Develop Thermoelectric Technology for Automotive Waste Heat Recovery

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General Motors Research & Development

June 11, 2010

Project ID # ACE050

Overview

Timeline

- Start date – May 2005
- End date – October 31, 2010
- Percent complete – 80%

Budget

- Total funding: $12,779,610
  - DOE share: $7,026,329
  - Contractor share: $5,753,281
- Funding received in
  - FY09: $920,987
  - FY10: $356,666 (10/09-2/10)

Barriers

- Barriers addressed
  - Integrating new advanced TE materials into operational devices & systems
  - Integrating/Load Matching advanced TE systems with vehicle electrical networks
  - Verifying device & system performance under operating conditions

Partners

- Interactions/collaborations

  ORNL – High temperature transport and mechanical property measurements

  UNLV – Computational materials development

  Marlow – TE module development and fabrication

  Faurecia – Exhaust subsystem fabrication and integration
- Project lead: GM R&D

Relevance – Objectives

- **Achieve 10 % improvement in fuel economy (FE) by 2015 without increasing emissions**
  - Demonstrate FE improvement for the Federal Test Procedure driving cycle (~3%)
  - Demonstrate that actual FE improvement for real world driving conditions is closer to DOE goal
- **Demonstrate commercial viability**
  - Assemble, install, and test prototype TEG on a production vehicle
  - Collect performance data, show viability
  - Identify specific design, engineering, and manufacturability improvements for path to production

Current Specific Objectives:

- **Complete initial TEG prototype construction**
  - Translate conceptual design from GE into buildable unit
  - Fabricate subsystem parts and complete assembly
- **Complete test vehicle modification and integration**
  - Exhaust system modification and bypass control for thermal management
  - Integration of electronic systems and controls for electrical power management
  - Install TEG on vehicle
- **Collect performance data**
- **Improve material ZT and thermo-mechanical properties**
  - Adjust composition and processing for best results
  - Synthesize material batches for TE module production
- **TE module production**
  - Complete metallization studies and fabrication method study
  - Fabricate modules for TEG

Relevance – Milestones

Previous Year

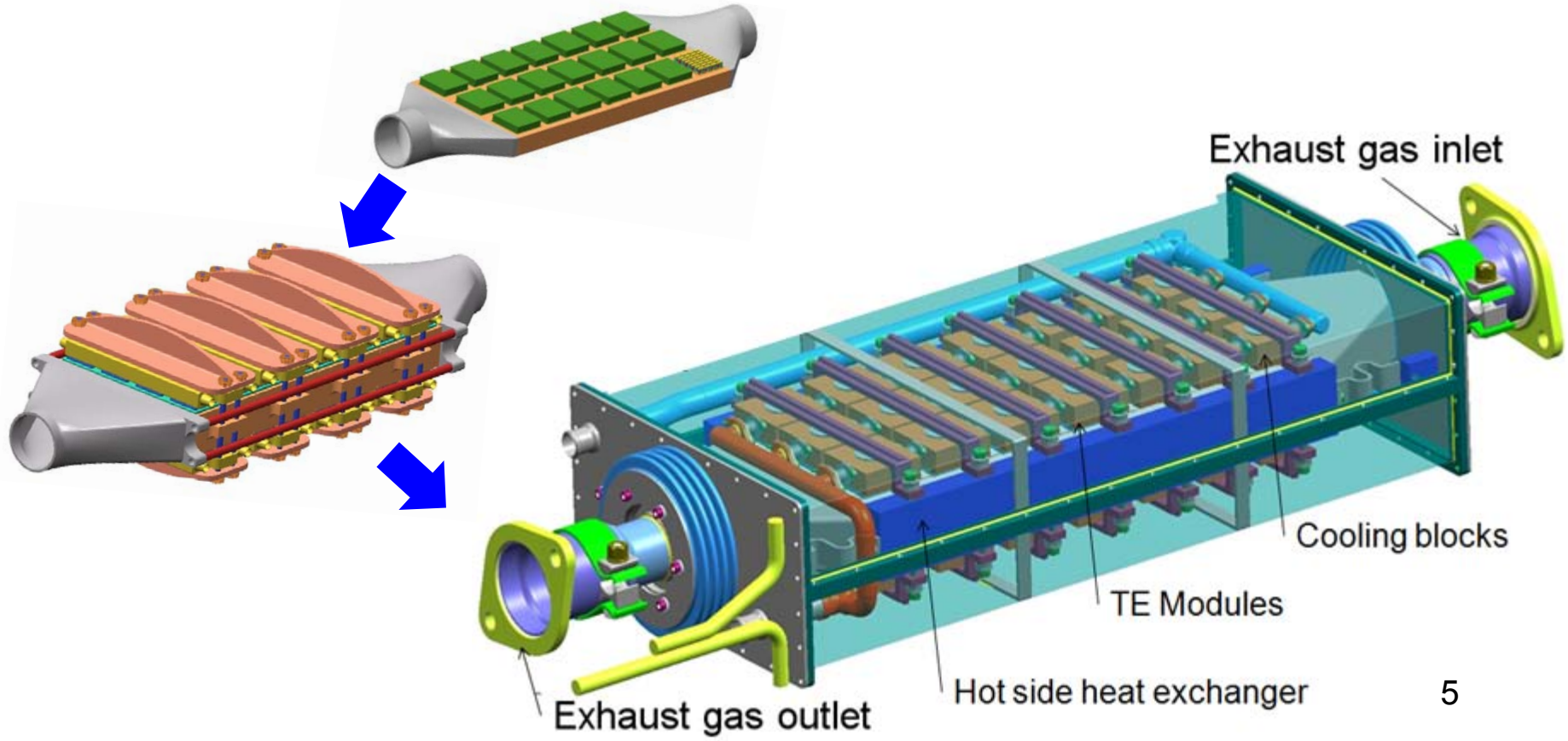
- Provide the initial TE waste heat recovery subsystem design
- Provide initial lab test data for TE modules
- Finalize TE waste heat recovery subsystem design

Current Year

- Provide initial production ready TE modules for application-based testing -- Mar 31, 2009
- Complete prototype TE generator subsystem parts fabrication and assembly – Oct 31, 2009
- Complete vehicle modification and system integration of controls and electrical system of test vehicle for first TE generator unit – Jan 2010
- Install first TE generator unit onto test vehicle – Feb 2010

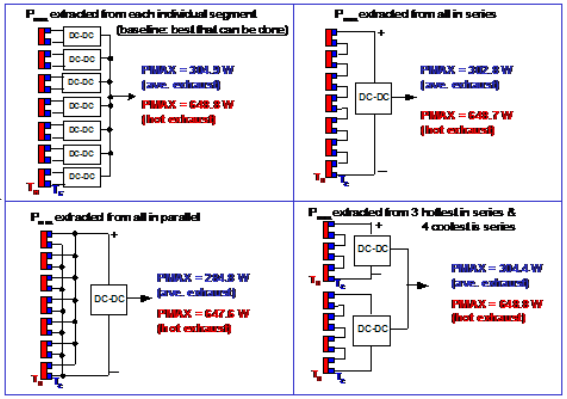
Approach

- Develop models and computational tools to design TE generators which include heat transfer physics at heat exchanger and interfaces; TE material properties; and mechanical reliability
- Finalize design, fabricate, and assemble prototype TE generator

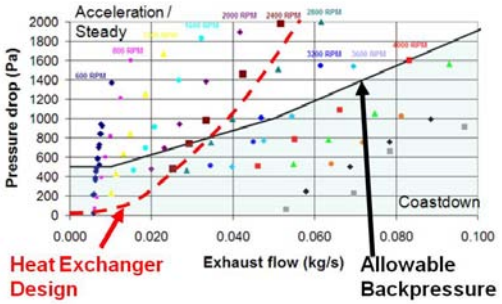


Approach (cont.)

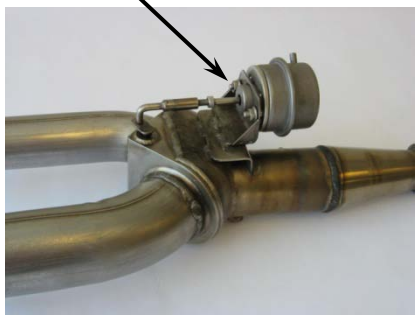
- Develop power electronics design for power conditioning and vehicle control



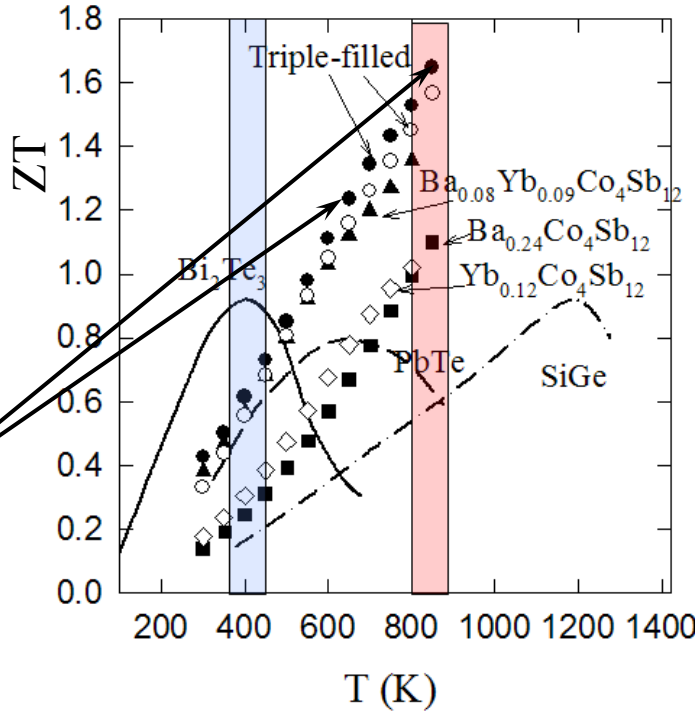
- Develop control algorithms for improved thermal-to-electrical conversion efficiency



Bypass valve for exhaust gas



- Improve TE materials (skutterudites) based on the concept of phonon engineering: (ZT = 1.6 at 850 K, and ZT_{ave}= 1.2)

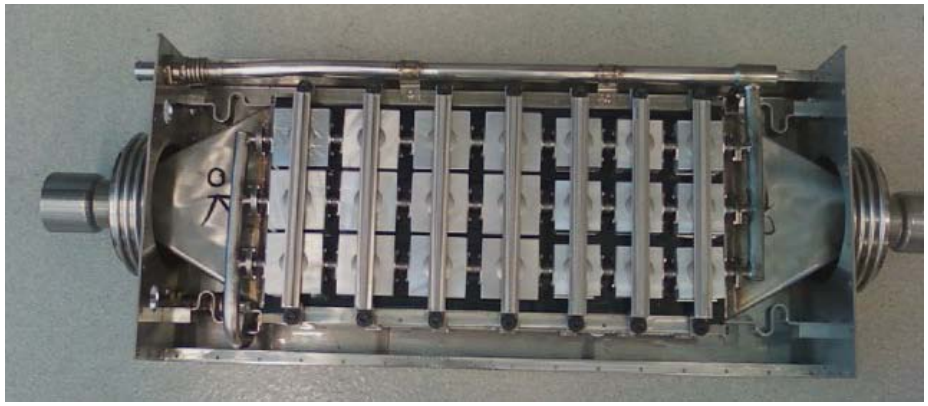


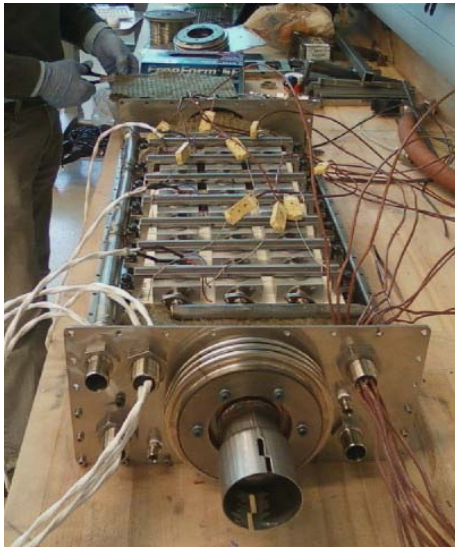
Approach (cont.)

- Assess TEG Performance
  - Start-Cart
    - First step in integration development
    - Provides a decoupled testing environment
    - Provides easy access for modification and debugging
  - Chassis-Rolls Dynamometer
    - Provide a realistic loading and repeatable environment, though not a realistic environment
    - Precise data collection
    - Standard test method for fuel economy and emissions measurements
  - Environmental Dynamometer
    - Chassis-rolls dynamometer which simulates grades, atmospheric environment
  - Real World Driving

Technical Accomplishments and Progress

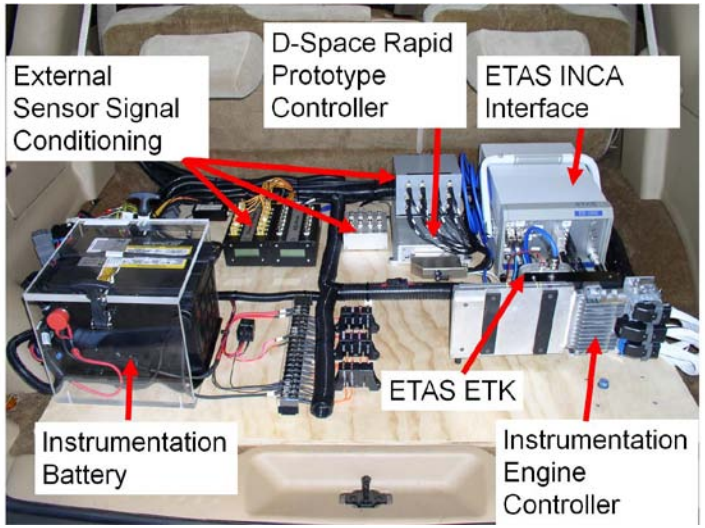
- Completed thermoelectric generator design and began fabrication of heat exchanger subassemblies. First prototype completed, second one in progress.



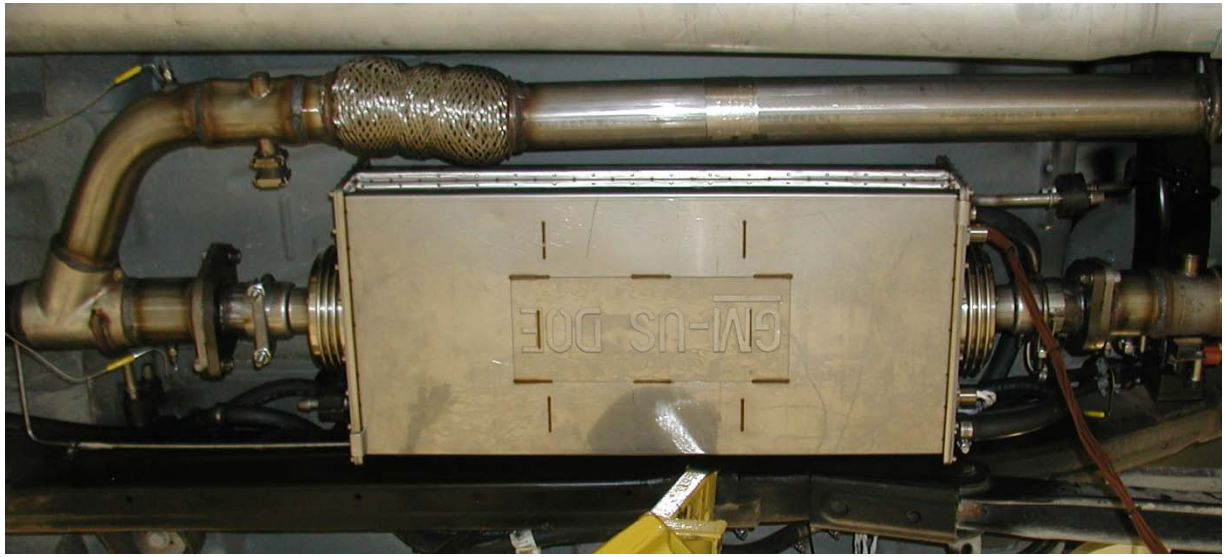


Technical Accomplishments and Progress (cont.)

- Completed detailed design and assembly of power electronics for vehicle integration, installation and vehicle modification.

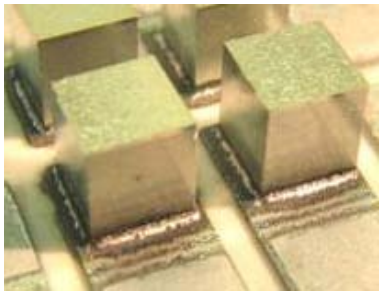


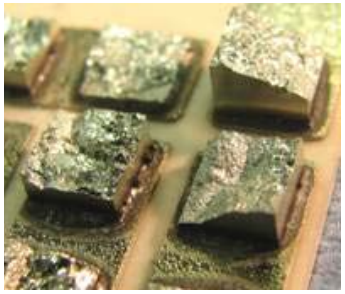
- Completed exhaust system modification: parts fabricated and installed



Technical Accomplishments and Progress (cont.)

- Evaluated braze methods for electrical connections to PbTe .

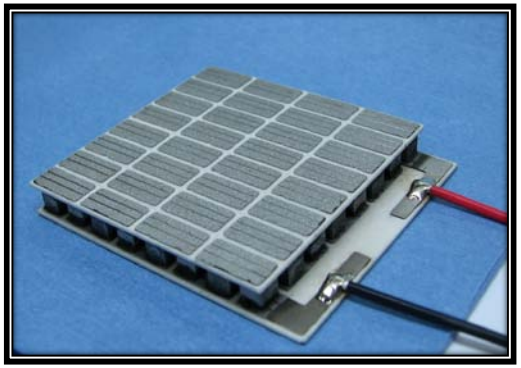
(a) 

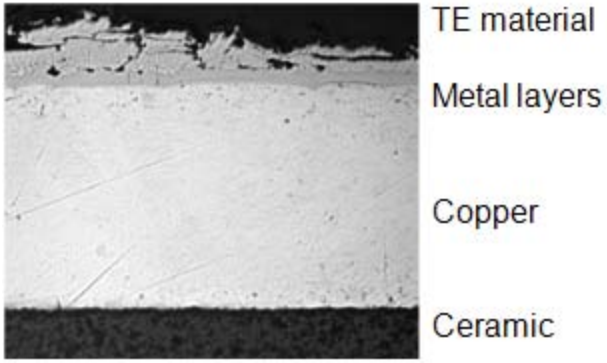
(b) 

(a) PbTe elements with a thick nickel end cap brazed to the metallization layer, and (b) shear test results with adhesion promoting heat treatment (failure is in bulk material.)

- Designed tooling for fabricating ceramic headers for TE modules.
- Synthesized several n-type PbTe ingots and explored processing variables to reduce cracking and fragility, and to improve adhesion of electrical and thermal contacts.

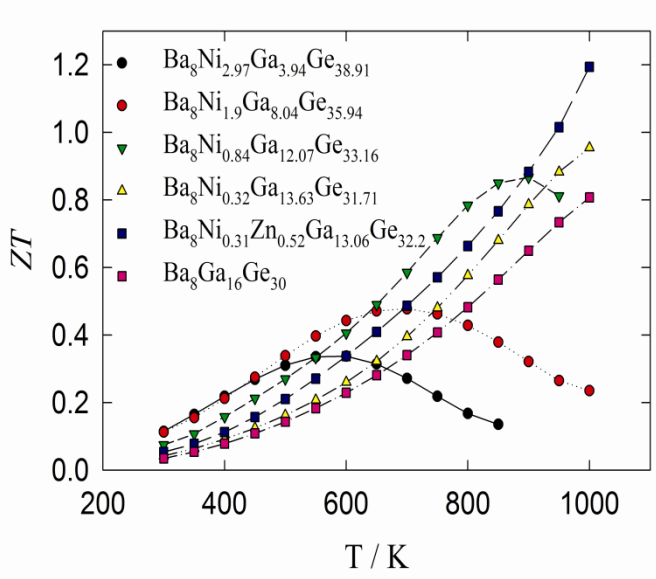
Prototype PbTe module

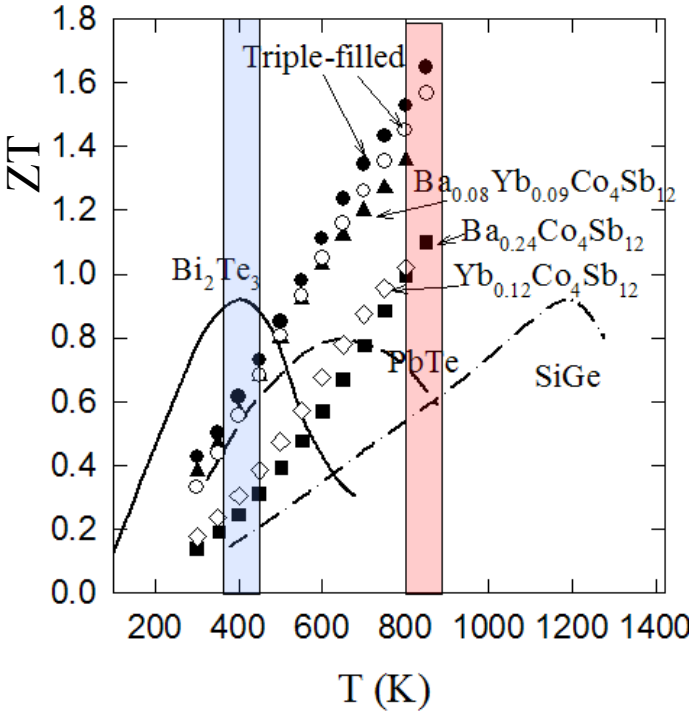




Technical Accomplishments and Progress (cont.)

- Validated measurements of transport and mechanical properties and performance at high temperature.
- Explored optimization of preferred materials for use in TE modules.
- Improvement in the synthesis, processing, and transport properties of Yb-filled skutterudites associated with specifically created nano-scale precipitates at grain boundaries and within grains.
- Achieved a figure of merit ZT = 1.6 for multiple filled skutterudites, highest value yet reached for any n-type filled skutterudite material.
- Improved TE properties of Type I clathrates by doping transition metals on the gallium sites.
- Investigated new TE materials: In_4Se_3, In_4Te_3, Cu-Ge-Se.



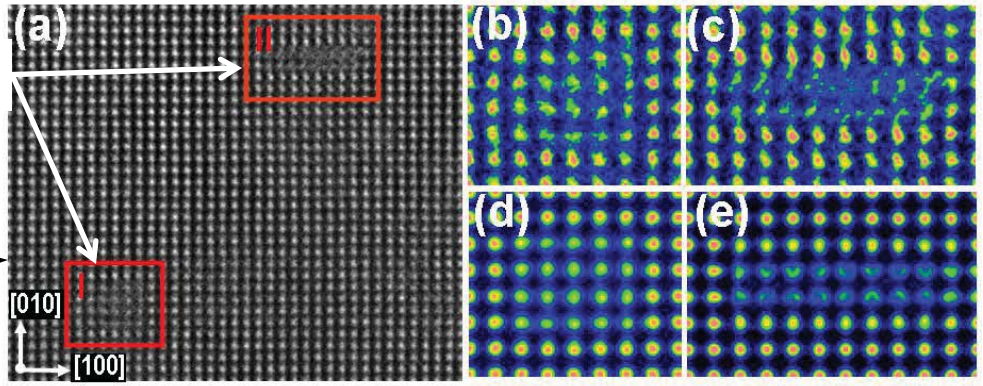


Technical Accomplishments and Progress (cont.)

- Conducted computational and experimental studies of the microstructure and nucleation mechanisms of nanoprecipitates that lead to the superior TE performance of $(PbTe)_{1-x}(AgSbTe_2)_x$.

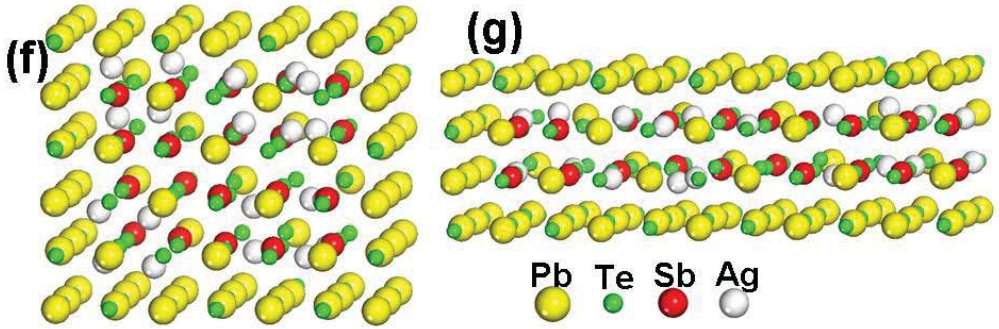
nanoprecipitates

HRTEM image of single crystal $(AgSbTe_2)$-$PbTe_{18}$



Simulated images

Atomic positions predicted by DFT calculations



PRL 103, 145502 (2009) PHYSICAL REVIEW LETTERS week ending 2 OCTOBER 2009

Microstructure and a Nucleation Mechanism for Nanoprecipitates in PbTe-$AgSbTe_2$

Xuezhi Ke,[1,2,*] Changfeng Chen,[1,†] Jihui Yang,[3,‡] Lijun Wu,[4] Juan Zhou,[4] Qiang Li,[4] Yimei Zhu,[4,§] and P. R. C. Kent[5]

Collaboration and Coordination with Other Institutions

Current Collaborators (subcontractors):

- ORNL – High temperature transport and mechanical property measurements
- UNLV – Computational materials development
- Marlow – TE module development and fabrication
- Future Tech – Consultant (Francis Stabler)

Suppliers:

- Faurecia – Exhaust subsystem fabrication and integration
- HTI – Heat Exchangers

Previous Collaborators (subcontractors):

- General Electric – subsystem modeling and design
- University of Michigan, Michigan State University, Brookhaven National Lab, University of South Florida, RTI – TE materials development

Proposed Future Work

(Activities for the remainder of this project, ending October 31, 2010)

- Provide test results for initial TE generator (1st unit)
- Complete assembly of 2nd TE generator unit with full electrical system components.
- Finalize and implement vehicle integration with TE waste heat recovery system and complete the necessary vehicle modifications.
- Develop TE modules for 3rd TE generator unit.
- Carry out dynamometer tests and proving ground tests for vehicle equipped with the TE waste heat recovery system.
- Demonstrate fuel economy gain using TE waste heat recovery technology.

Summary

- Prototype TEGs are being assembled and installed on the test vehicle.
- Vehicle modifications and system integration are being completed as the TEGs are installed on the vehicle.
- Improvements in the performance of TE materials have been achieved, particularly for skutterudites.
- Skutterudite modules are being developed for the final prototype TEGs.