Nanostructured High Temperature Bulk Thermoelectric Energy Conversion for Efficient Waste Heat Recovery

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GMZ Energy

May 18, 2012

ACE082

Project Overview

Timeline

- October 1, 2011
- September 30, 2015
- ~15% complete

Budget

- Total project funding
  - $7,964K DOE
  - $3,386K Cost-Share
- Funding received in FY11
  - $0
- Funding for FY12
  - $1,641K obligated to date
  - $547K available

Barriers

- Barriers addressed
  - Cost-competitive TE systems
  - Scale-up to practical device size
  - TE device/system packaging
  - Component/system durability

Partners

- Robert Bosch, LLC, Boston College, Oak Ridge National Laboratory
- Project Lead - GMZ Energy

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Project Relevance

- Project Objectives:
  - The final objective of this program is to demonstrate a robust, thermally cyclable thermoelectric exhaust waste heat recovery system that will provide at least a 5% fuel efficiency improvement for a light-duty vehicle platform.
  - A small-displacement engine of approximately 2.0 liters will act as the platform for the demonstration of the developed exhaust waste heat recovery system.
  - In the first phase of the program (ending 1/31/13), the team will develop:
    - TE device technology to enable reliable power generation systems: TE materials, contact metallization, joining, characterization (electrical and mechanical)
    - System design/architecture for reliable operation and maximizing cost/performance ($/fuel efficiency increase)

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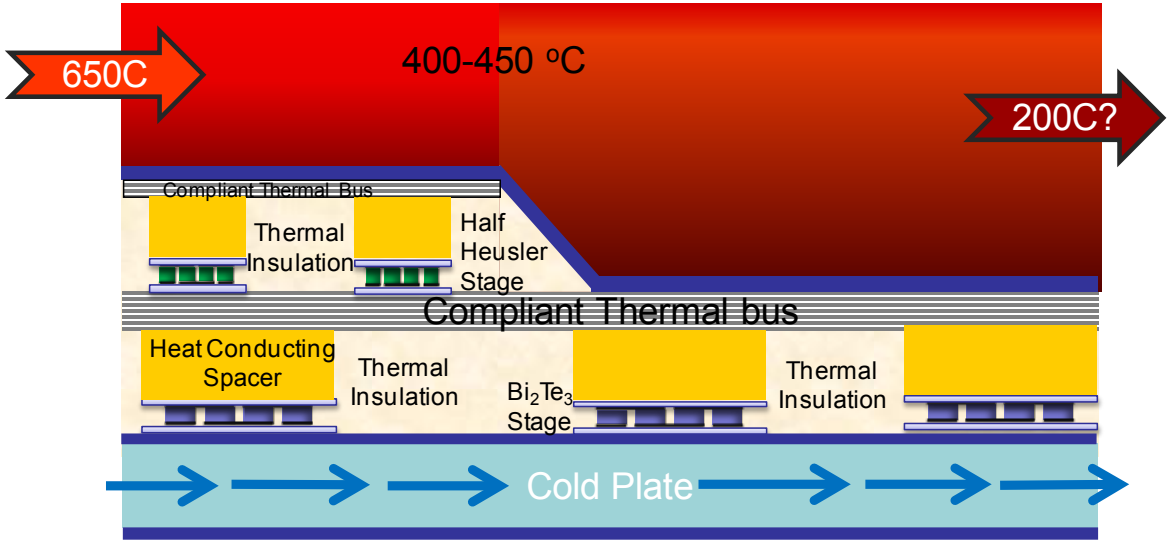
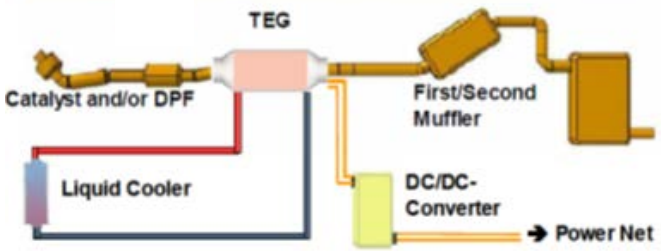
Project Milestones – Phase 1

Milestone Title/Description	Planned Completion Date	Actual Completion Date	Verification Method
Bi_2Te_3 device, 4% efficiency	12/12		GMZ Testing
Half-Heusler device, 4% efficiency	12/12		GMZ Testing
Heat exchanger and system initial design	12/12		DOE Submission
Initial vehicle model	12/12		DOE Submission
Initial testing plan	12/12		DOE Submission
Initial cost assessment	12/12		DOE Submission

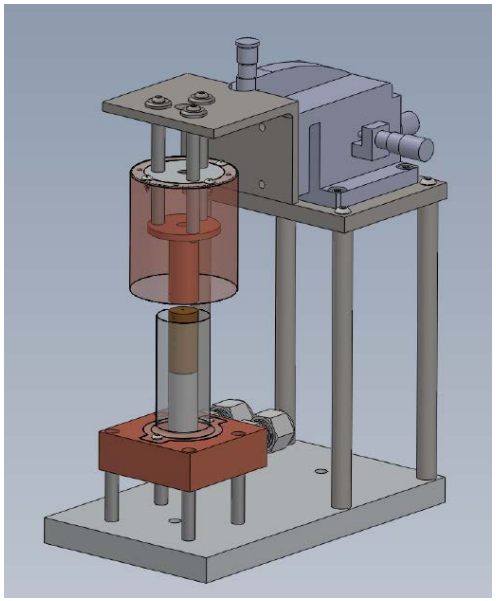
Project Approach

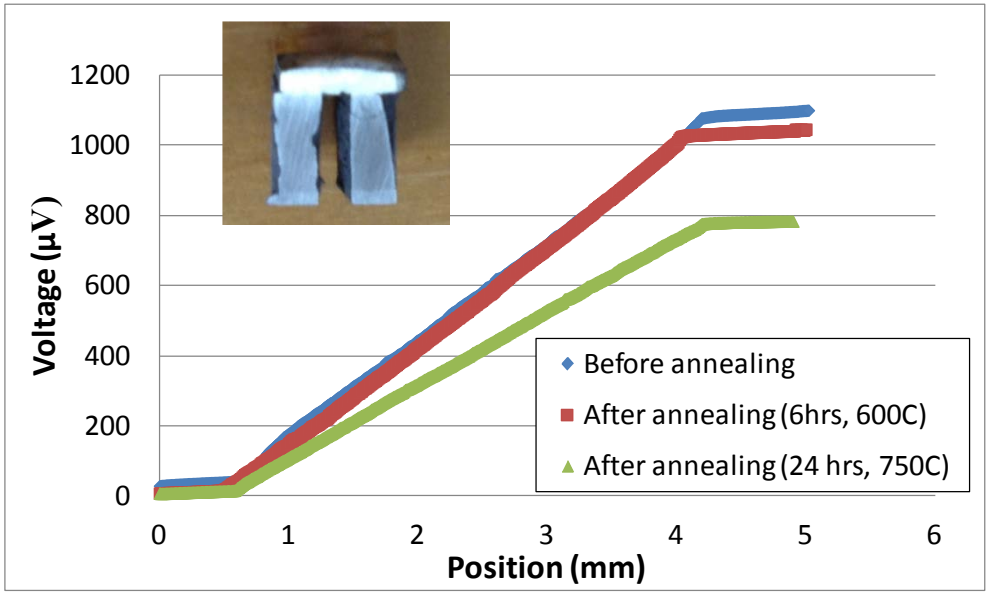




- Proposed two-stage TEG system with half-heusler as the first stage, and Bi_2Te_3 as the low temperature stage. Thermal buses and high thermal conductivity spacers, together with thermal insulation are used to concentrate heat to low-profile generators, significantly reducing the amount of materials used for the TEGs.
- This program uses unique high-performance nanostructured TE materials based on half-heusler alloys, which have superior mechanical strength and durability compared to competing materials (e.g. skutterudites) and can still be made with low-cost, large volume processes – currently underway at GMZ.

Project Approach – Phase 1





- Phase 1 will see the team focus on progress on TE device performance (electrical and mechanical) with three characterization systems:
  - Scanning probe for high-resolution spatial resistance characterization (contact resistance, diffusion of contacts and joints
  - High-temperature power generation efficiency measurement system (power output, efficiency, thermal cycles)
  - Electro-mechanical testing system (Instron) for tension, compression and shear testing (device/joint strength, input in system mechanical design)

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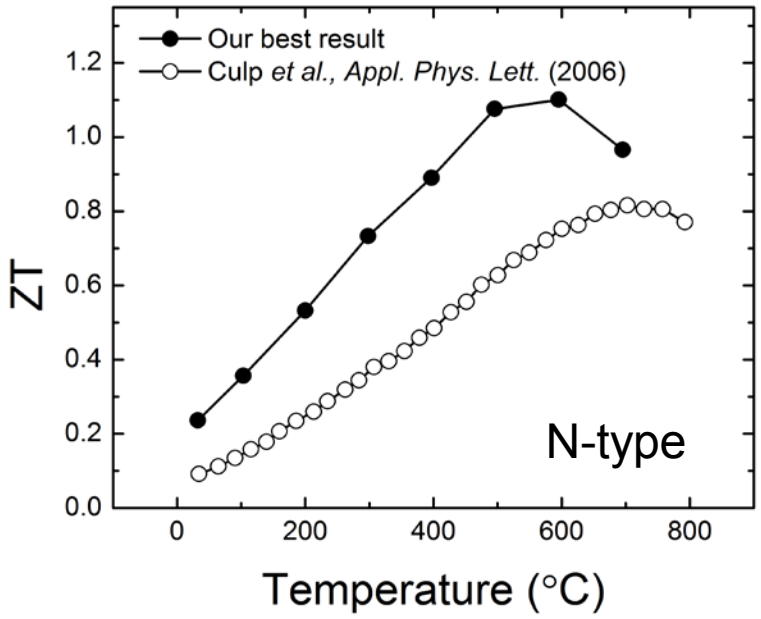
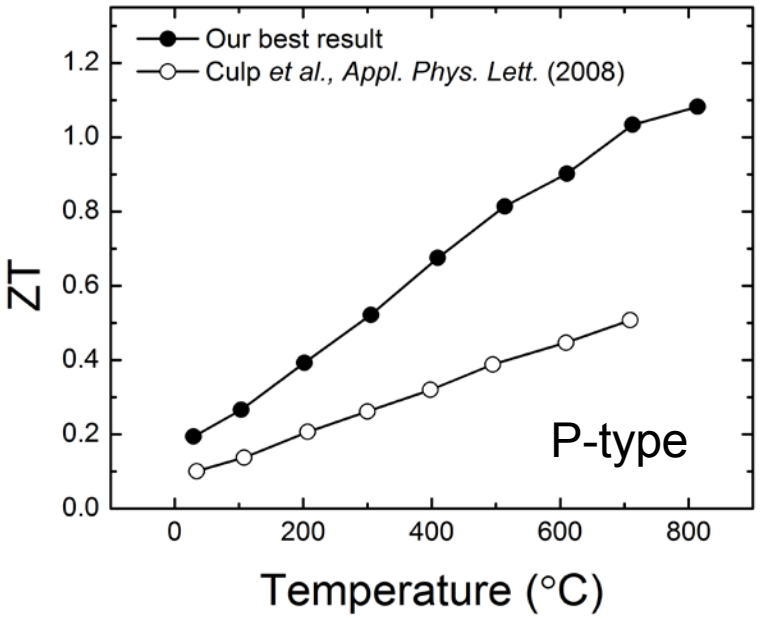
Project Technical Accomplishments and Progress: Summary

- Half-Heusler Materials (Boston College, GMZ Energy):
  - Repeat legacy materials fabrication process from BC at GMZ to give high repeatable high ZT materials
  - Initial reduction of costly Hf component shows good initial success
- Half-Heusler Devices (GMZ Energy):
  - Initial contact metallization shows low contact resistance and good diffusion barrier properties
  - Power generation system designed and will be operational April 2012
  - Instron mechanical test system delivered and will be operational April 2012
- TEG System and Vehicle Model/Design (Bosch, ORNL, GMZ Energy):
  - Initial models using ANSYS at GMZ and Bosch; engineering staff developing strategy for merging models
  - Workshop on system design scheduled at GMZ for May 2012

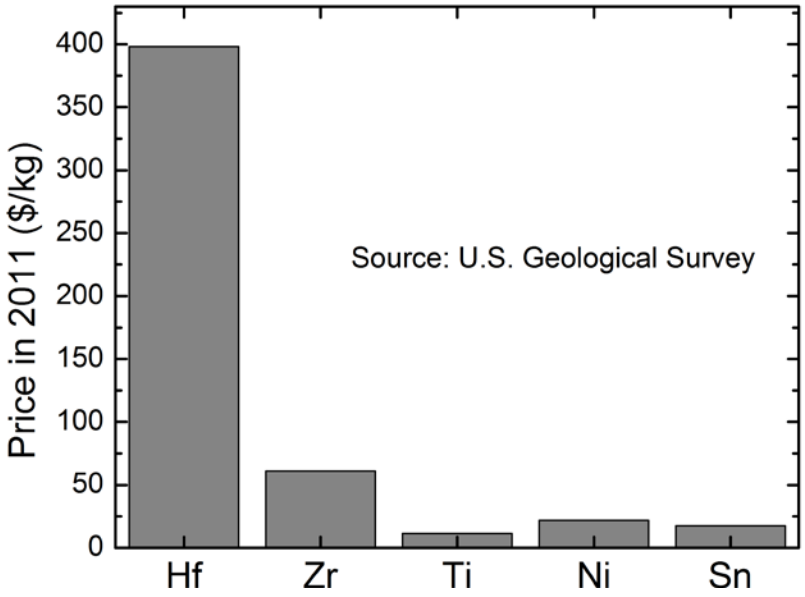
Technical Accomplishments and Progress: Half-Heusler Materials

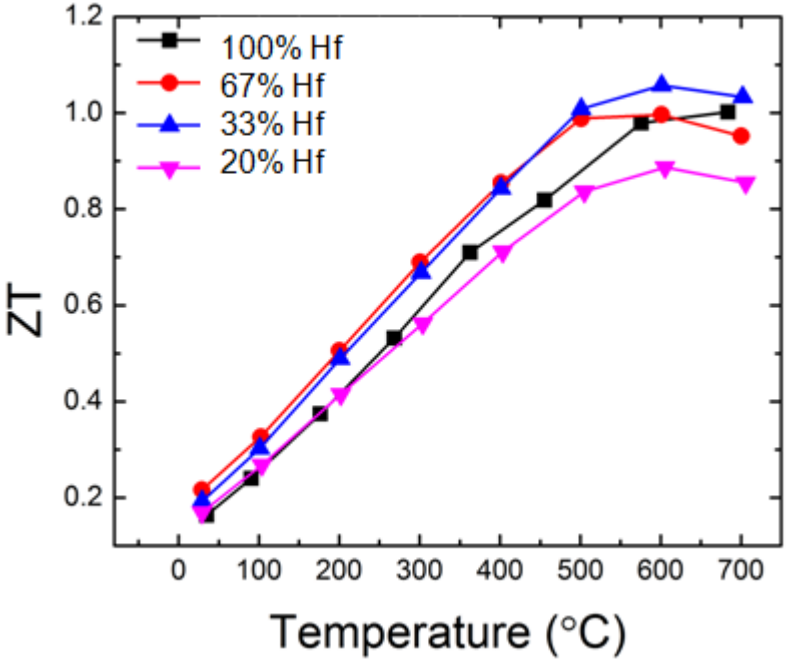




- Boston College and GMZ Energy have now made high-performance half-heusler materials (both n-type and p-type) in repeatable fashion in both locations
- P-type performance gain is >100% improvement and drives half-heusler as a newly realistic option for use in the TEG

Technical Accomplishments and Progress: Half-Heusler Materials

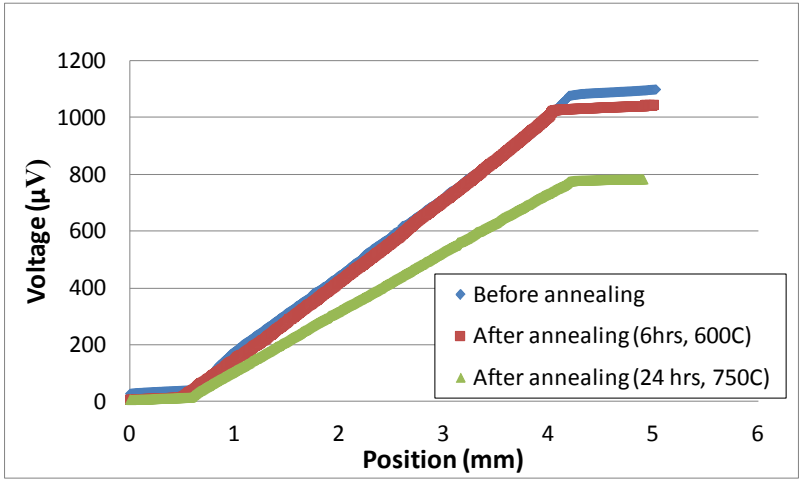


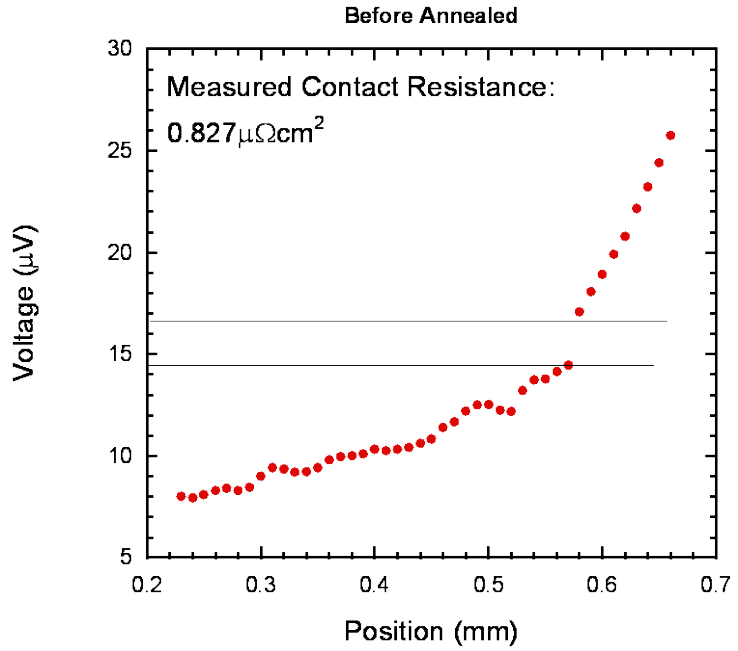


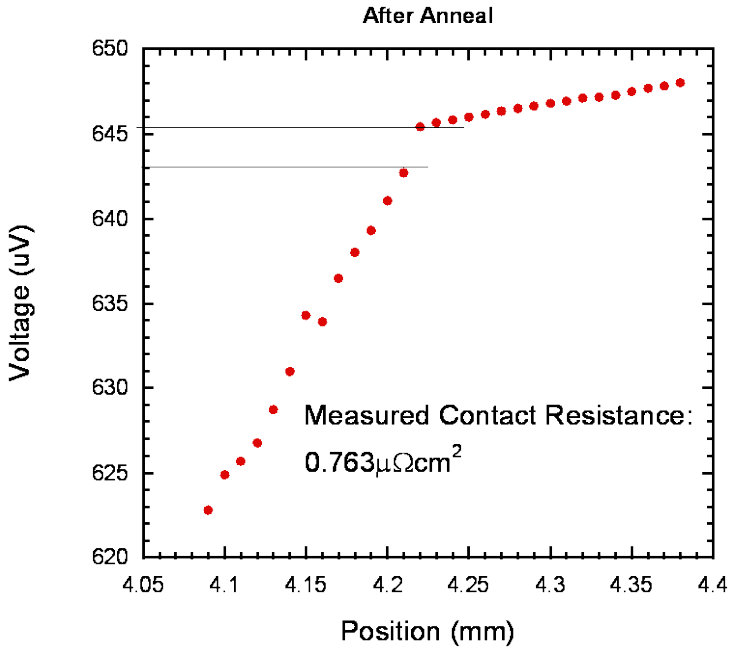
- In order to reduce the cost of the half-heusler materials, the reduction in Hafnium is necessary as the most costly component
- Initial work at BC and GMZ has shown that the Hf can be reduced by nearly 3x while maintaining high TE performance

Technical Accomplishments and Progress: Half-Heusler Devcies

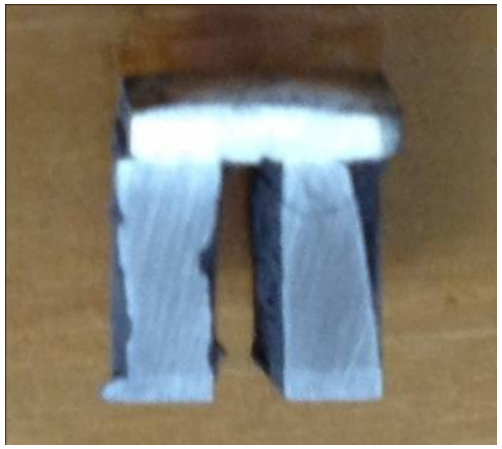
- In order to make good devices, good contact layers are needed
- GMZ has successfully applied thick (diffusion barrier) contacts with low contact resistivity – precursor to high-performance devices and modules



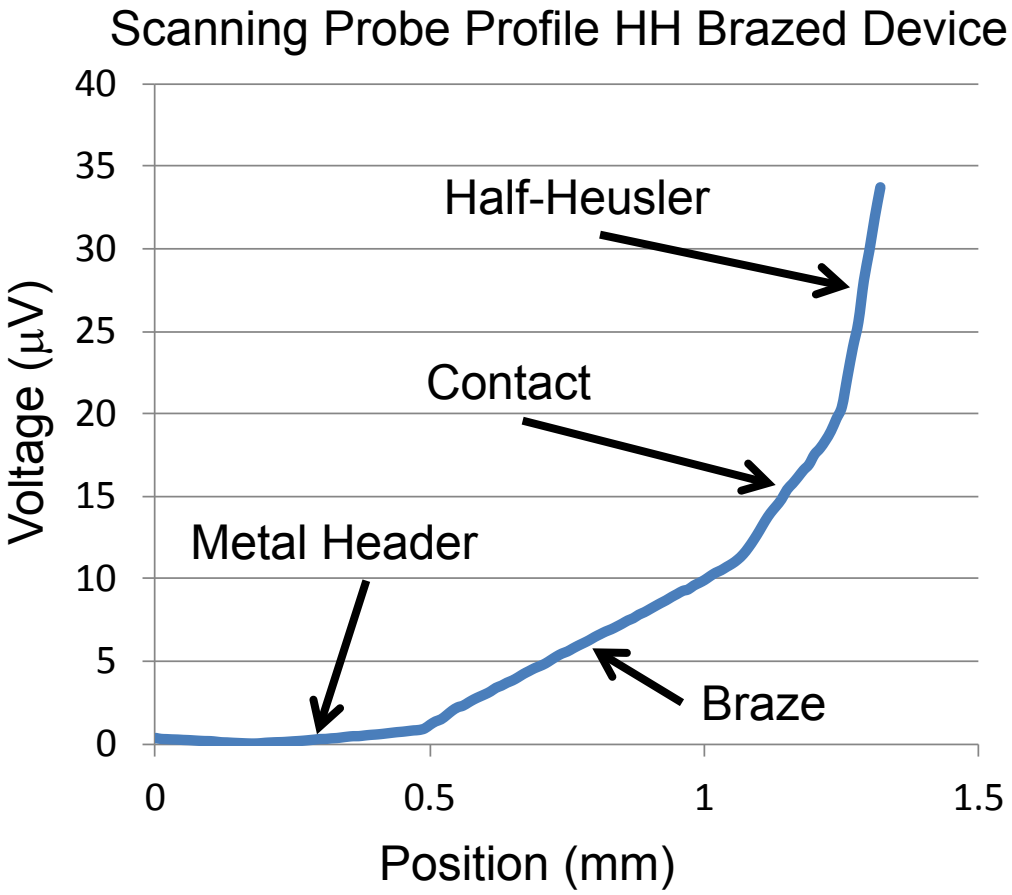




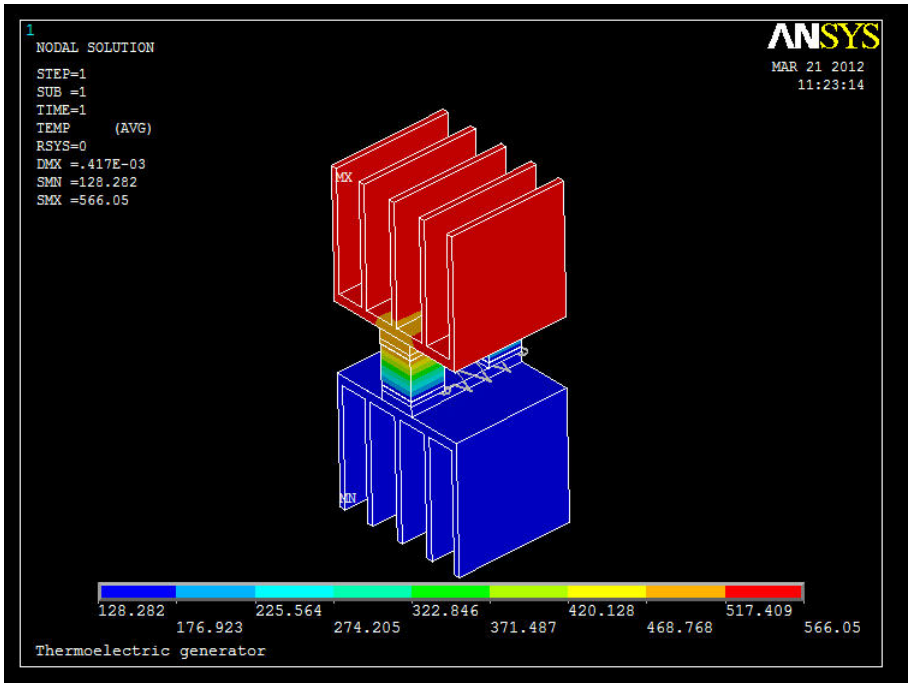
Technical Accomplishments and Progress: Half-Heusler Devcies

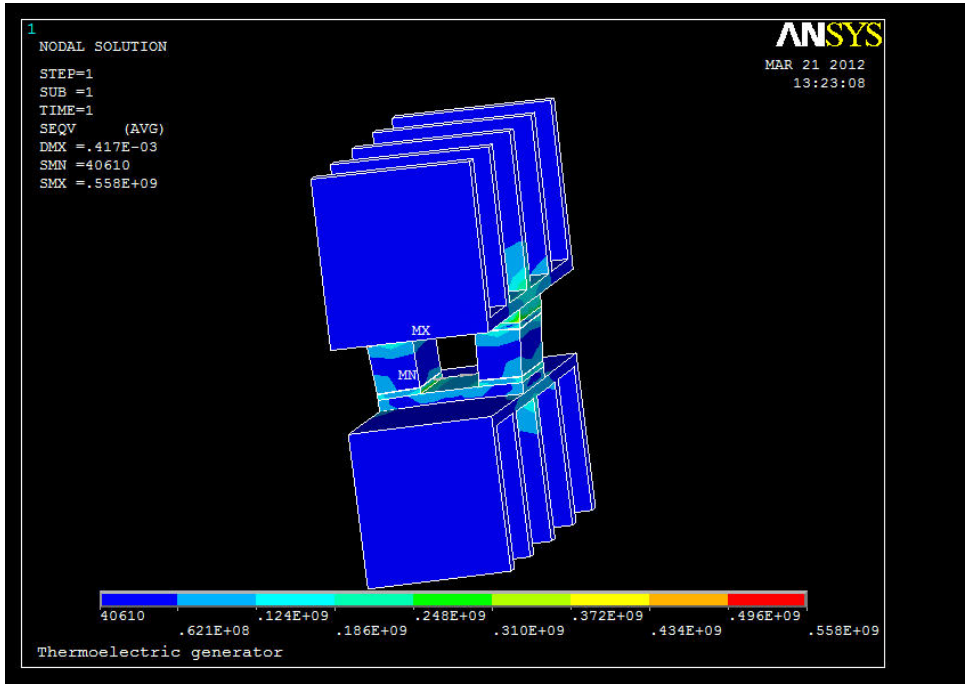


- Initial brazing has confirmed HH mechanical and temperature stability
- GMZ is positioned to move quickly to make device measurements and show high power generation efficiency



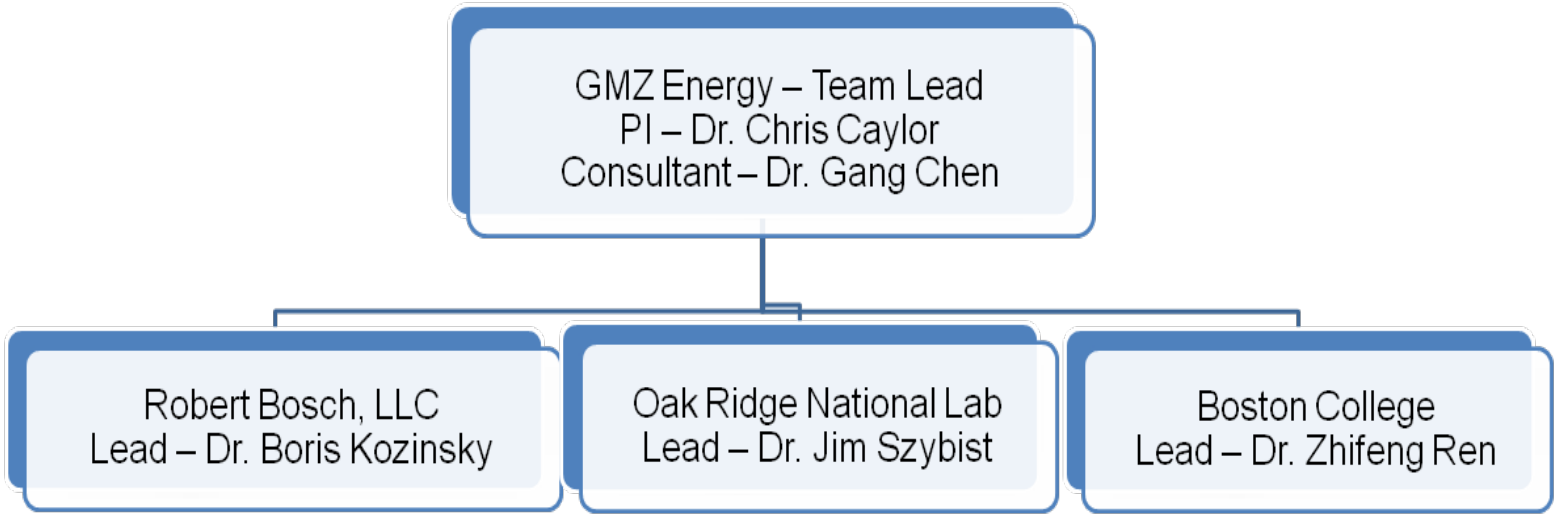
Technical Accomplishments and Progress: TEG System and Vehicle Model/Design





- GMZ is building up a full performance model of power generation devices in ANSYS including TE output and thermo-mechanical stresses
- GMZ and Bosch have a plan to merge our TE model with their heat exchanger/system multi-scale model. Details will be discussed at a workshop hosted at GMZ in May, 2012.

Collaboration and Coordination with Other Institutions



- GMZ (Industry) – TE (materials, devices, integration and testing), heat exchangers, module integration and subsystem testing, prototype fabrication
- Robert Bosch (Industry) – automotive systems (electrical, vehicle models and testing), TE materials contacts and integration, heat exchangers
- Boston College (University) – TE materials (ZT improvement, cost-reduction, thermal-mechanical testing)
- Oak Ridge National Lab (Federal Laboratory) – dynamometer testing and vehicle model

Proposed Future Work

- Half-Heusler Materials
  - Build up inventory of HH materials for device making (GMZ)
  - Confirm and refine Hf reduction in HH materials (GMZ and BC)
  - Experiments to increase ZT of HH materials (BC, Bosch and GMZ)
- Half-Heusler Devices
  - Power generation testing of HH devices (GMZ)
  - Mechanical testing of HH devices (GMZ)
  - Diffusion and thermal cycle data on HH devices (GMZ and Bosch)
- Bismuth Telluride Devices
  - Power generation testing of BT devices (GMZ)
  - Mechanical testing of BT devices (GMZ)
  - Diffusion and thermal cycle data on BT devices (GMZ and Bosch)
- Heat Exchanger Design
  - Workshop on system design (GMZ and Bosch)
  - Mechanical and performance model of initial design (GMZ and Bosch)
- System/Vehicle Model
  - Workshop on system/vehicle model (GMZ and Bosch)
  - Study of fabrication and materials costs, performance and fuel efficiency gains (GMZ and Bosch)

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Project Summary

- Project Relevance: this program speaks directly to the major challenges in bringing TE devices to bear on automotive efficiency
  - Nanostructured HH and BT materials offer a low-cost, high-performance, reliable and durable option for TE power generation and offers the promise of affordable scale-up and system packaging
- Project Approach: early verification of materials and device performance through power generation and mechanical testing – by December 2012
- Technical Accomplishments:
  - Repeatable HH materials with good indication of lower cost through Hafnium reduction
  - Repeatable and low resistance metal contacts and brazing to HH materials
  - Initial ANSYS model for merging with Bosch's multi-scale system model
- Collaboration and Coordination: Interaction with BC, Bosch and ORNL going well with planned workshops to jump start collaborations on heat exchanger and system architecture and designs

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