QUANTUM WELL THERMOELECTRIC TRUCK AIR CONDITIONING

Presented at 2012 Thermoelectric Application Conference

Baltimore, Maryland

March 20-22, 2012

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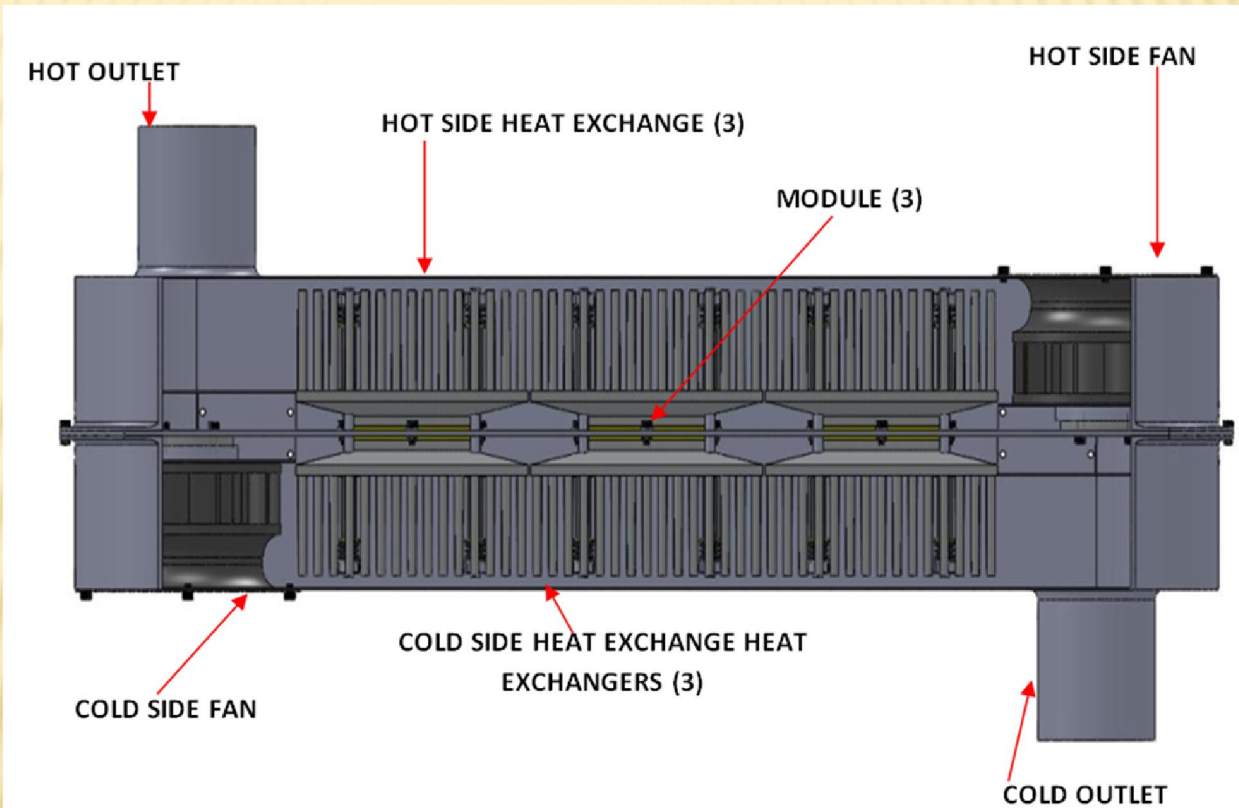
OUTLINE

a. Describe Pre-prototype Cooler
b. Heat sinks used
c. Flow Directions
d. Discuss Quantum Wells
e. Eggcrate Design
f. How module is made
g. Significance of Rapid Thermal Annealing
h. Some recent results from Small Film Sample on SOI

DESCRIPTION OF PROTOTYPE HEATER/COOLER

- 3 HZ-14 Modules
- 6 Aluminum Pin Fin Heat sinks
- 2 Motorized Centrifugal Impellers
- Insulation
- Aluminum Covers

COOLER ASSEMBLY, SIDE VIEW

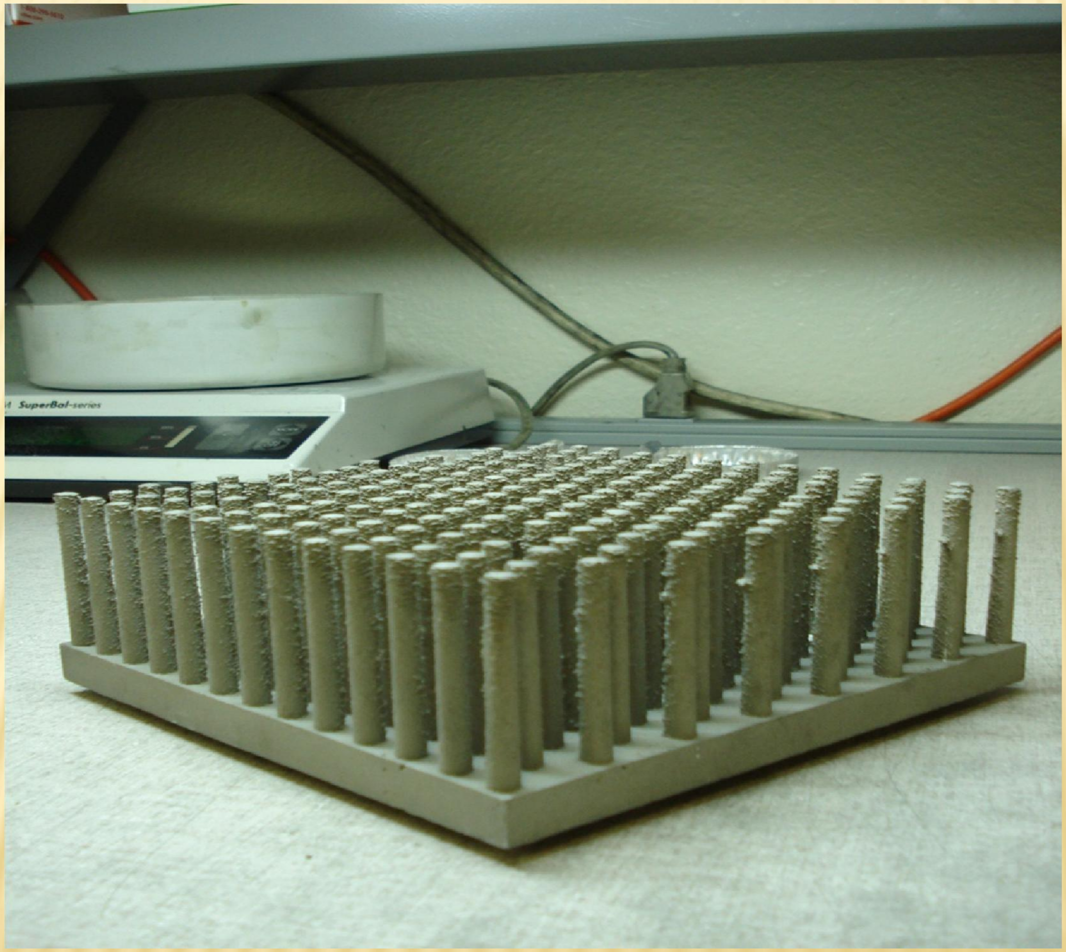


AIR COOLED HEAT SINKS

PHYSICAL DIMENSIONS

- Size 6” x 6” X 2”
- 188 PINS
- 3/16” Diameter
- Cast Aluminum

AIR COOLED HEAT EXCHANGER



INVESTIGATED FLOW DIRECTION

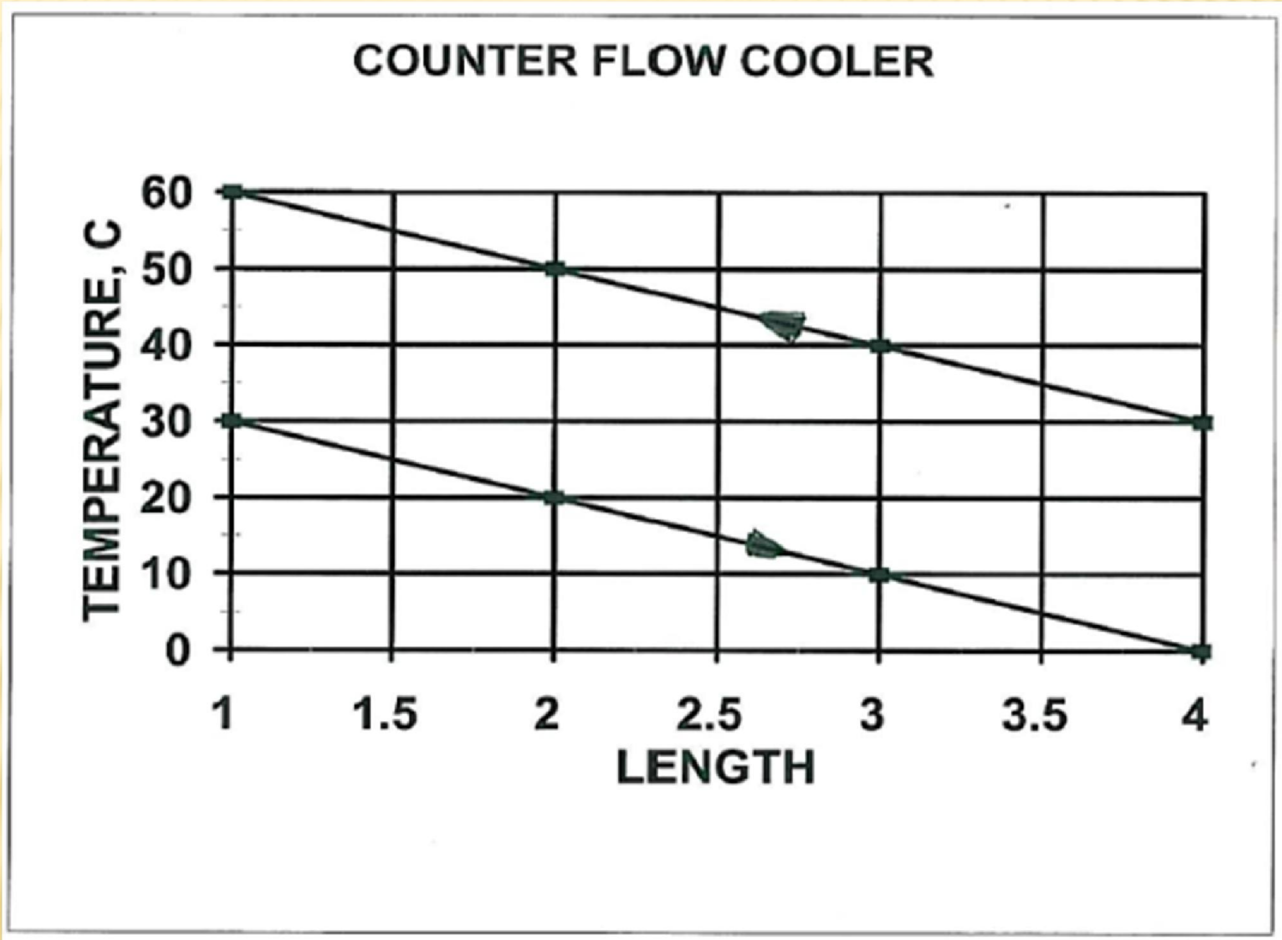
Look at Both Counter and Parallel Flow

Graphs shown for equal Volumetric Flow Both Sides

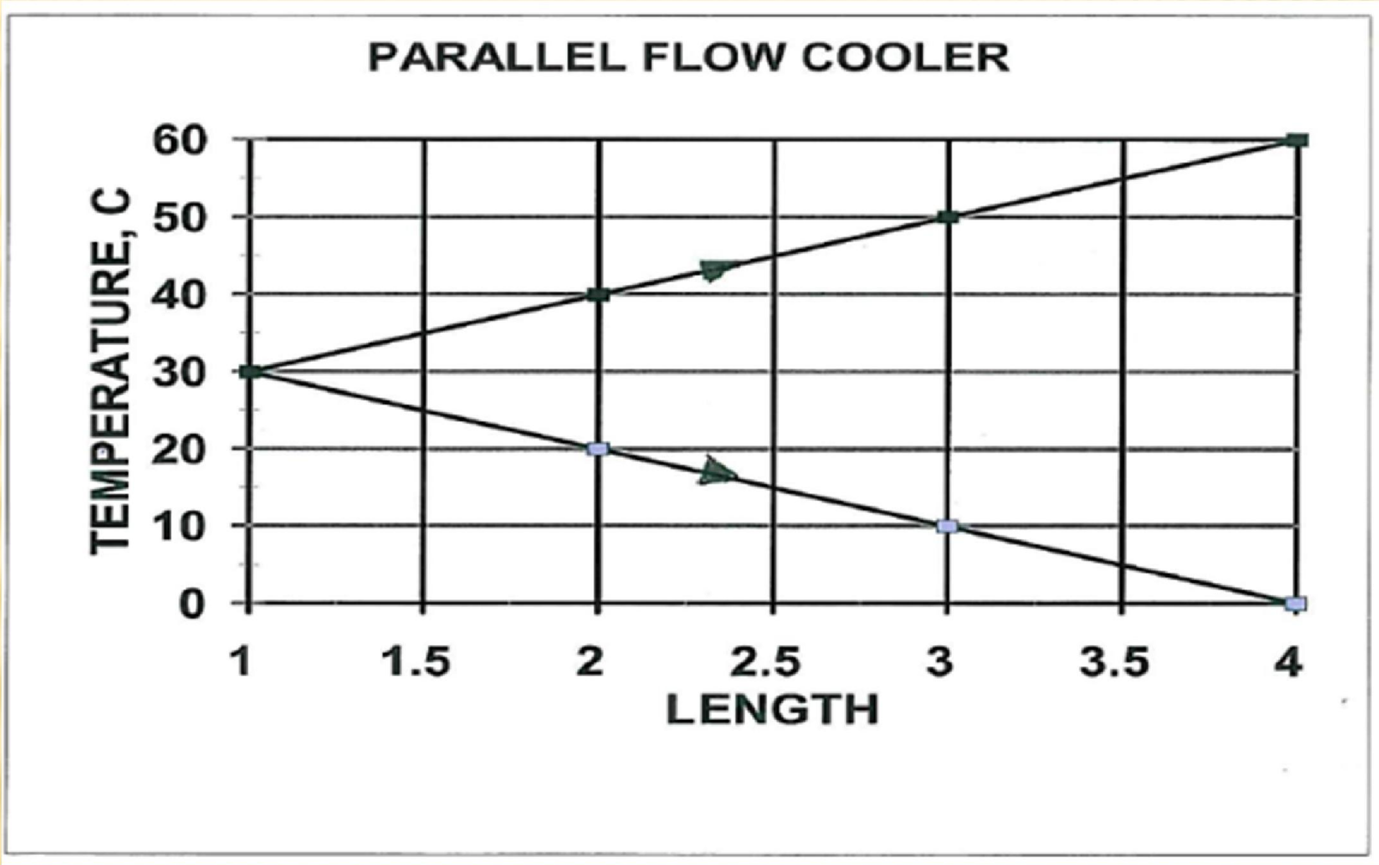
Investigated Variations IN Volumetric Flow

Attempted to Take Advantage of High Thermal Efficiency at Low Delta T

COUNTER FLOW COOLER



PARALLEL FLOW COOLER



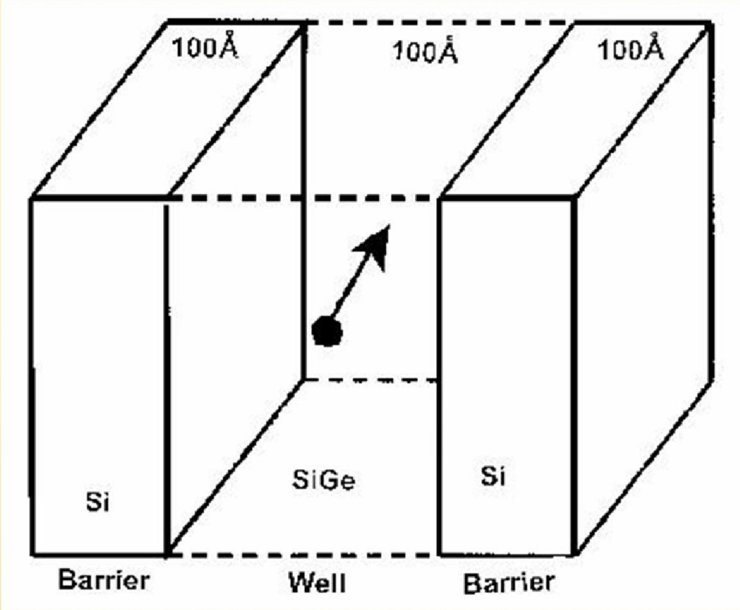
INSIDE OF HEATER/COOLER (COVER REMOVED)

QUANTUM WELL THEORY

- Modules multiple layers of Si and 80Si/20Ge
- Layers 50 to 100 Å thick
- Stacked up to thickness of 1μm or more
- Made by MBE are Sputtering
  - -Sputtering used by Hi-Z to Lower Cost
  - -Machine Range from 2“ to 6” diameter
- Films Deposited on Silicon, Kapton , Glass or SOI substrates.

TWO-DIMENSIONAL QUANTUM WELL TE

- Active layer sandwiched between materials with band offset to form a barrier for the charge carriers
- Increased Seebeck coefficient (α) due to an increase in the density of states
- Significant reduction on resistivity (ρ) due to quantum confinement of carriers
- Significant reduction on thermal conductivity (κ) due to strained lattice and other factors
- Quantum Well (QW) effects become significant at a layer thickness of <200Å



QUANTUM WELL AND THE DE BROGLIE RELATIONS

The de Broglie equations relate the wavelength λ and frequency f to the momentum p and energy E, respectively, as

$$\lambda = \frac{h}{p} \qquad f = \frac{E}{h}$$

where h is Planck's constant. The two equations are also written as

$$p = \hbar k$$
$$E = \hbar \omega$$

Thermal de Broglie wavelength

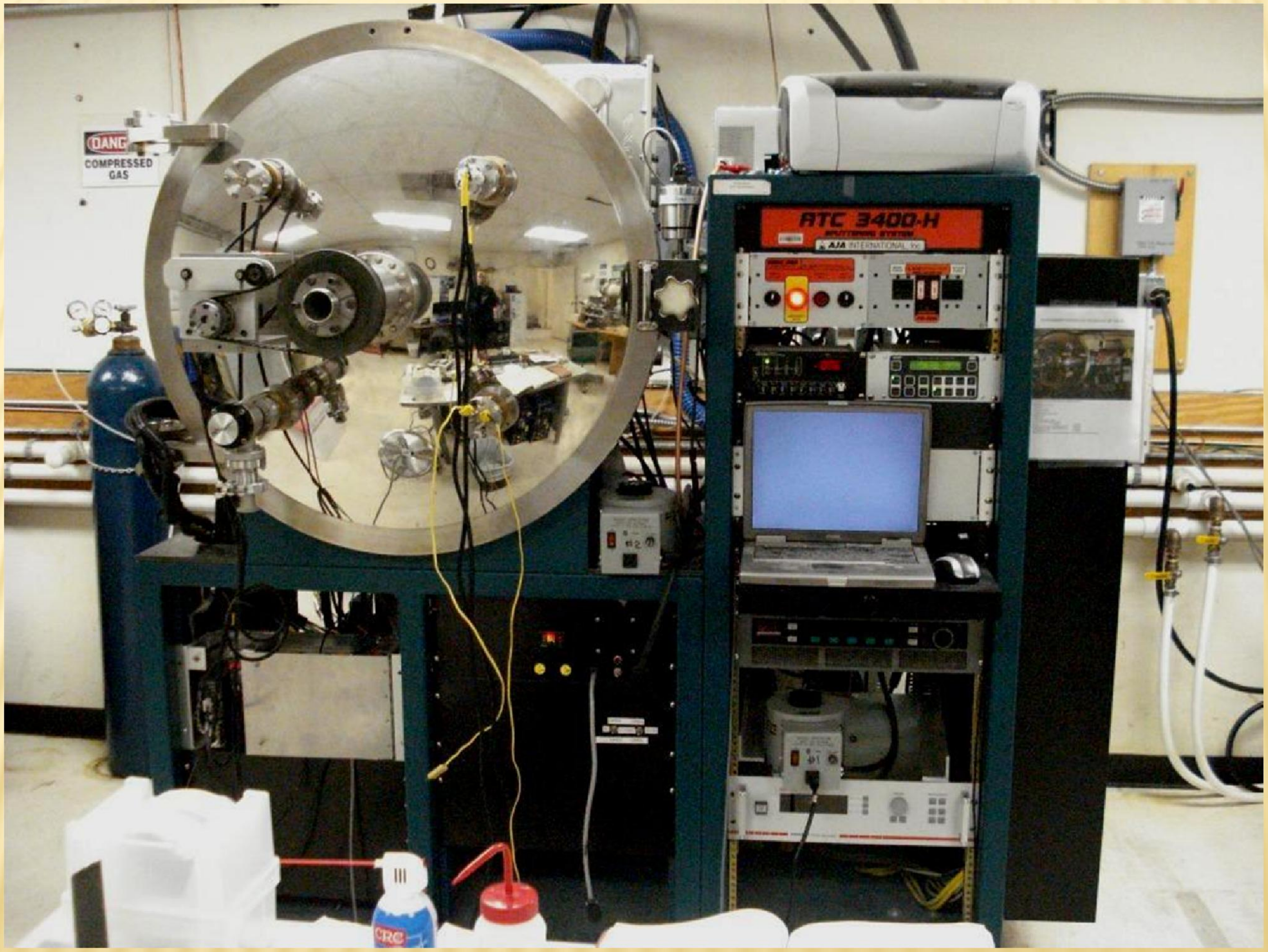
The "Thermal de Broglie wavelength" is defined for a free ideal gas of massive particles in equilibrium as:

$$\Lambda = \sqrt{\frac{h^2}{2\pi mkT}} = \frac{h}{\sqrt{2\pi mkT}}$$

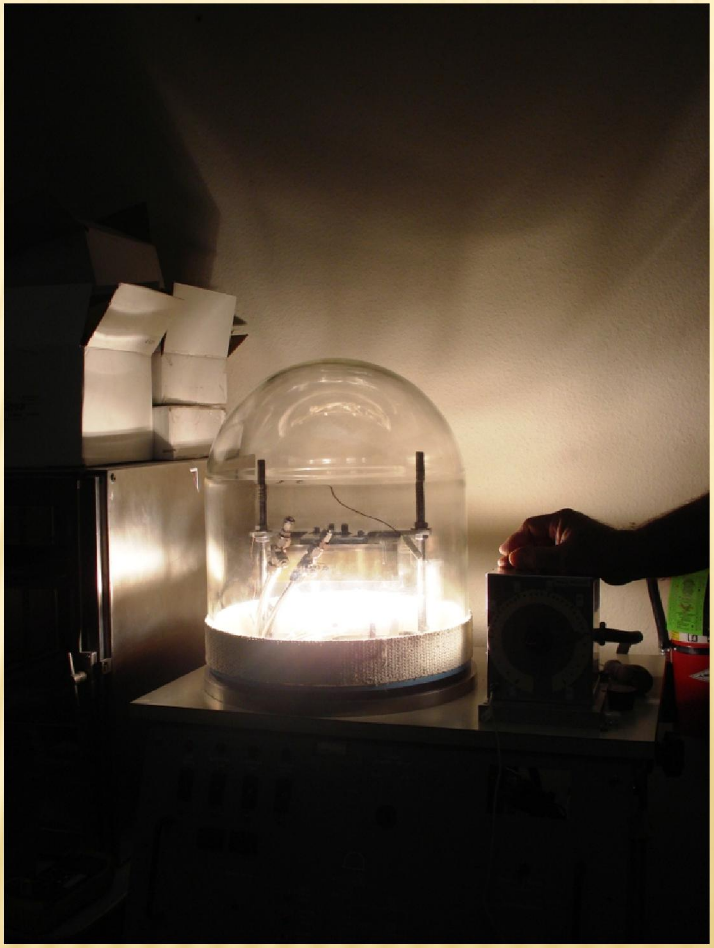
where

- h is Planck's constant = 6.626X10^{-34} J-sec
- m is the effective mass of a gas particle
- k is Boltzmann's constant = 1.381X10^{-23} J/K
- T is the Temperature of the gas
- Quantum effects appear if the barriers are much larger than kT and the layer spacing is smaller than the thermal deBroglie wavelength.
- For the films $\Lambda_{Si/SiGe}$ ~ 300 Å and $\Lambda_{Si/SiC}$ ~ 500 Å at RT all larger than 100Å the layer thickness. Therefore, the films are Quantum Well effects

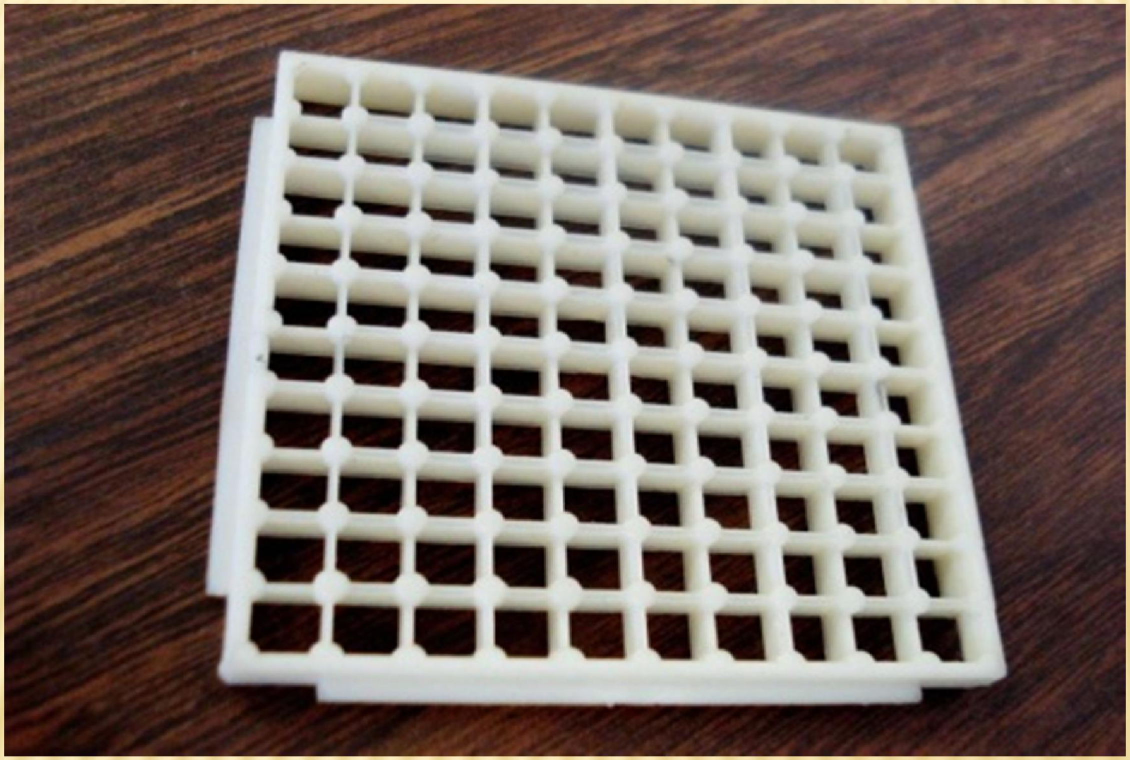
6" MAGNETRON SPUTTERING MACHINE



LIGHT EMITTED FROM RTA IN OPERATION



EGGCRATE



EXAMPLES OF FILMS MADE OR SMALL MACHINE

- Less then 2”Diameter samples
- Magnetron Sputtering Machine

N-TYPE SI/SIGE QW FILMS ON SOI

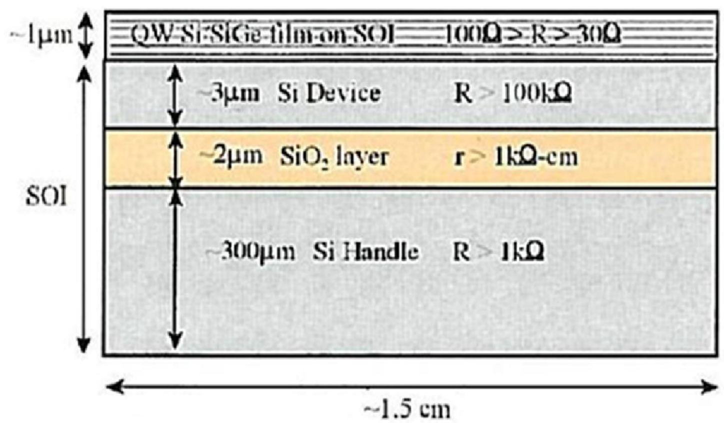
N-Type Si/SiGe QW Films on SOI (experimental error = +/-5%)

1um QW film, 10nm each layer, on SOI: 3um Si device 300um handle.
Resistivity of SiO2 > 1kOhm-cm from 300-1300K. TE properties went back after cool down.

T(K) Temperature	Rfilm(Ohm) Sample	Svolt(mV) SeebkVolt	Rdev(kOhm) Device	Rhan(kOhm) Handle	r(mOh-cm) Film	S(uV/°C) Film
300	31.68	-9.95	115.20	1.271	1.056	-995
325	33.93	-10.33	110.40	1.300	1.131	-1033

$$\frac{1}{R_{Sample}} = \frac{1}{R_{SiDevice}} + \frac{1}{R_{SiHandle}} + \frac{1}{R_{Film}}$$

$$V_{Film} = \left(1 + \frac{R_{Film}}{R_{SiDevice}}\right) V_{Sample} - \left(\frac{R_{Film}}{R_{SiDevice}}\right) V_{SiDevice}$$



P-TYPE SI/SIGE QW FILMS ON SOI

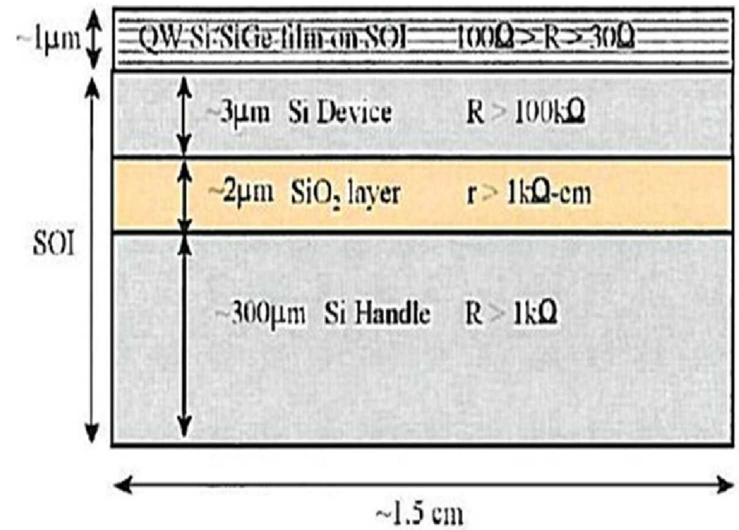
P-Type Si/SiGe QW Films on SOI (experimental error = +/-5%)

1um QW film, 10nm each layer, on SOI: 3um Si device 300um handle.
Resistivity of SiO2 > 1kOhm-cm from 300-1300K. TE properties went back after cool down.

T(K) Temperature	Rfilm(Ohm) Sample	Svolt(mV) SeebkVolt	Rdev(kOhm) Device	Rhan(kOhm) Handle	r(mOh-cm) Film	S(uV/°C) Film
300	33.06	10.10	126.83	1.309	1.102	1010
325	34.05	10.85	154.53	1.684	1.135	1085

$$\frac{1}{R_{Sample}} = \frac{1}{R_{SiDevice}} + \frac{1}{R_{SiHandle}} + \frac{1}{R_{Film}}$$

$$V_{Film} = \left(1 + \frac{R_{Film}}{R_{SiDevice}}\right) V_{Sample} - \left(\frac{R_{Film}}{R_{SiDevice}}\right) V_{SiDevice}$$



RESULTS

- Air Conditioning with No moving parts
- No Gases except air involved
- Performance on a Par with Vapor Compression
- Can be used as Heat Pump by Simply Reversing Polarity

ACKNOWLEDGEMENT

Hi-Z would like to thank the Department of Energy for its support and patience in this matter. Particularly our mentor at the DoE Mr. Charles Russomanno.