Development of a Scalable 10% Efficient Thermoelectric Generator

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Build on Recent Successes

Materials:

ZT substantially greater than unity has been demonstrated at places such as Michigan State, Research Triangle Institute (RTI), and MIT Lincoln Labs

Segmentation devices have successfully been demonstrated at Jet Propulsion Laboratory (JPL)

Thermodynamics and Heat Transfer:

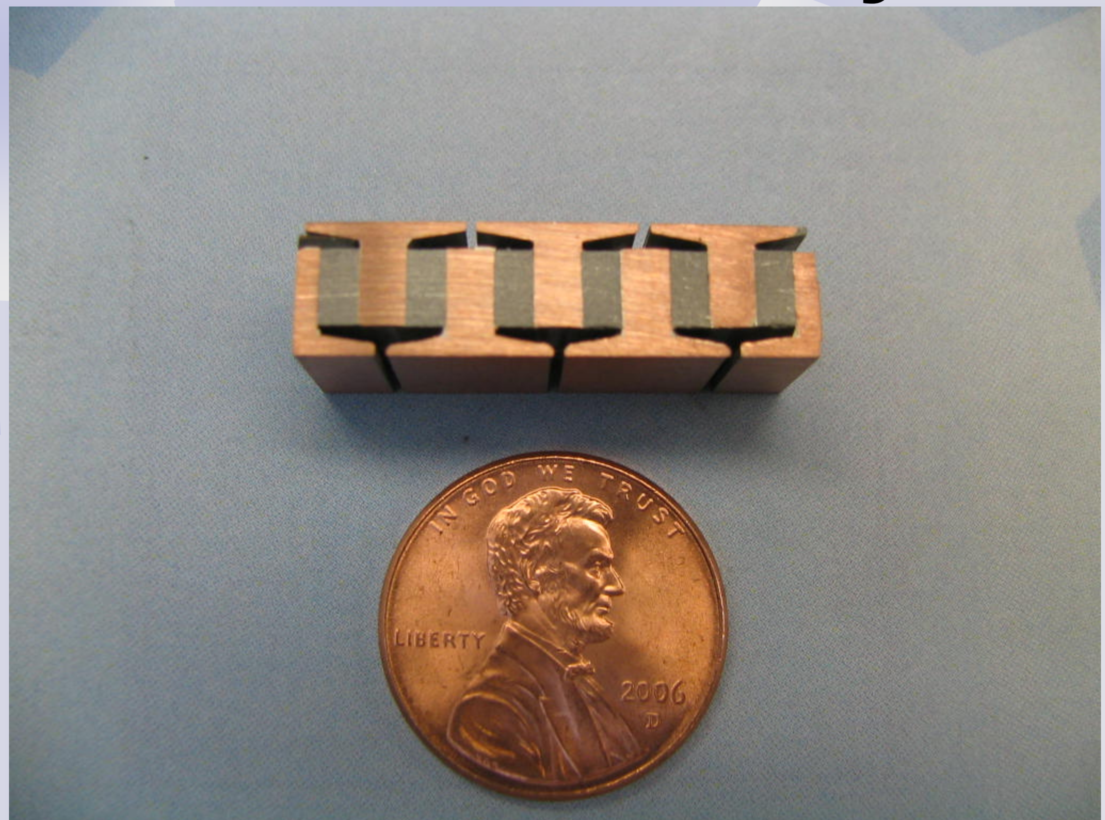
Thermal isolation in the direction of flow that can improve cooling/heating performance by a factor of two

High power density designs that require 1/6 the thermoelectric (TE) material usage of conventional designs

TGM Development Methodology

- Model, design and build fractional generator, first with low temperature TE material followed by high temperature TE material and finally segmented TE material
- Validate performance model under varying operating conditions
- Replicate fractional generator to scale up to >500 watts for low temperature TE material followed by similar scale up for high temperature (20W) and segmented TE materials
- Integrate fractional generators with heat exchangers on the hot and cold side
- Test and revalidate the performance model at varying operating conditions

Low Temperature Bi_2Te_3 Subassembly



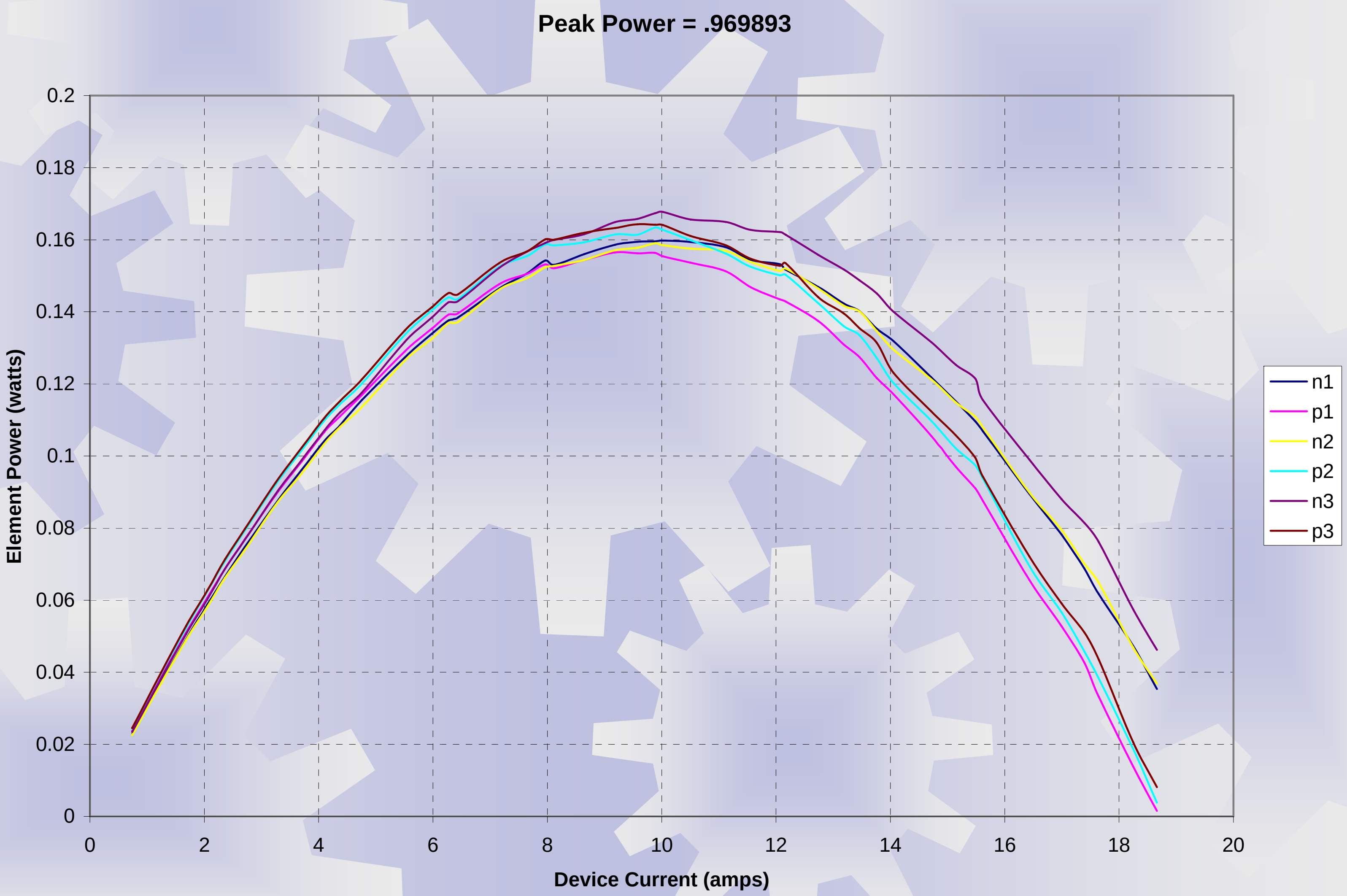
Low temperature device built to continue learning process while high temperature material systems are being developed

Bi_2Te_3 thermoelectric generator module (TGM) output nominally targeted at > 500 watts

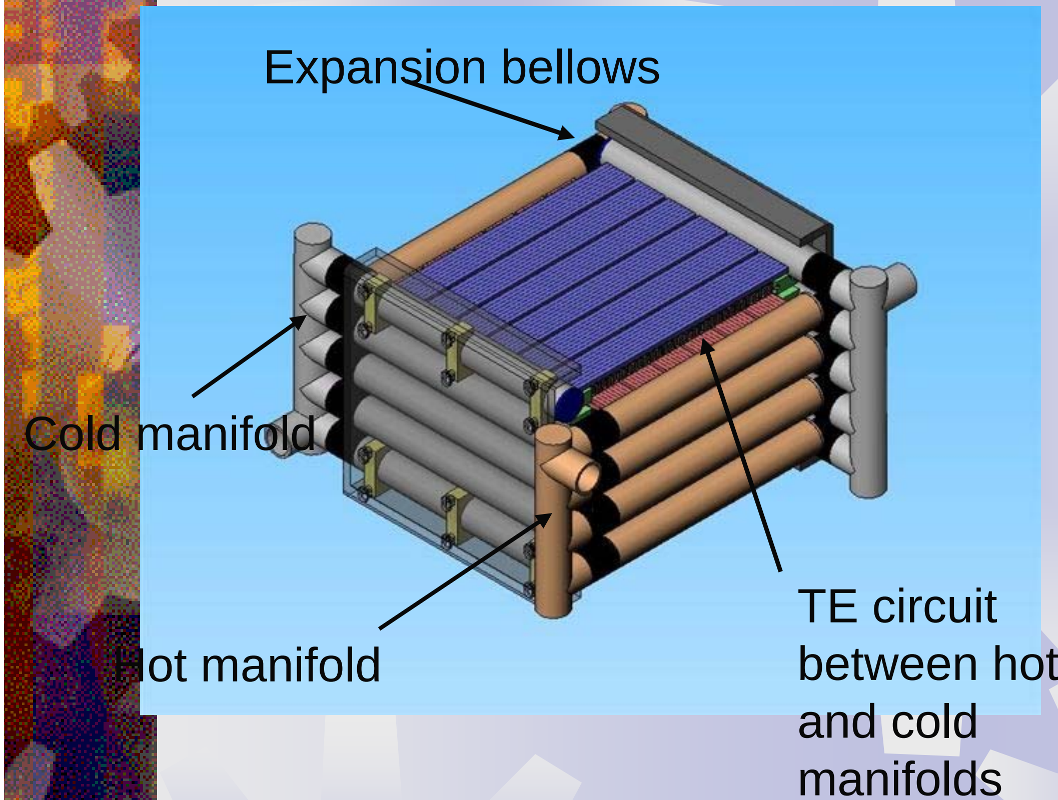
- Hot side fluid: oil, inlet temperature = 200 to 250C
- Cold side fluid: water or glycol/water, inlet temperature = -5 to 30C

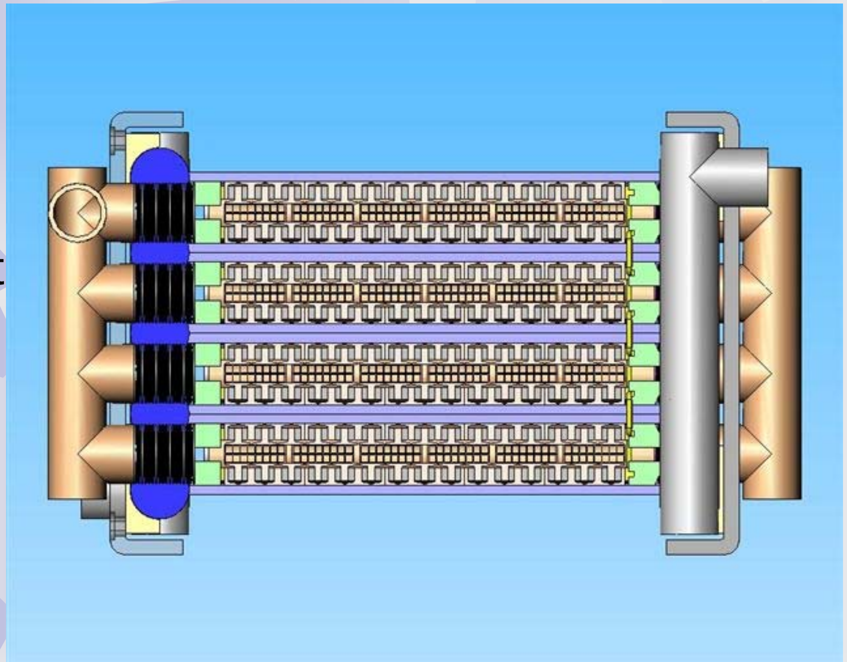
Test Results of Single Module

(T_h = 190C, water bath = 20C)

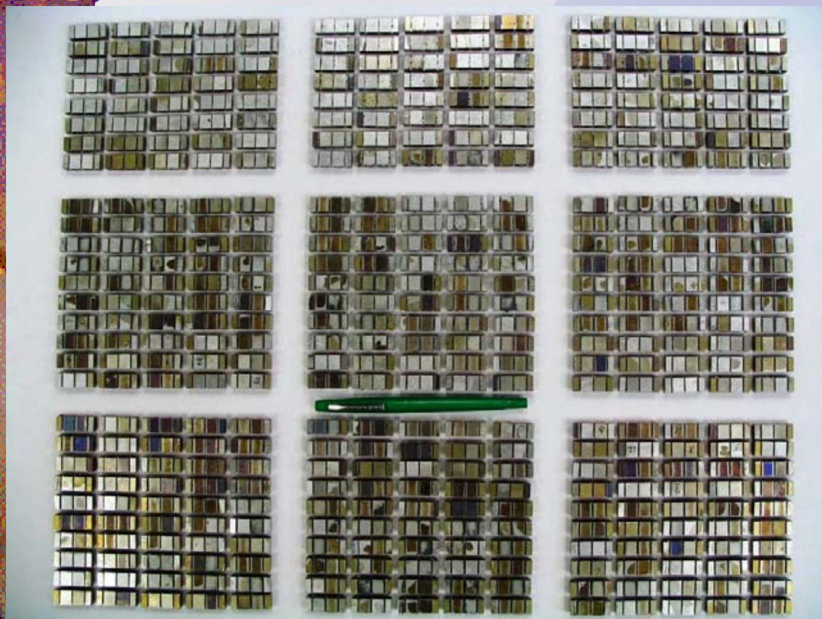


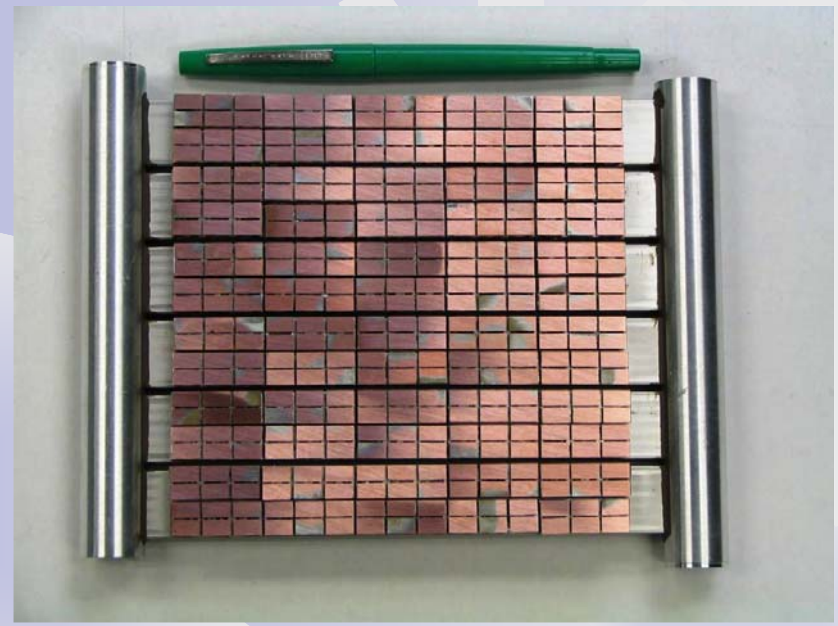
Solid Model Isometric & Cross Section Views

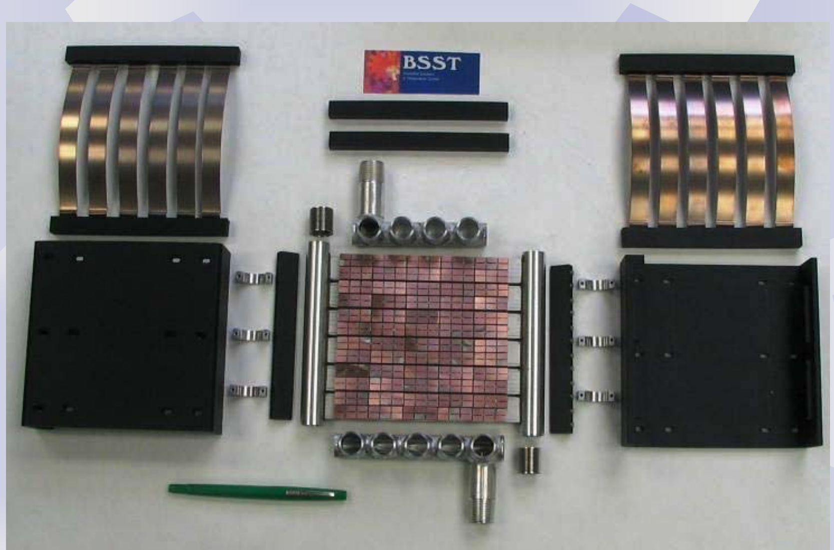




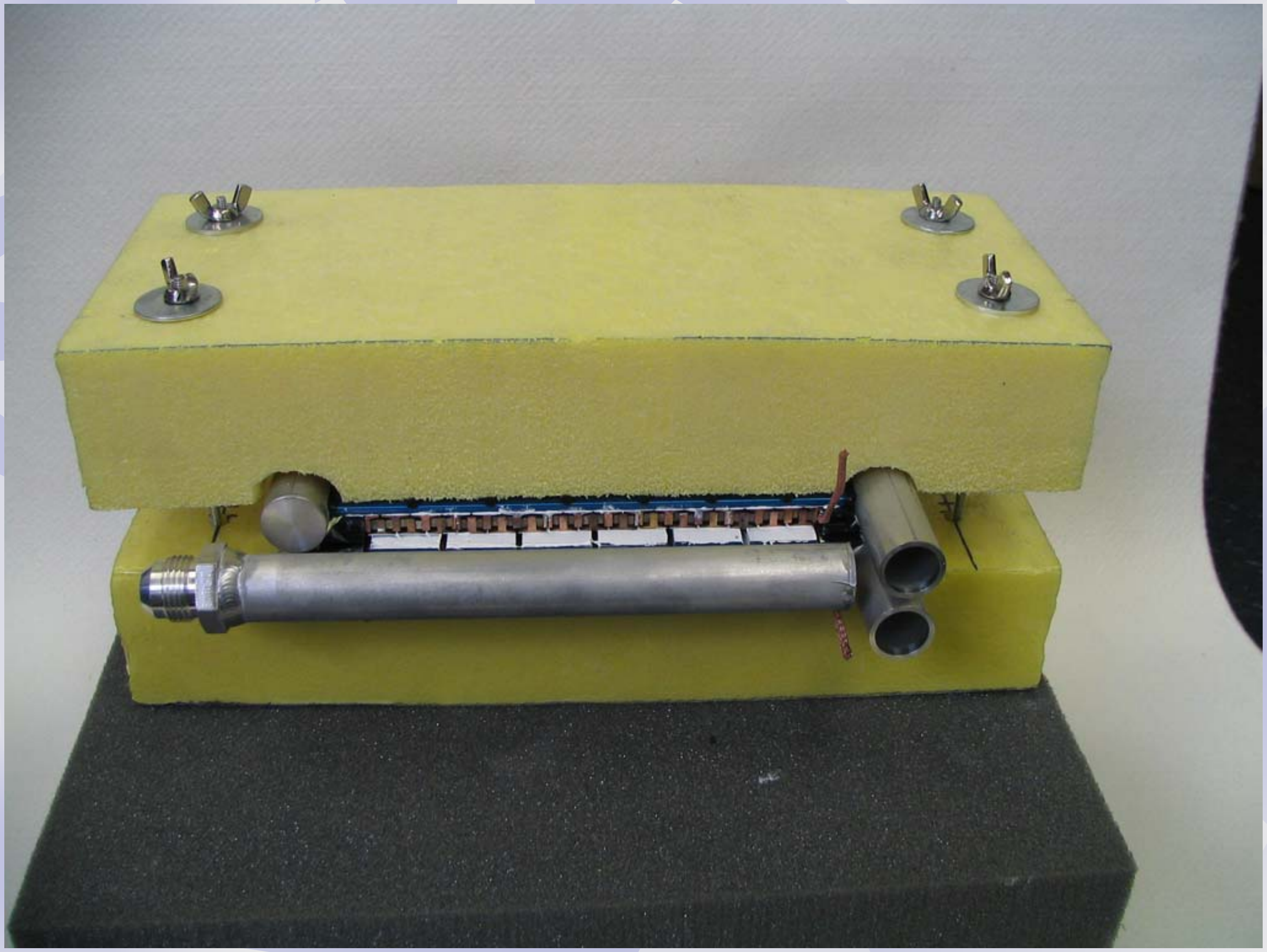
Thermoelectric Subassemblies



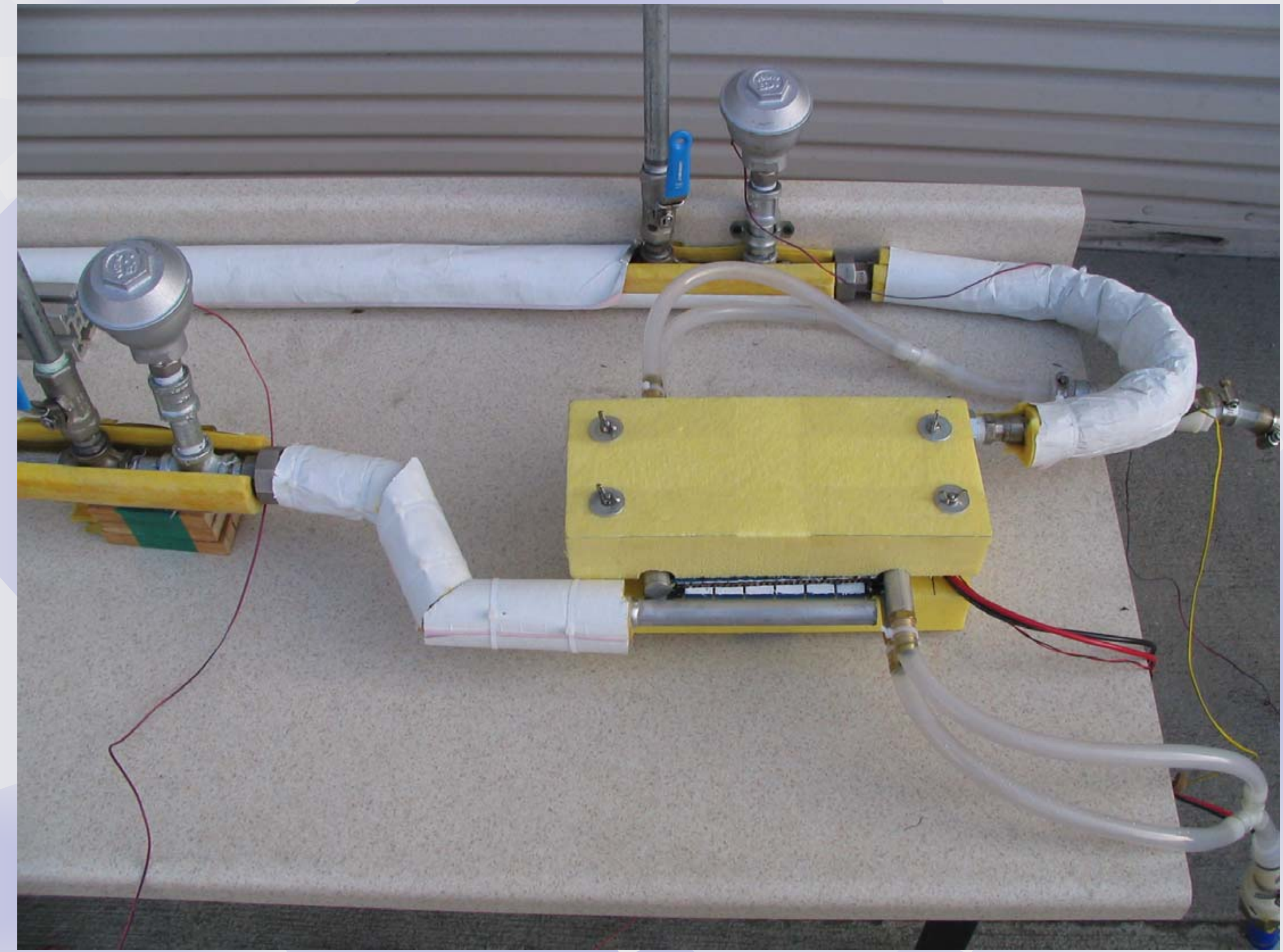




Assembled Single Hot Plate TE Generator

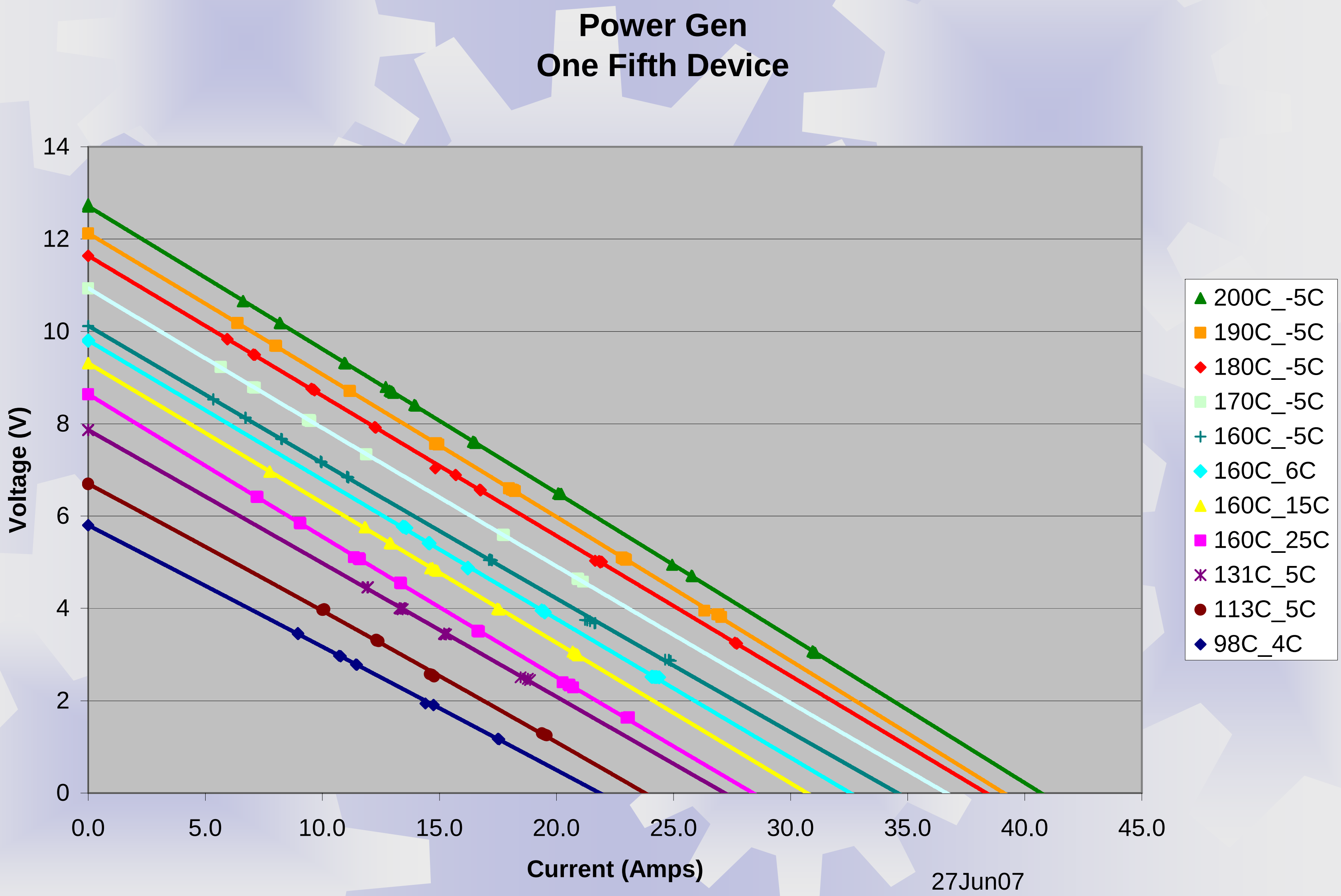


Generator Test Setup



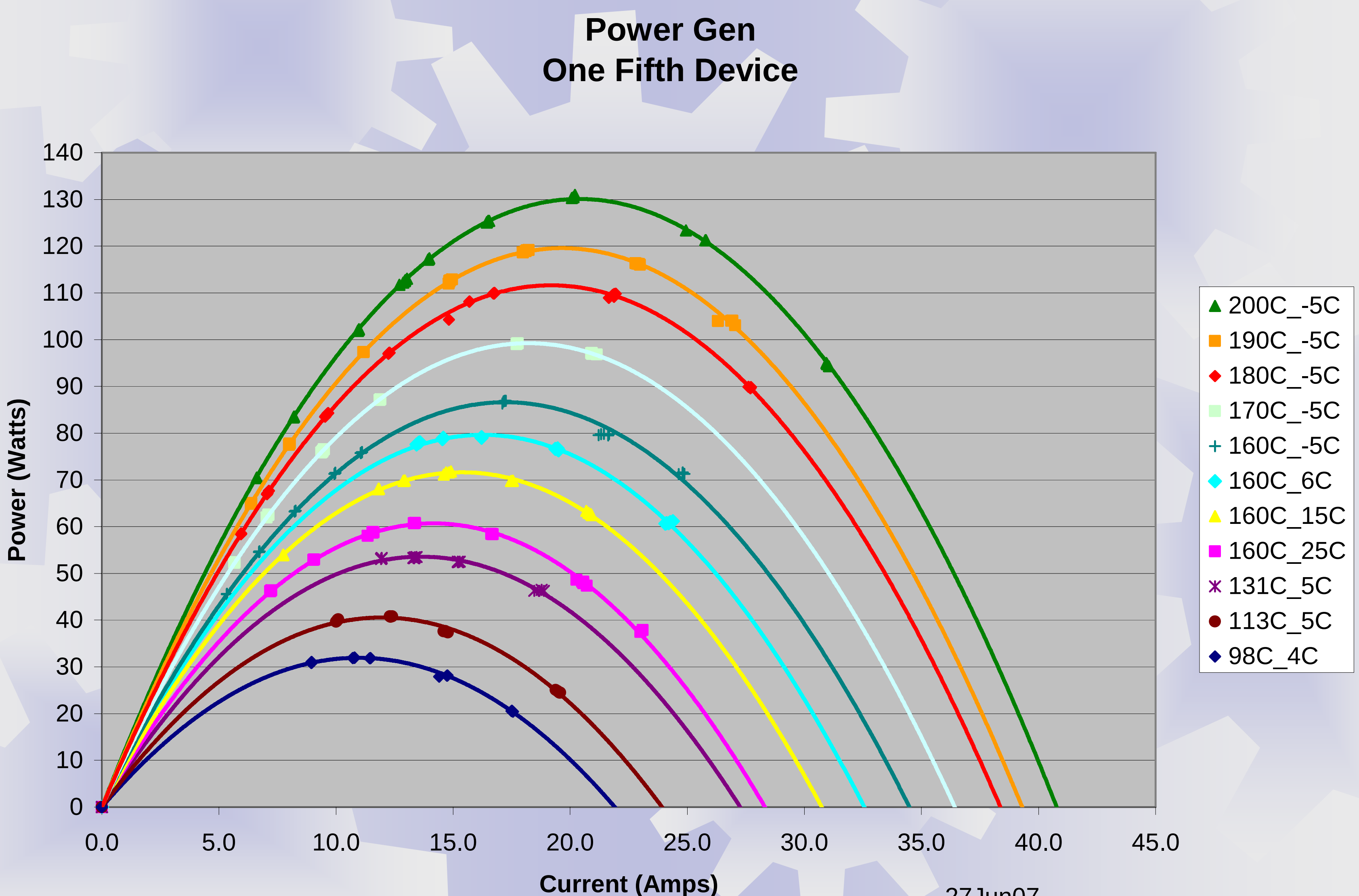
Test Results

Maximum Open Circuit Voltage >12V



Test Results

Maximum Peak Power of 130W



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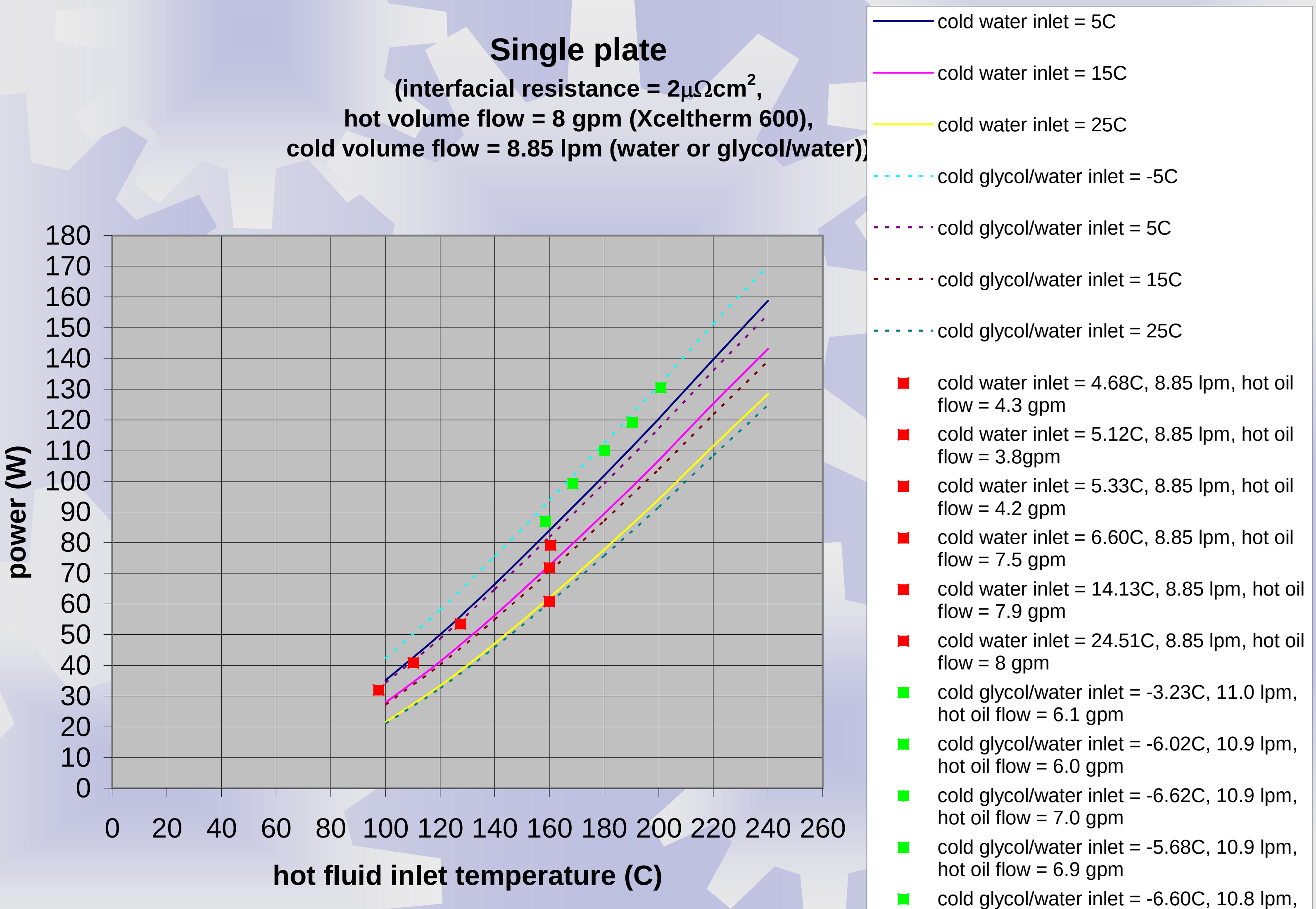
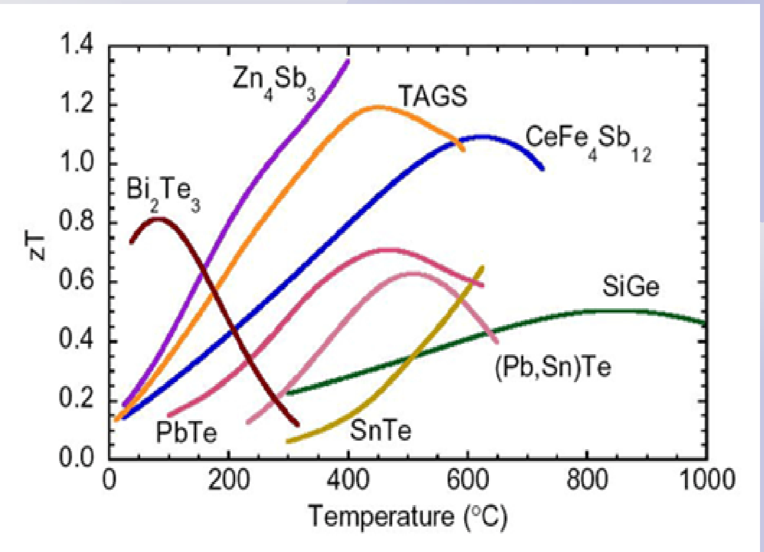
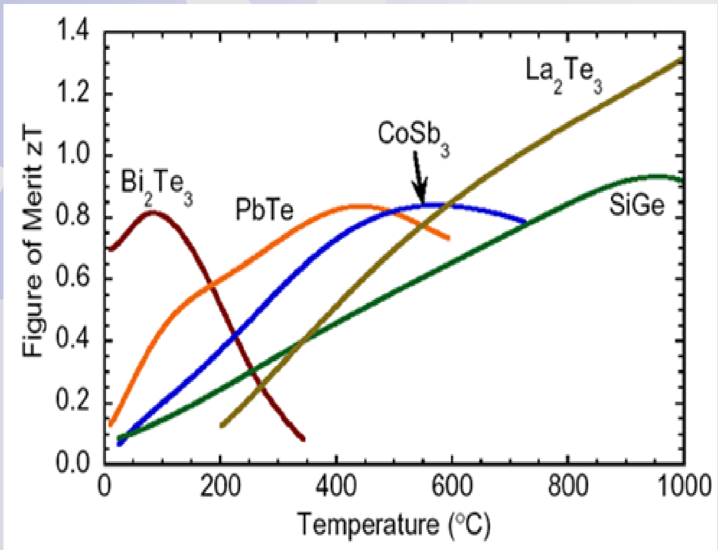
Peak Test Results Compared to Simulations

Measured to simulated values vary by < 5%



TE Figure of Merit for Current Materials



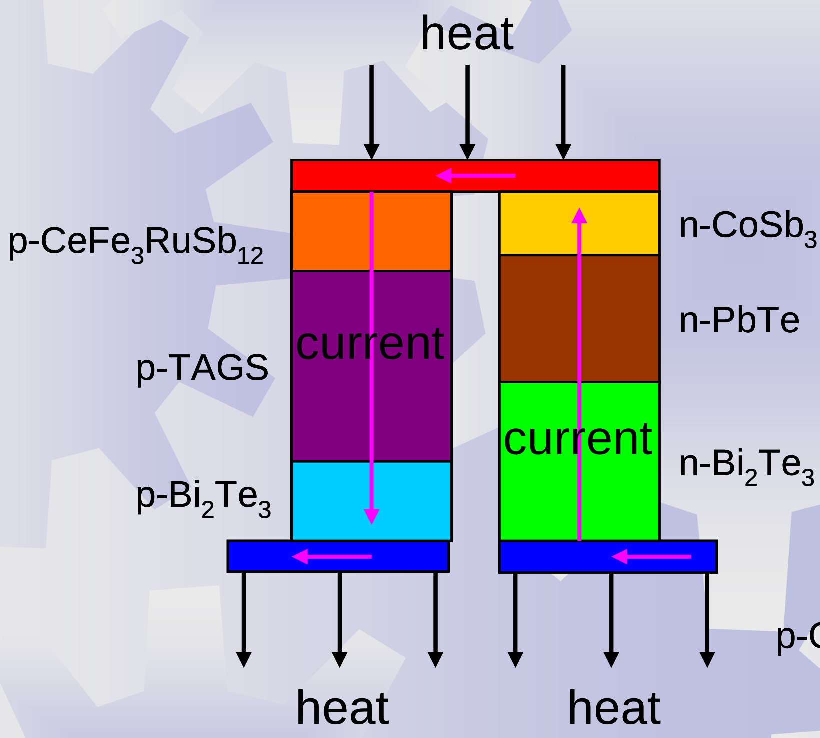


Materials for segment layers are chosen to maximize ZT over each element's exposed temperature range.

Materials of choice currently include p- and n-type skutterudite and Bi_2Te_3 as well as TAGS and n-type PbTe.

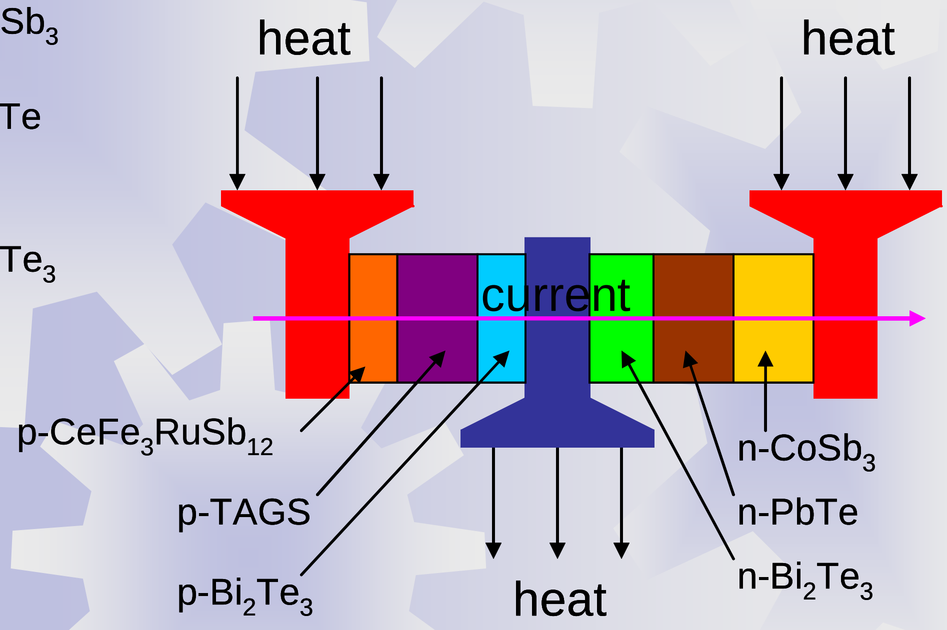
Ref: Modified from - http://www.its.caltech.edu/~jsnyder/thermoelectrics/

TE Couple Configuration Alternatives with Segmented Elements



Traditional configuration

Alternative “Y” configuration

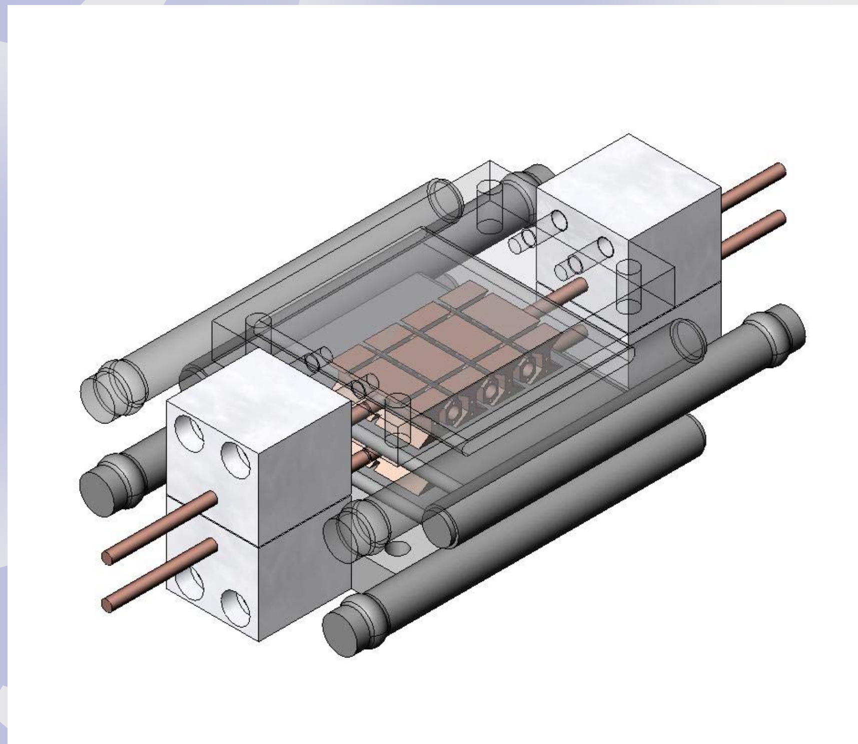


TGM Design Objectives

- State-of-the-art thermoelectric materials
- Thermally isolated elements in the direction of flow
- High power density design
- Segmented elements to maximize ZT over entire temperature range
- Ability to adjust segment thicknesses to increase TE material compatibility within elements
- Use “Y” configuration to accommodate differing element thicknesses and differing thermal expansion coefficients
- Use non-rigid joints to reduce the effects of thermal expansion mismatch

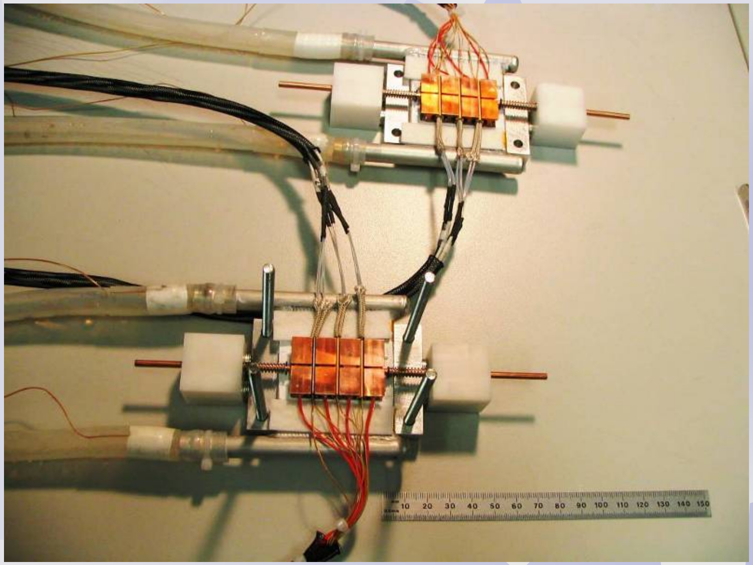
High Temperature TGM Developmental Prototype (20W)

TGM subassembly (cartridge heaters on hot side- full scale TGM will use hot gas heat exchangers)

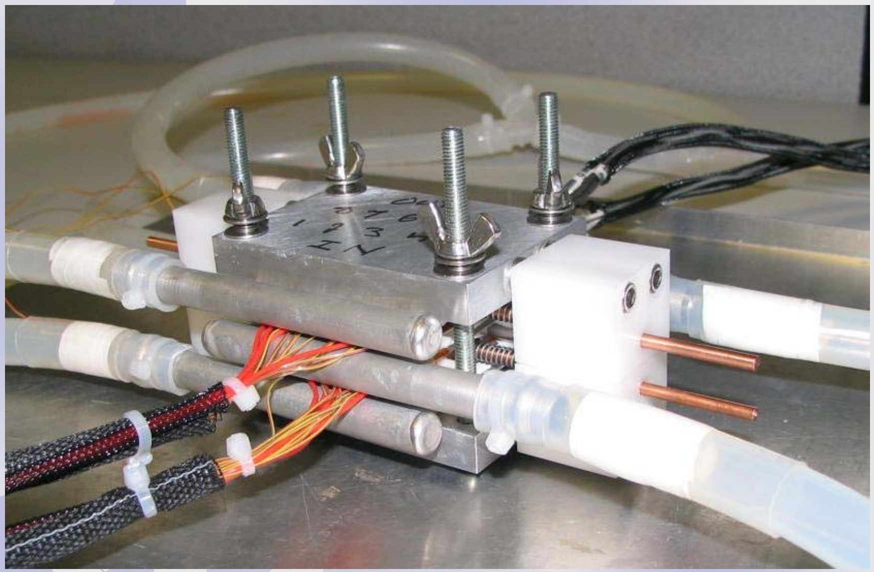


Solid model of fractional TGM in its test fixture

20W Generator Build

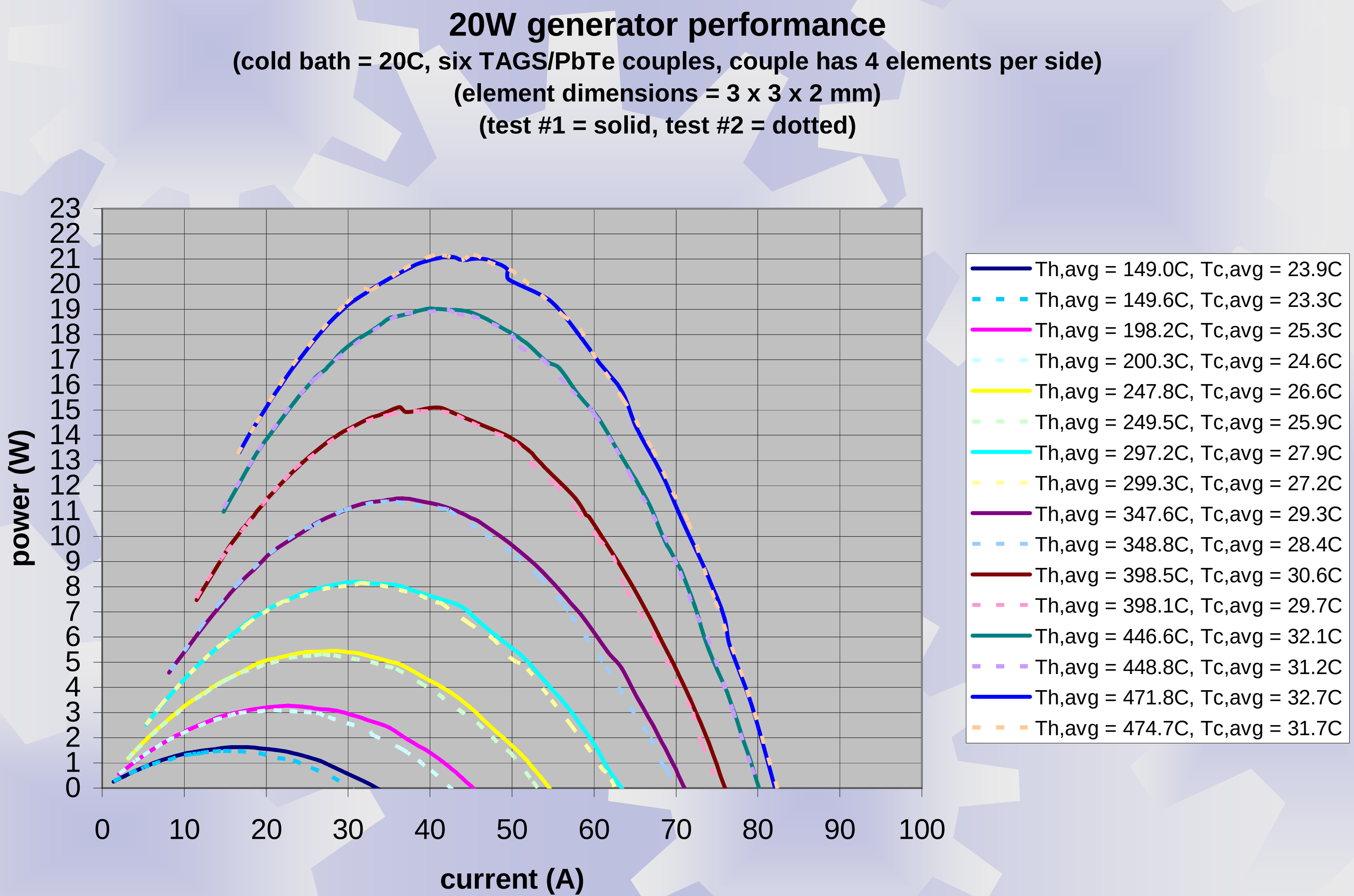


Completed halves of the 20W device, prior to the final assembly

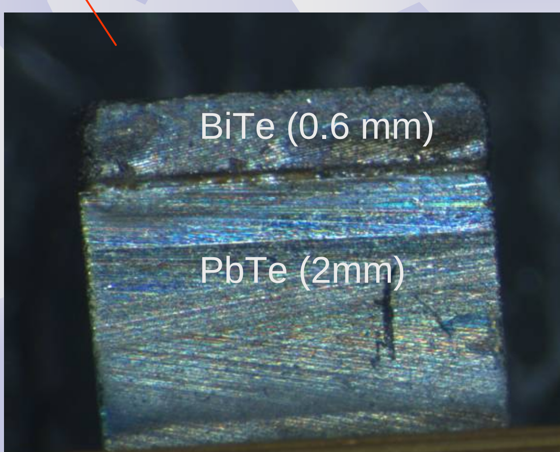


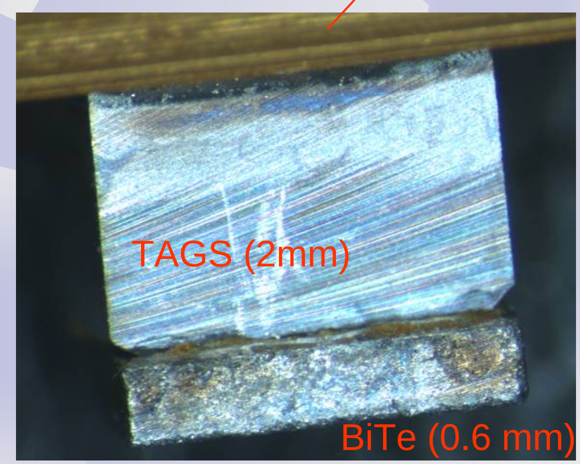
Final assembled 20W device, plumbed and ready for testing

Test Results for the 20W Generator



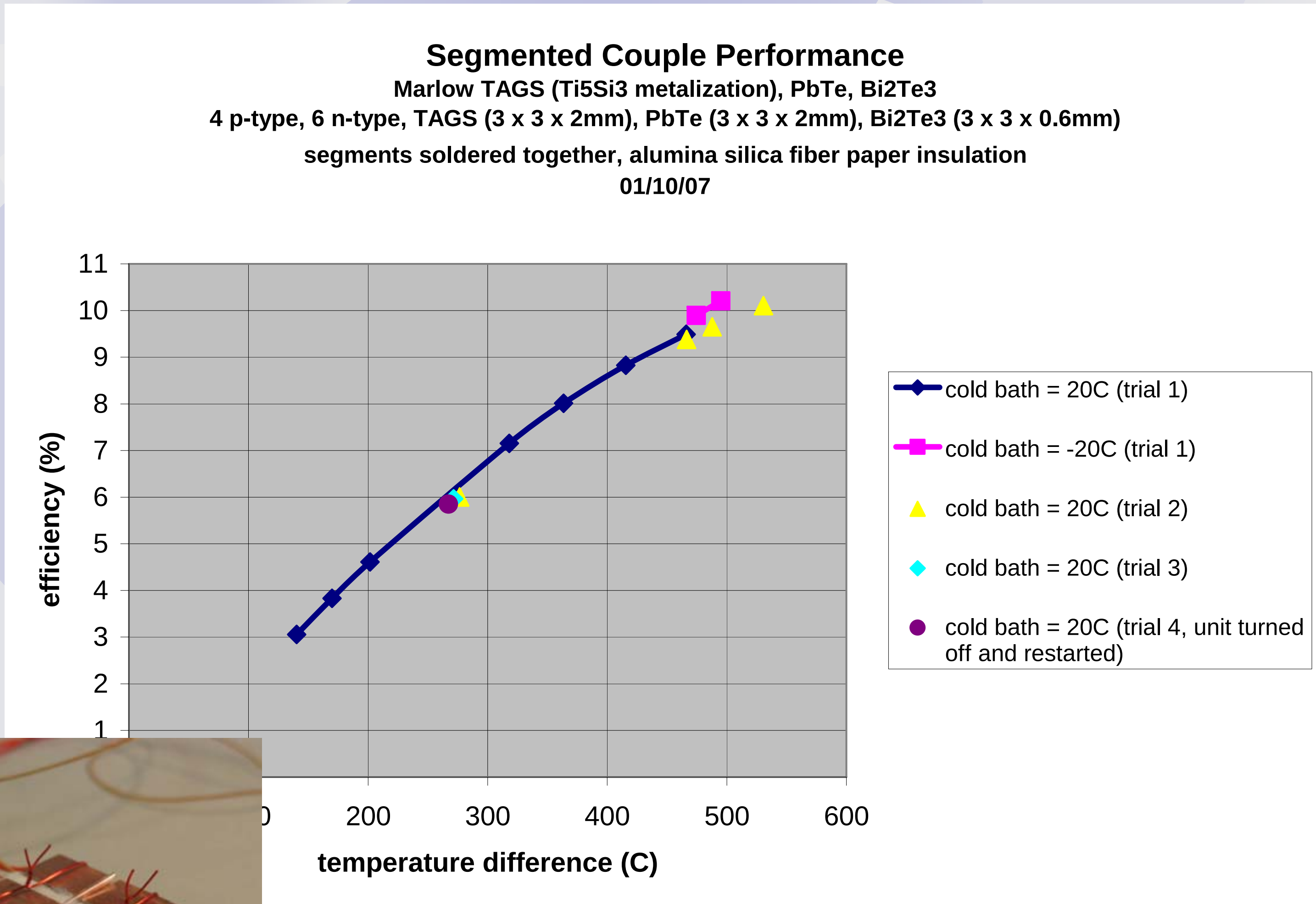
Segmented TAGS/PbTe-BiTe Couple

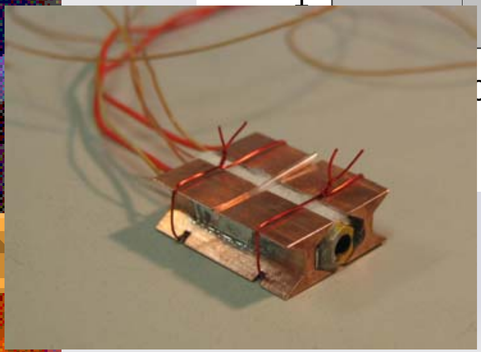




10% Efficiency Demonstration

Performance is reproducible after thermocycling





Next Steps

Complete assembly and testing of full-scale low temperature generator

Evaluate new design concepts that enhance performance and structural integrity of the device over the usage temperature range and during thermal cycling

Test fractional-scale prototype segmented element devices to analyze problem areas in the design, validate the model, and develop different segmentation techniques

Continue working with and testing new TE materials and new TE material combinations to push towards increasing average ZT

Continue working with partners to reduce interfacial resistance to 0.1 $\mu\Omega cm^2$ at room temperature

Continue working on reducing heat losses from the system

Build full-scale high temperature TGM device using segmented elements

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