Commercialization of Bulk Thermoelectric Materials for Power Generation Applications

2011 DOE Thermoelectrics Applications Workshop
January 3 - 6, 2011
San Diego, CA

Dmitri Kossakovski, Ph.D.
Managing Director, ZT Plus
dmitri.kossakovski@ztplus.com
• Update on ZT Plus activities
• Experimental approaches to accelerate bulk materials R&D
• ZT data analysis approaches
ZT Plus develops and produces *high performance* thermoelectric materials for efficient energy conversion for mid temperature waste heat recovery and power generation applications.

ZT Plus is a division of Amerigon Inc.
• BSST has been funding internal Materials Research Program since 2006, establishing Emerging Materials Department in 2008.

• In 2009 BSST formed ZT Plus to commercialize improvements in bulk TE material performance demonstrated by Ohio State, Michigan State and Northwestern Universities.

• Formation and funding of ZT Plus was partially made possible by ONR’s long term support of academic research, DARPA’s targeted research and DOE sponsored vehicle research and development initiatives.

• DOE sponsorship of device-level development has been, and continues to be, of paramount importance for TE market development.
ZT Plus Capabilities Update

- New facility in operation since Nov. ’09
- Proximity to Amerigon/BSST, Caltech and JPL
- 10,000 sq.ft., all operations are in clean room space
- R&D and pilot manufacturing capabilities
- Ingot casting, powder metallurgy
- Metallization
- Materials metrology to 600°C
• Currently sampling to select customers: high performance PbTe (no Thallium)
• Ongoing testing: mechanical, thermocycling
• Future plans:
  • PbTe production scale up
  • Pb and Te-free materials
Technology Commercialization

Raw materials input

1. Casting of ingots

2. Ball milling

3. Sieving

4. Pressing

5. Annealing

6. Metallization

Final product output

Testing 1: thermoelectric and mechanical properties

Testing 2: contact resistance and long-term stability

Long feedback loops are prohibitive!

Advanced Thermoelectric Solutions
1. Implement Design of Experiments methodology → reduces time by shrinking the experimental space.

2. Matching throughput of metrology with that of synthesis is a critical enabling feature for shortened information feedback loops.

3. Use fast, but not necessarily precise, tools for material screening → allows to arrive to negative results faster, thereby reducing the bottleneck of slow metrology.

4. Track and eliminate sources of variability → results have high robustness and reproducibility.
Rapid Screening – Scanning Seebeck

Uniform vs. Non-Uniform Cast Ingots

Measurements take tens of minutes instead of tens of hours. Experimental feedback is drastically reduced.
Example: Non-Uniform Pressed Coin

Fails ‘Gaussian Distribution’ Test

Bimodal – Seebeck changes within the ingot

**Scanning Seebeck uncovers process-induced material variation**
Example: Uniform SPS Coin

Passes ‘10% of Mean’ Test
Passes ‘Gaussian Distribution’ Test
Even Faster Screening – Multi-probe Seebeck: Simultaneous Measurement with 60 Probes

60 voltage probes and 4 thermocouples
Even Faster Screening – Multi-probe Seebeck: Simultaneous Measurement with 60 Probes

Measurements take tens of minutes instead of tens of hours.
Not only material development cycle is long, but also device optimization is complex. Simple tools are desirable to compare the benefits of variations of material properties.

Average ZT is the property that is being used extensively for performance estimates.

Average ZT is a function of temperature range.

**Which material is better?**
Convert ZT(T) plot into <ZT> (ΔT) contour map

Example: <ZT> between 280 and 430°C is 1.15
Example: <ZT> between 280 and 430°C is 1.15
**Differential <ZT> Plot**

Average P, N differential $zT = \frac{\int_{T_1}^{T_2} [zT(T)_{P-type} - zT(T)_{N-type}]dT}{T_2 - T_1}$

**Which material is better?**
Judging by average <zT> these materials are relatively well matched.
<ZT> of a Couple

Average P, N pair $zT = \frac{1}{2} \int_{T_1}^{T_2} \left[ zT(T)_{P-type} + zT(T)_{N-type} \right] dT$

Approximate temperature range of typical use
Assumptions: no parasitic losses; not accounting for material self-compatibility.
Conclusions

- ZT Plus has successfully transitioned advanced PbTe materials from academic laboratories to pre-production sampling; currently gearing up for scale-up.

- Experimental cycle of material development needs to be fast and robust for optimization experiments targeting production-viable materials.

- Careful selection of measurement and analysis tools need to be employed for rapid characterization of TE materials.

- Sore issue – universally acceptable metrology of TE materials, especially for power generation applications.
Acknowledgments

- Government support – DOE, DARPA, ONR
- OEM and T1 partners – BMW, Ford, Faurecia
- Academic partners – OSU, Northwestern University
- Colleagues at ZT Plus, BSST and Amerigon