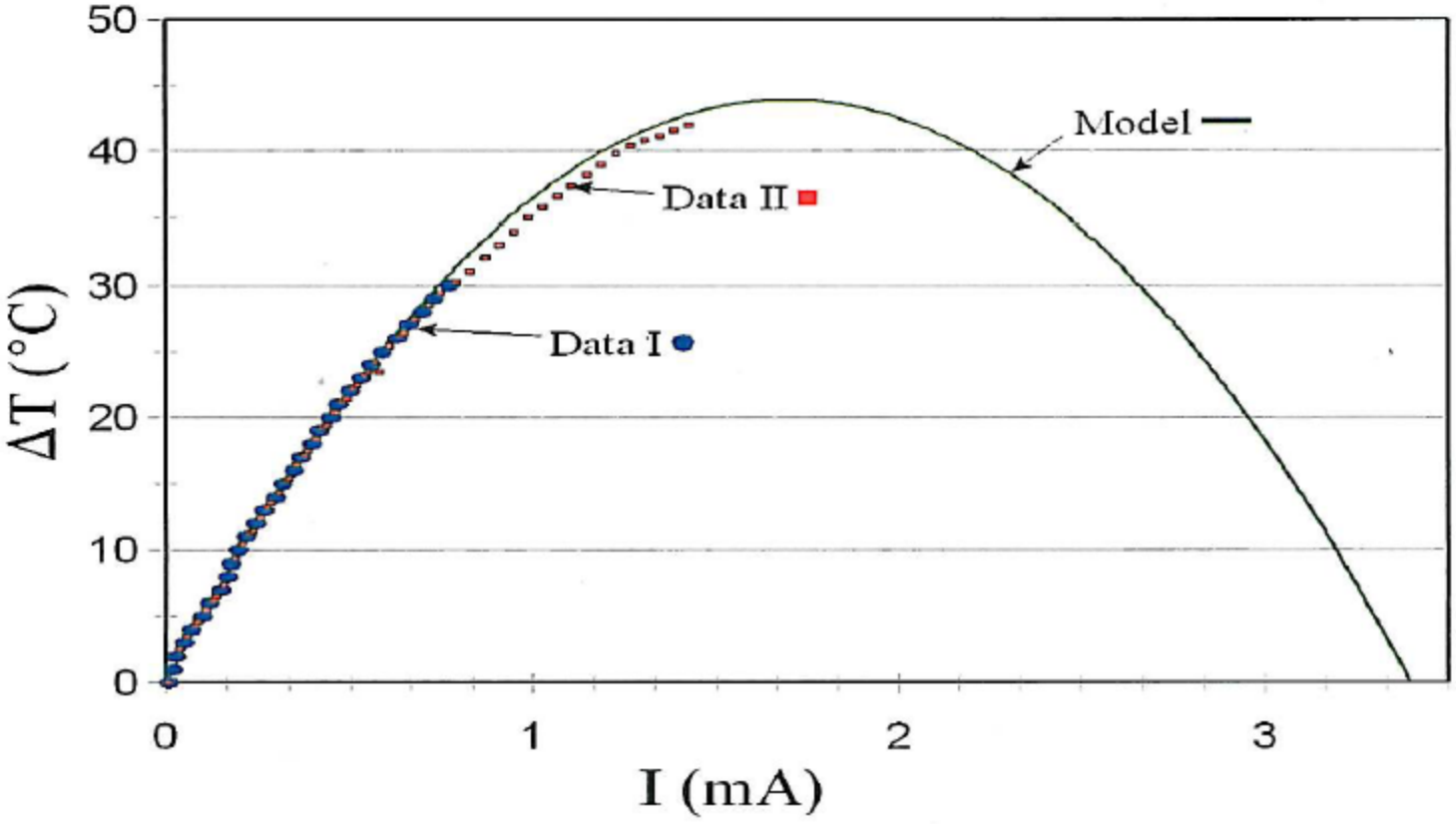
Side view

Thermoelectric Properties of QW Device on Kapton® Substrate with Mo Contacts Compared to Calculated Values:

Each N and P leg is 200 periods of Si/SiGe, and each layer is 100 Å thick (total 4 μm). Each legs area is ~0.07 in. x 0.2 in. The Kapton® is 0.005 in. thick. The performance is compared to current bulk thermoelectric material.

T_{COLD} = 26°C T_{HOT} = 66°C	EXPERIMENTAL QW RESULTS		CALCULATED	
	2 Couples Measured at ΔT = 40°C	2 Couples Measurements Extrapolated to 26 Couples at ΔT = 40°C	26 Couples at ΔT = 40°C	
			QW with ZT ~ 3.0	Bulk $(Bi,Sb)_2(Se.Te)_3$ with ZT ~ 0.75
Voltage	225 mV	2.93 V	3 V	0.5 V
Power	0.371 mW	4.82 mW	5 mW	1.5 mW

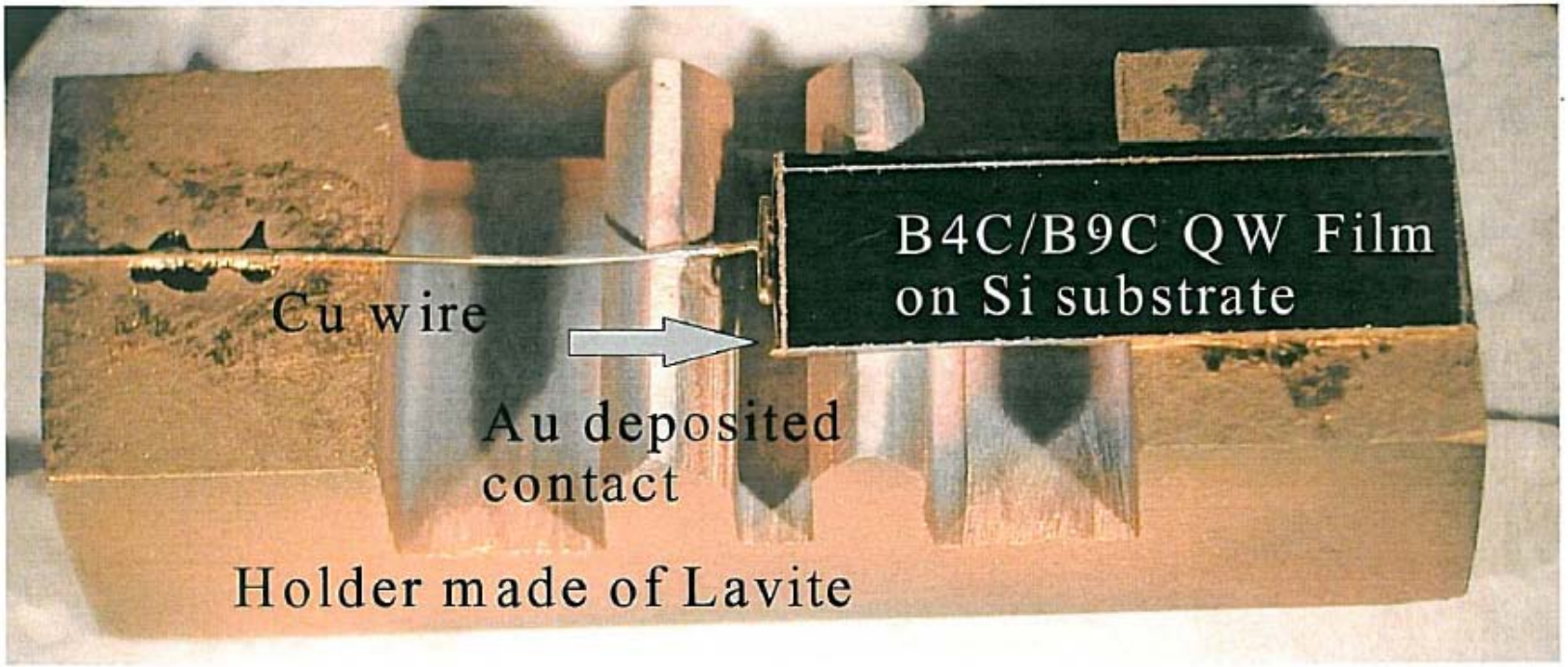
Test Results of Si/SiGe QW Leg on Kapton® Substrate Operated as a Cooler



Single Leg Cooler

- B_4C/B_9C On Si Substrate
- Copper Wire for Other Leg

P-Type B_4C/B_9C QW Film Joined to a Copper Wire Operating as a Cooler



HVAC Systems Design

Flow Systems Considered

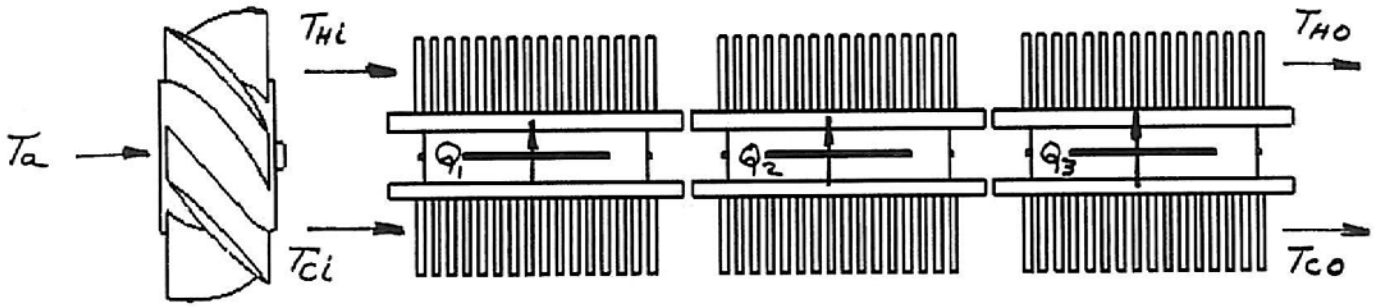


Figure 2a. Parallel Flow System

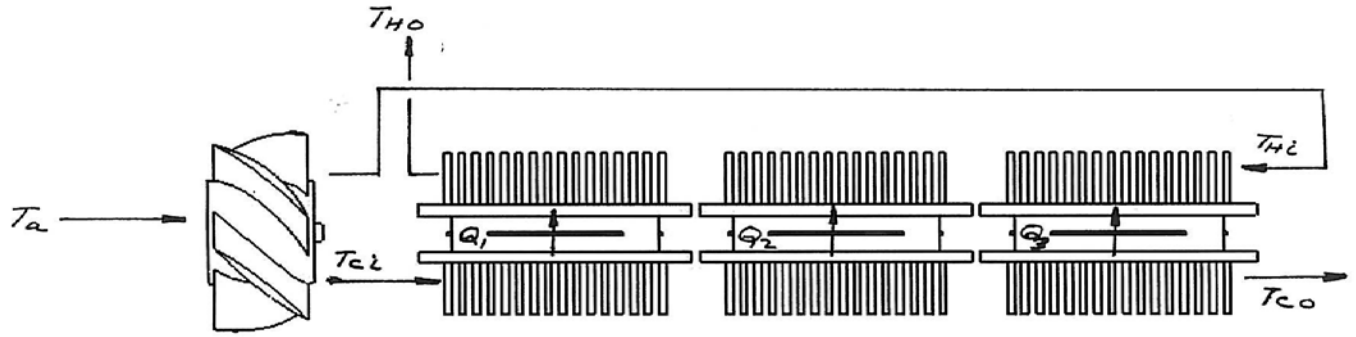
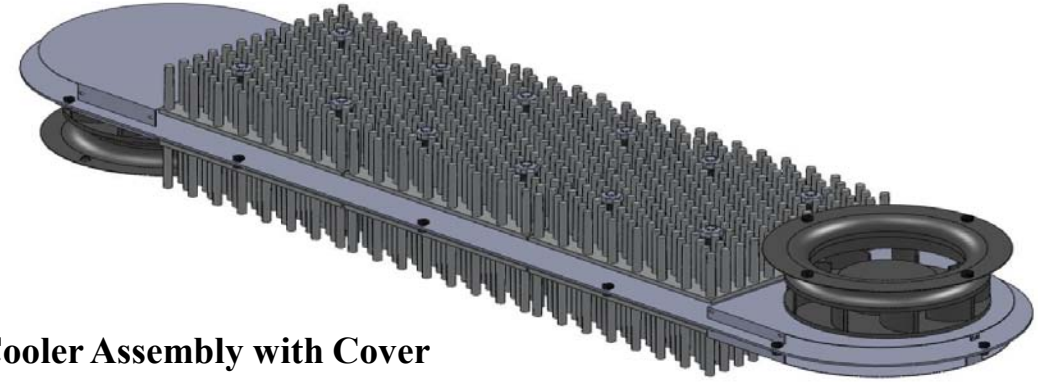
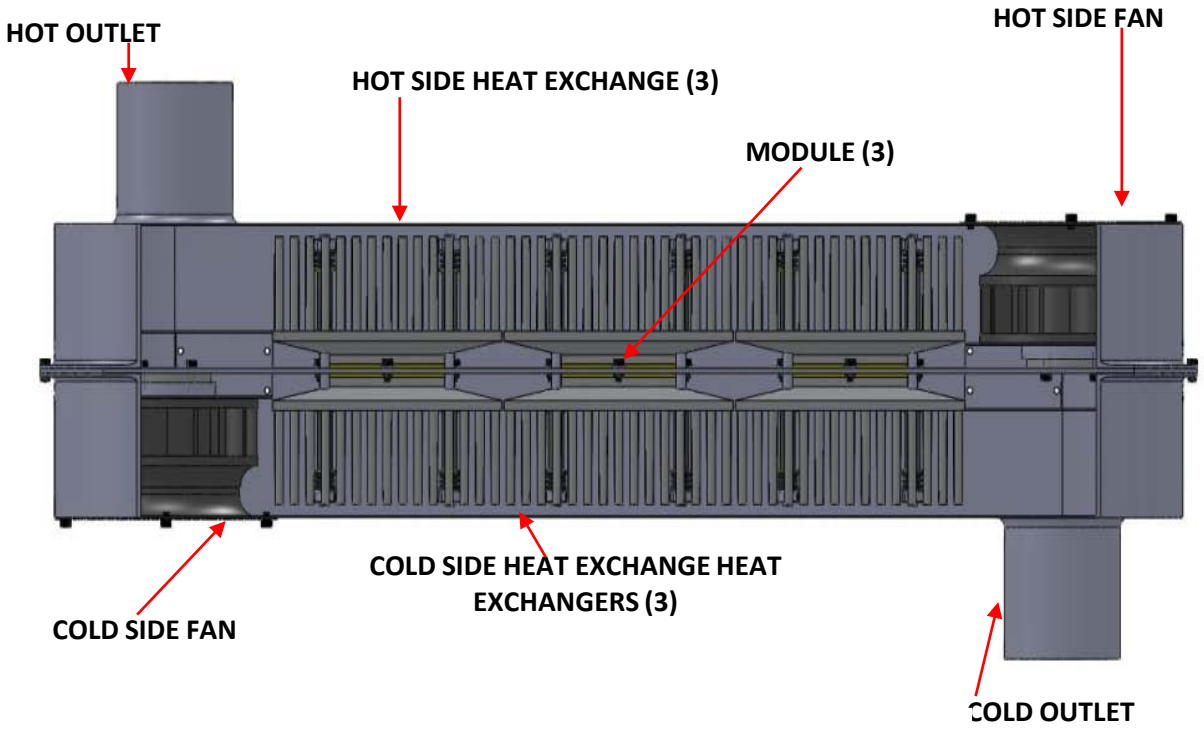


Figure 3a. Counter Flow System

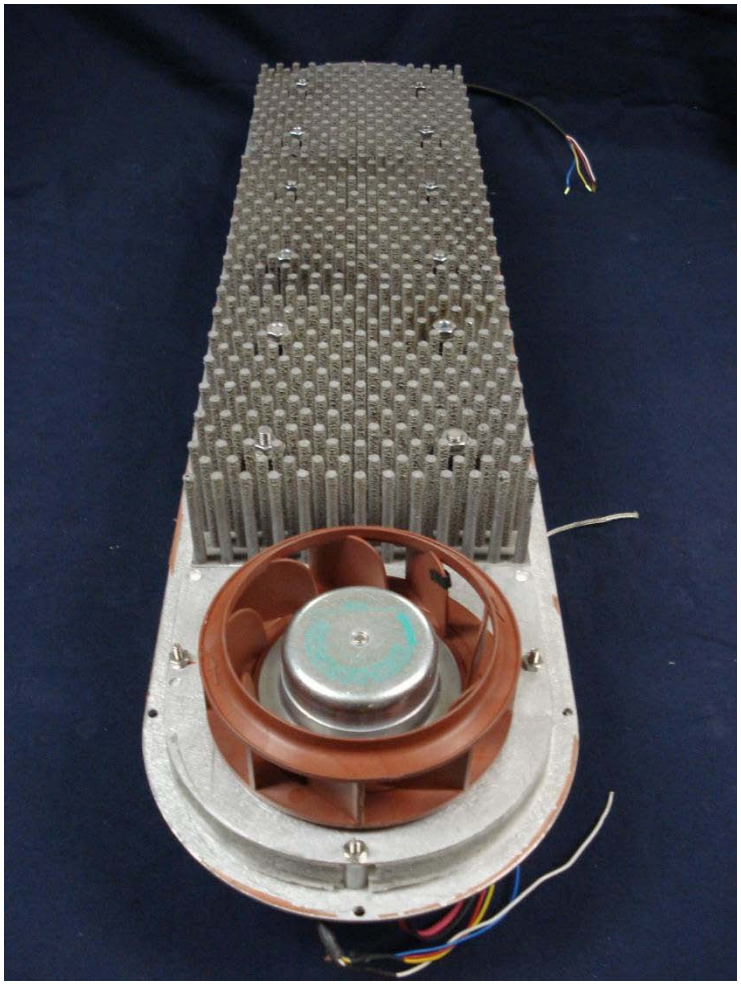


Cooler Assembly with Cover Removed



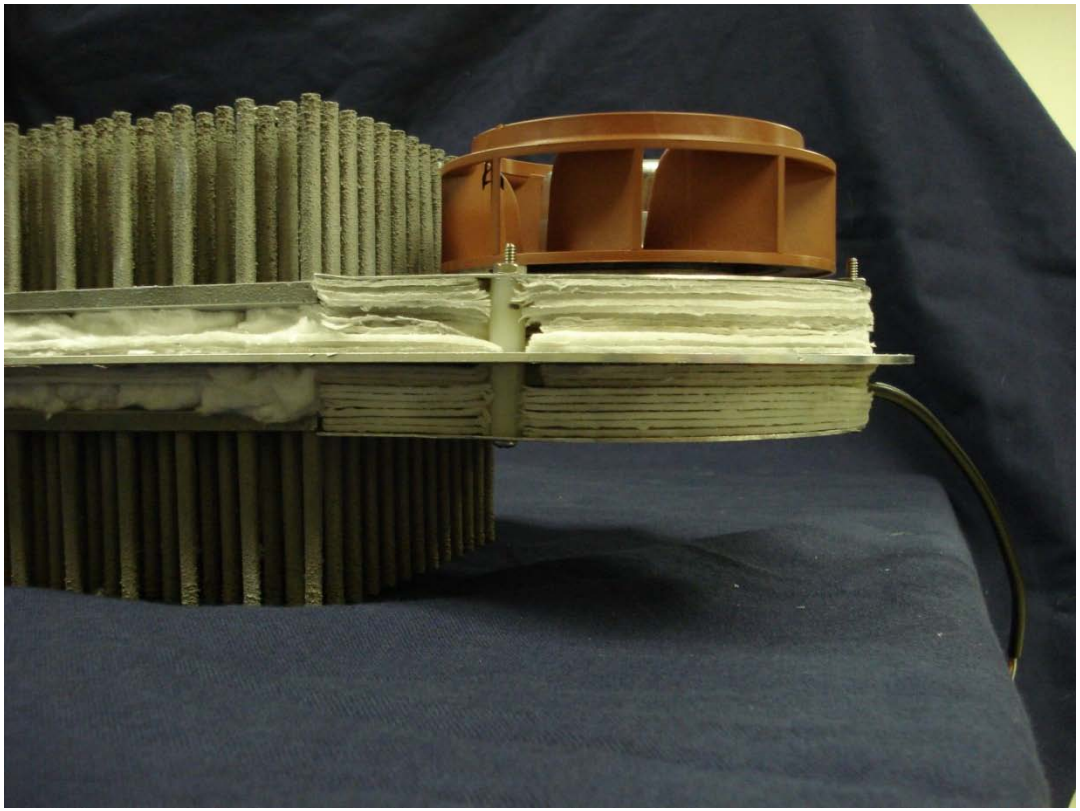
Cooler Assembly, Side View

One Side of Cooler/Heater



Cooler Showing Heat Exchangers and Fan

One Side of Cooler Heater



Picture of Side of Cooler Showing Fan and Heat Sinks

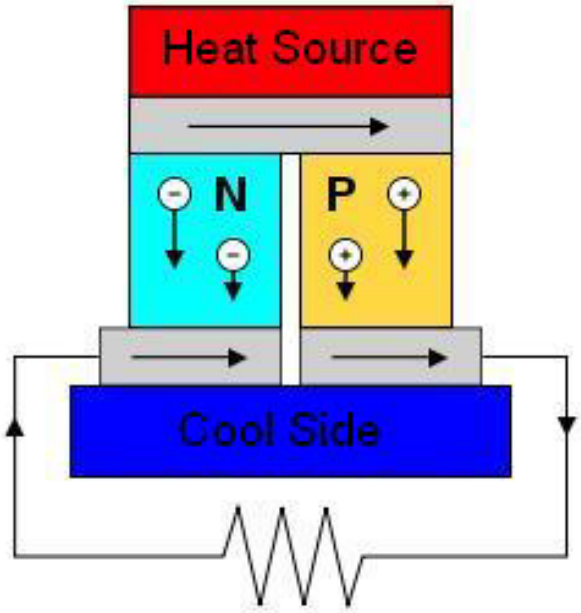
Complete Cooler/Heater

Both Covers in Place, Ready for Operation

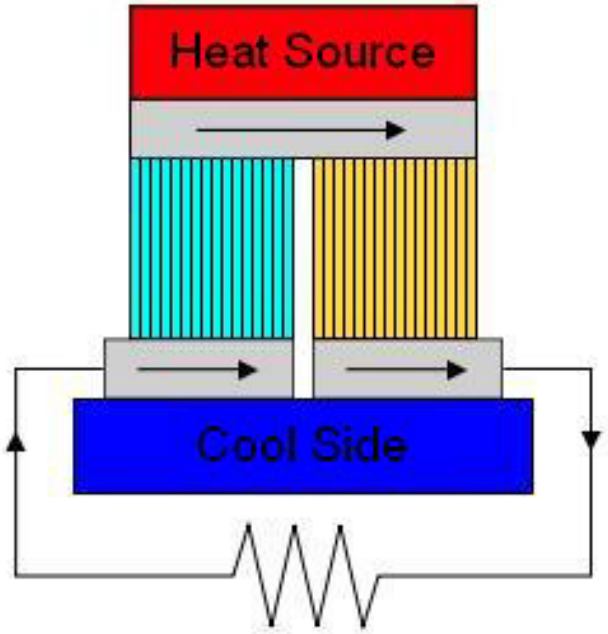
Construction of Module

- Multilayer Film Deposited on Substrate
- Use as in
- Transfer to Alternative Substrate and Remove the Original Substrate
- Use a Si Substrate and Remove it
- Clean Ends of Elementss add Deposit Metalic Contacts
- Deposit Directly on Kapton or Other Low K Material
- Cut Deposited Material to Leg Size Elements
- Stack Elements to Form N and P Legs
- Insert Legs into Egg Crate
- Apply Material by Spraying
- Lap to Finish Module

Either N-type or P-type QW thermoelectric material are deposited on the surface of the substrate wafers. After being sectioned into leg parts, the parts are stacked together to form one 'leg' (P or N) of a thermoelectric power-generating or cooler P-N 'couple'.



Typical Bulk Material Couple



Quantum Well Couple

Kapton Films

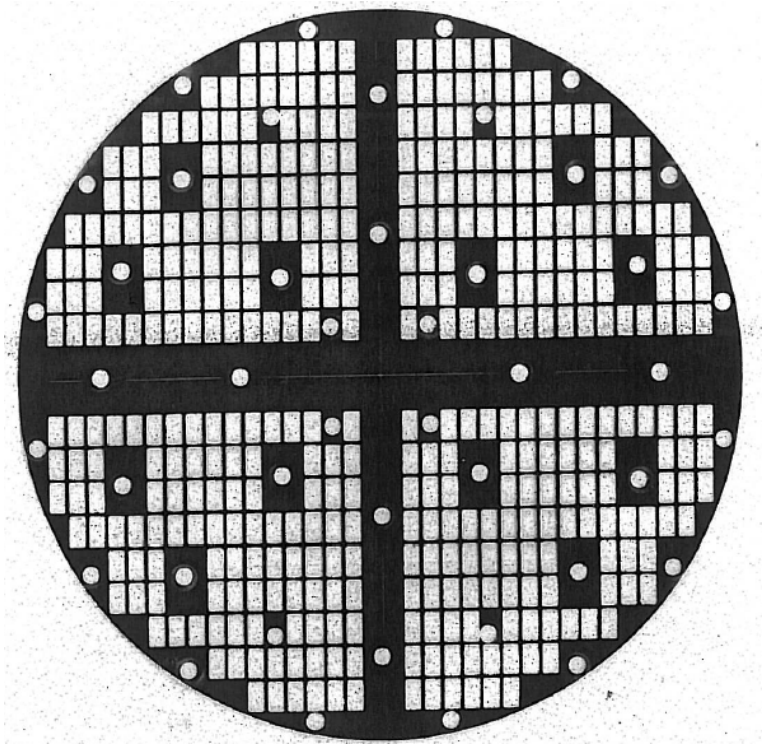
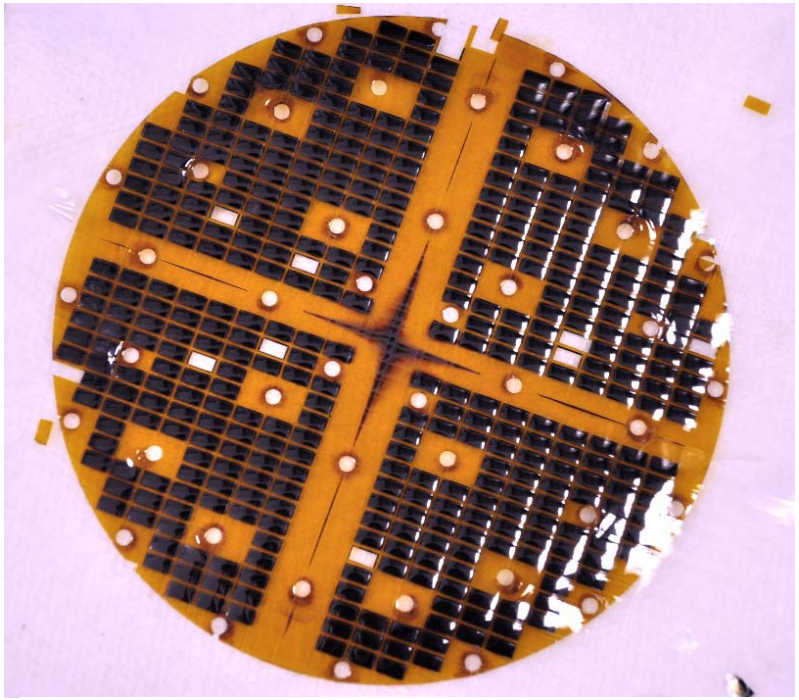
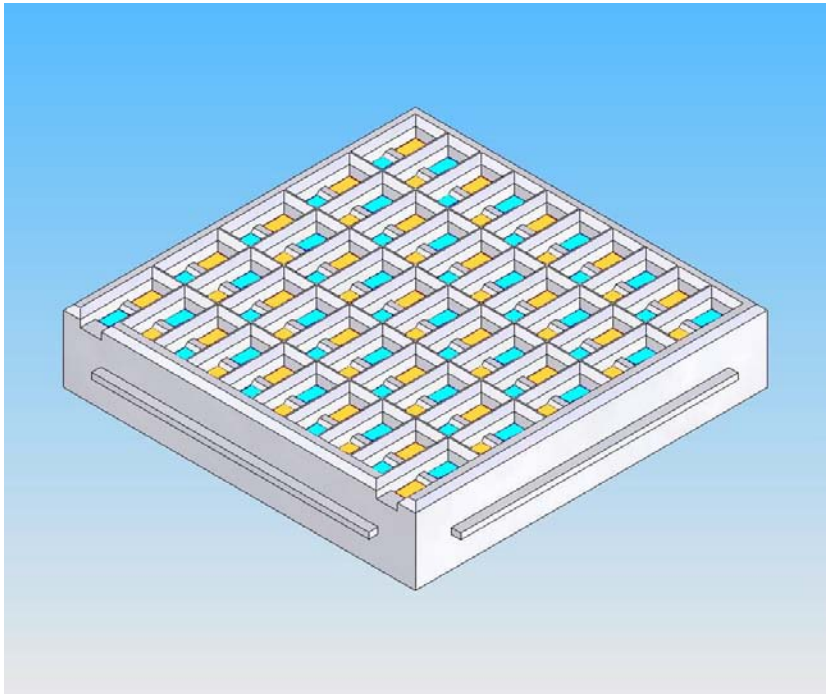


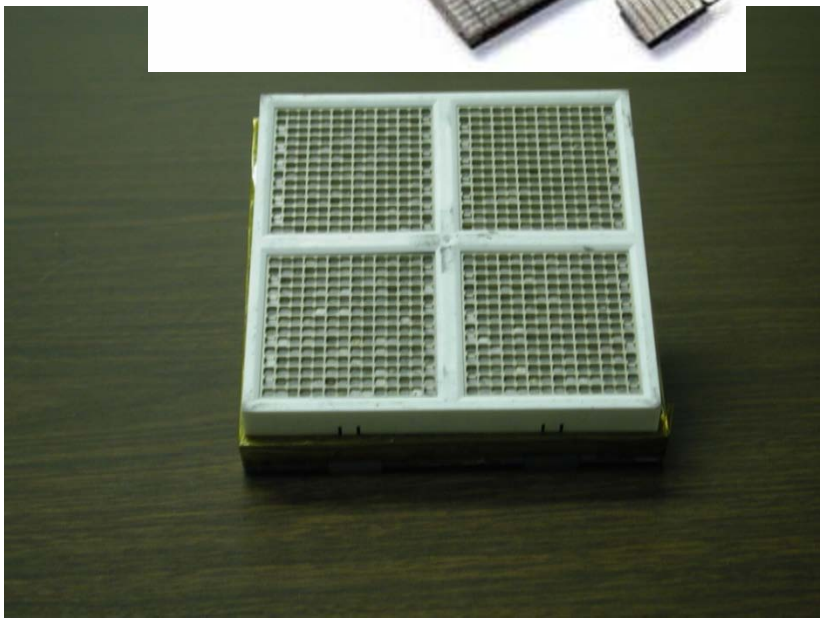
Figure 1. Mask used to deposit films



448 Samples deposited on Kapton with Mask of Figure1

By electrically connecting many couples in series, a quantum well thermoelectric module is created. The 'eggcrate' effectively arranges each of the legs in a series circuit. The modules (Hi-Z commercial shown) are finished by adding flat, thermally conductive surfaces to each side.





Present Status

- Currently Operating Cooler
  - Using HZ-14 Modules in Leu of Q.W.
- Checked Heat Exchangers for Pressure Drop
- Running HZ-14 Modules to Check Temperature
- Fabricating Q.W. Elements
- Cleaning and Depositing Metal for Contacts
- Building Equipment for Crystallization Process

Summary

- Film Started
- Eggcrate Design Completed
- Cooler/Heater Built
- Cooler/Heater Tested with HZ-14 Modules
- HZ-14 Modules to be replaced with Q.W.
- Calculations Indicated Operation Should Equal or Better Than Vapor Compression
  - Solid State
  - No Gasses
  - No Moving Parts Except Fans
- Can be Used as a Heater by Reversing Polarity

Acknowledgement

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