Large-dimension, High-ZT Thermoelectric Nanocomposites for High-Power High-efficiency Waste Heat Recovery for Electricity Generation

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Outline

- Introduction to Aegis Technology
- Development of Bulk TE Nanocomposites
  - Bi_2Te_3-Sb_2Te_3
  - PbSe-PbTe material system
  - SiGe material system
- TE modules, Devices and Systems
- Summary

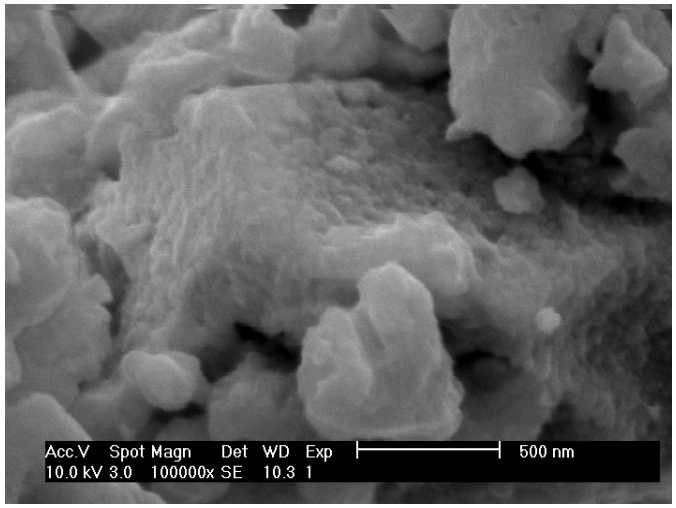
Introduction to Aegis Technology

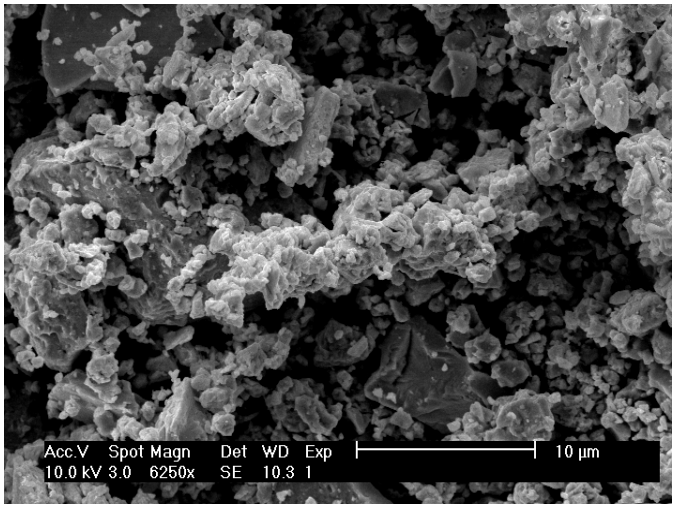
- **Operation since 2002** http://aegistech.net/
  - **20 SBIR/STTR (Phase I & II) contracts since 2003**
    - **DoD (Army/Navy), DoE and NASA**
  - **R&D team with 5 Ph.D Scientists & Engineers**
  - **Product and services to prime DoD contractors**
- **Key technologies**
  - **TE Nanocomposites and Advanced Bonding Technology**
  - **Thermal Management and Power Electronics**
- **Design, development and manufacturing**
  - **R&D and Engineering**
  - **Prototyping and production**

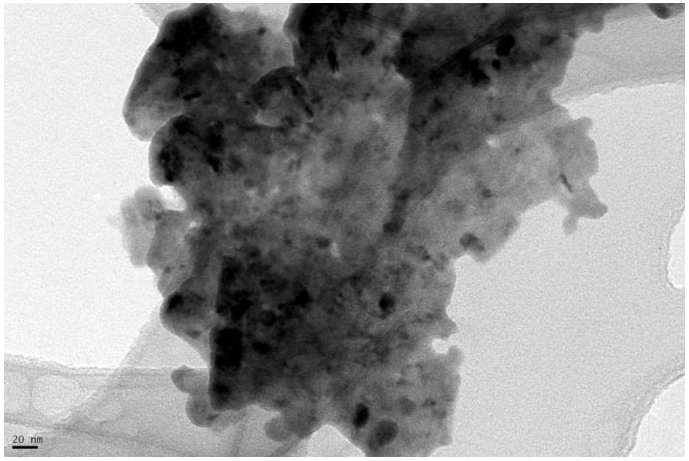
Significance Large-dimension Bulk TE Nanocomposites

- **Requirement in TE devices/systems**
  - Higher efficiency, lower cost
  - Higher power, higher power density
- **Improvement in TE materials**
  - Figure of merit (ZT) of the materials
    $ZT = S^2 \sigma T / K$
  - Increase in *S*, σ *and/or decrease in K*
- **Opportunity in TE nanocomposites**
  - Nanoscale structure -> High ZT and hence high efficiency
  - Nano TE material currently limited in small dimension -> limited power level
  - Desire for large-dimension, bulk TE nanocomposite -> High power, high efficiency TE devices/systems

Bi_2Te_3-Sb_2Te_3 Material System







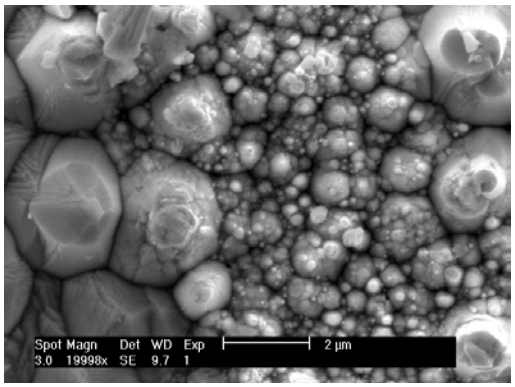
Cryomilled powders

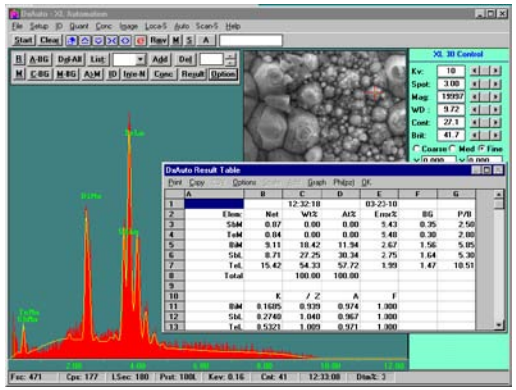
Bi_2Te_3-Sb_2Te_3 Material System

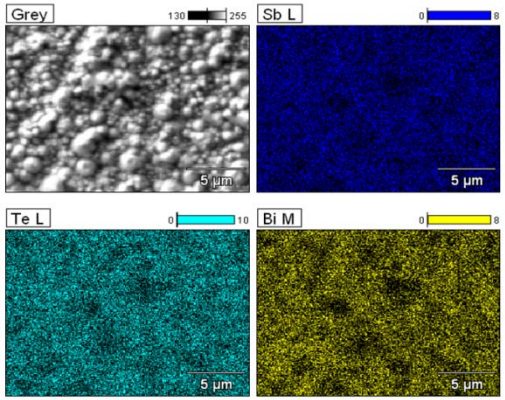
Photos of hot-compressed samples

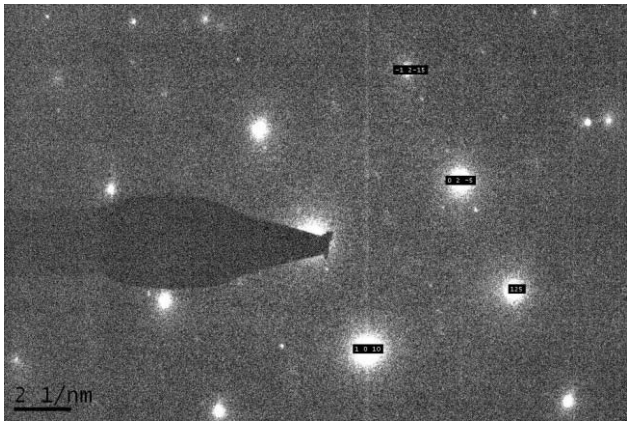
Being scaled up to large dimension (4-6 inch in diameter)

Bi_2Te_3-Sb_2Te_3 Material System





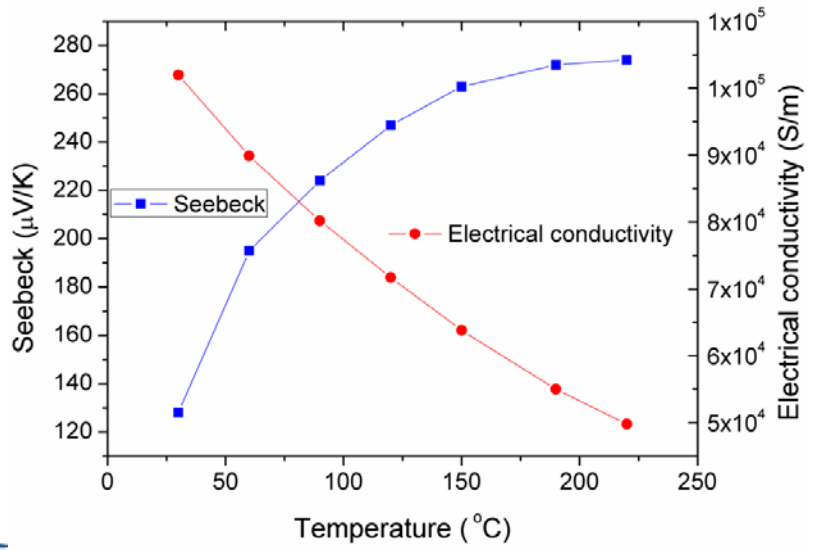


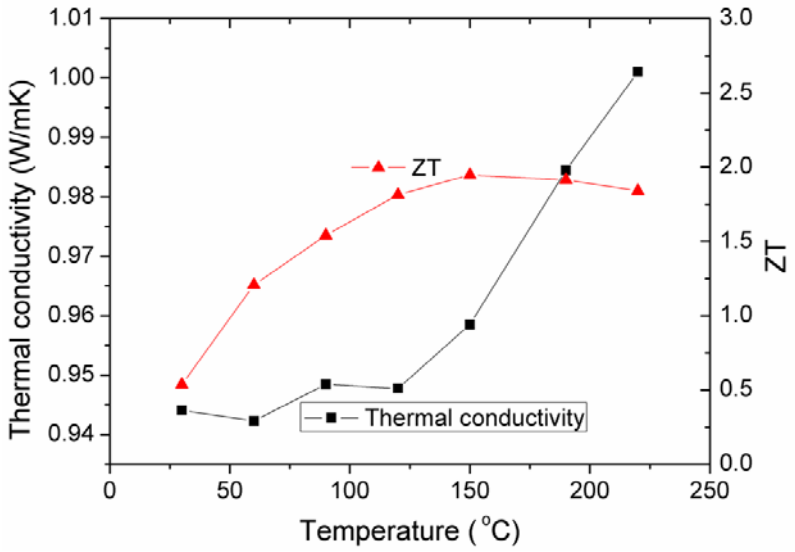


Microstructure of hot- compressed samples

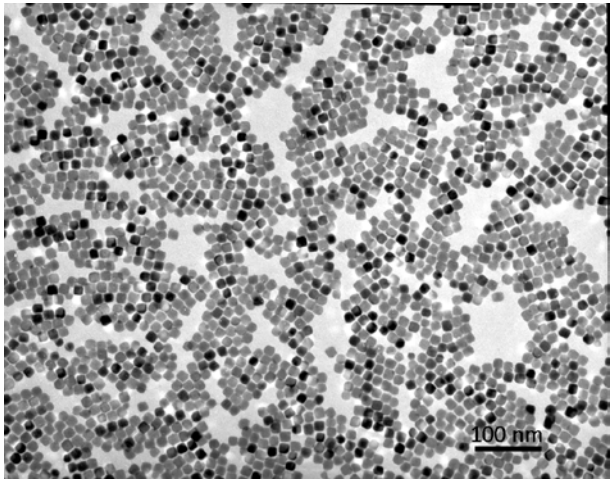
Bi_2Te_3-Sb_2Te_3 Material System

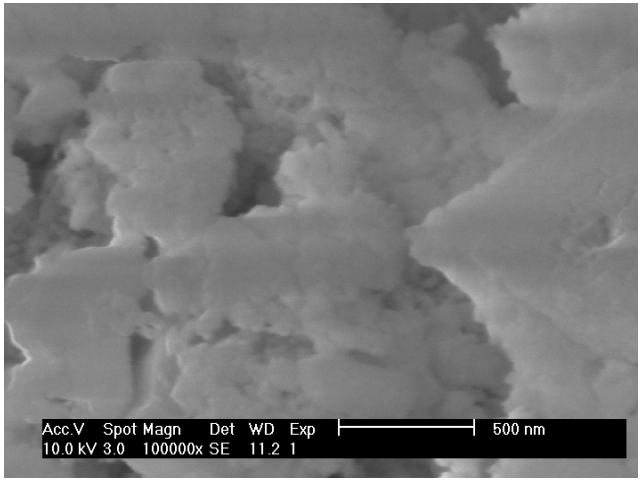
- Stable ZT values achieved in the range of 1.15-1.25
- A recent sample demonstrated ZT above 1.5 (reproducibility is under validation)



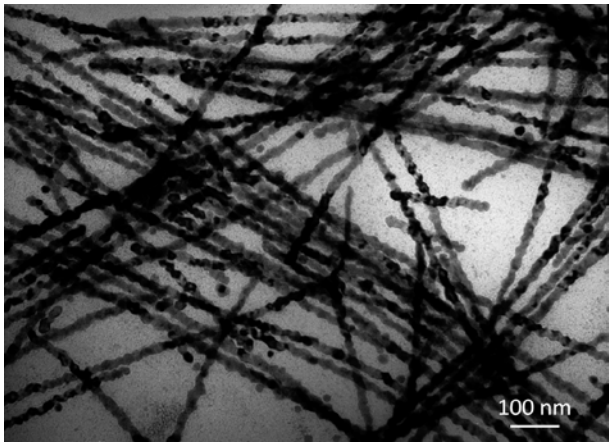


PbTe-PbSe Nanocomposites

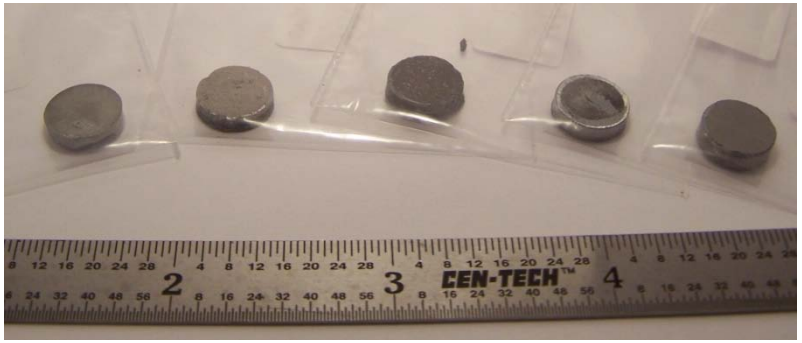




PbTe Cryomilled host powder

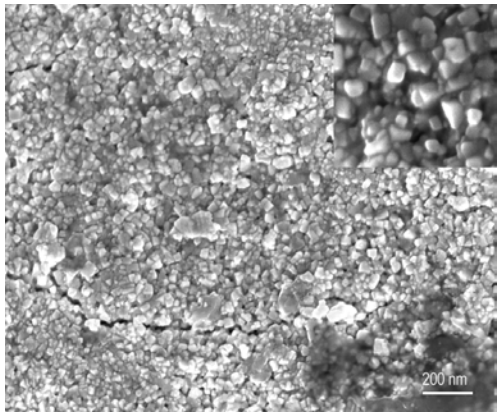


PbSe Nanocrystal enhancement elements

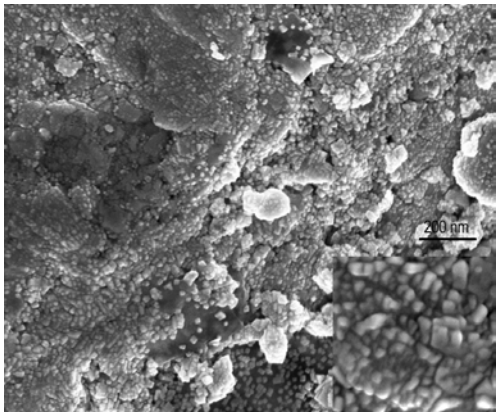


Hot-compressed samples

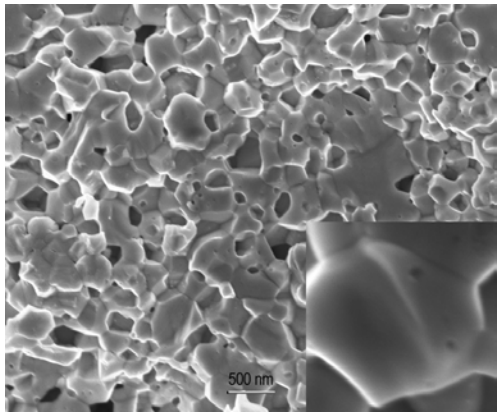
PbTe-PbSe Nanocomposites



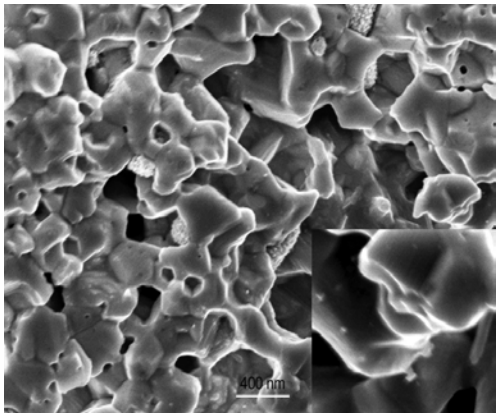
9% PbSe nanocubes + 91% cryomilled PbTe powder



5% PbSe nanocubes + 95% cryomilled PbTe powder



3% PbSe nanowires + 97% cryomilled PbTe powder

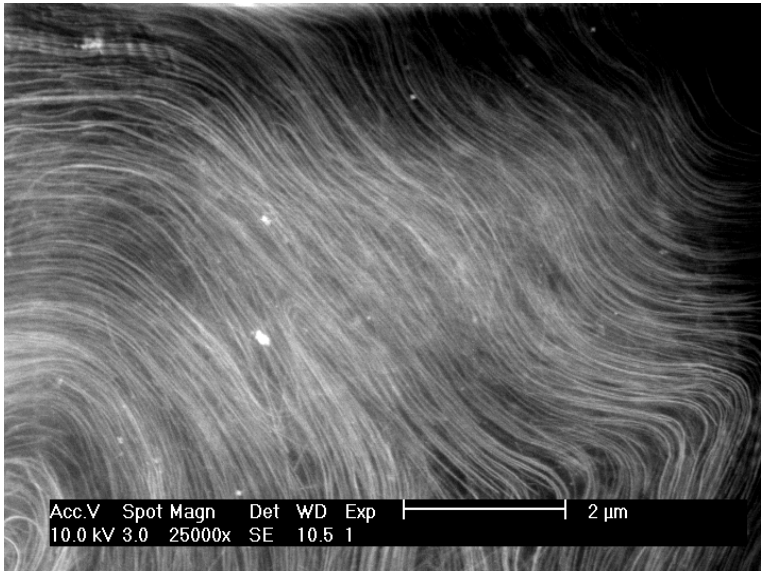


9% PbSe cryomilled powder + 91% cryomilled PbTe powder

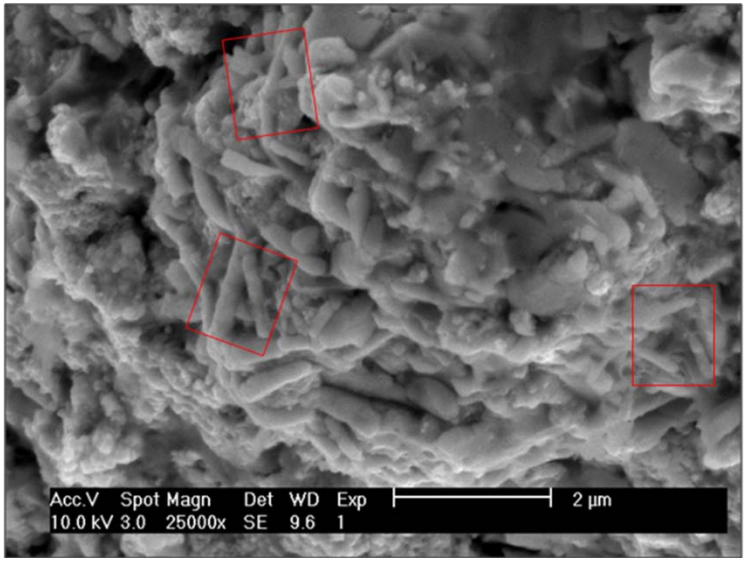
PbTe-PbSe Nanocomposites

Specimen ID	PbSe (wt. %)	PbTe (wt. %)	Room Temperature		330 °C	
			Seebeck (μV/K)	ZT	Seebeck (μV/K)	ZT
PSTCS9	9% Nanocubes	91% Ball-milled Powder	393	0.32	503	1.45
PSTCS5	5% Nanocubes	95% Ball-milled Powder	369	0.26	486	1.22
PSTWI3L	3% Nanowires, Aligned	97% Ball-milled Powder	365	0.21	484	0.98
PSTS9	9% Ball-milled Powder	91% Ball-milled Powder	342	0.17	444	0.79

PbTe-PbSe Nanocomposites



Thinner PbSe nanowires (diameter <10 nm) has been demonstrated and will be applied in the bulk nanocomposite

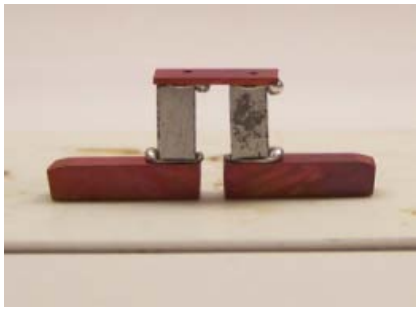


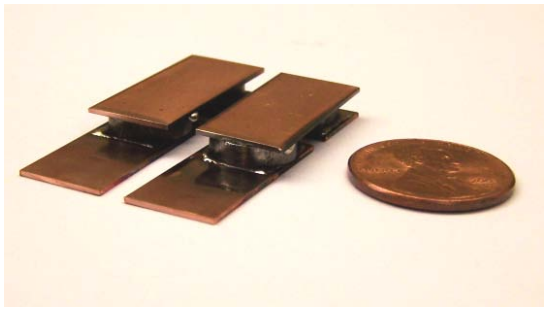
PbSe nanowires enhanced sample

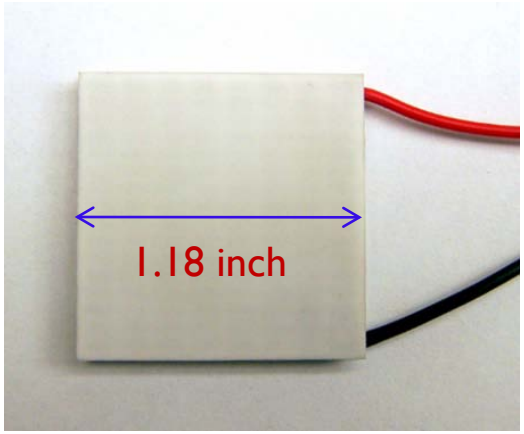
SiGe Nanocomposites

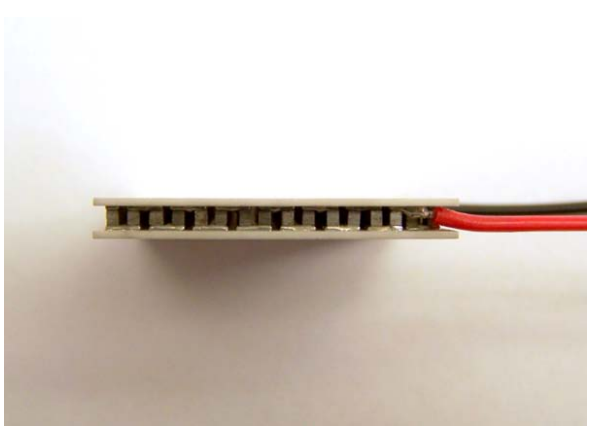
Aim to achieve thermal conductivity close to 2.0 W/mK and ZT >1.3

Modules, Devices and Systems









Fabricated modules for testing

Modules, Devices and Systems

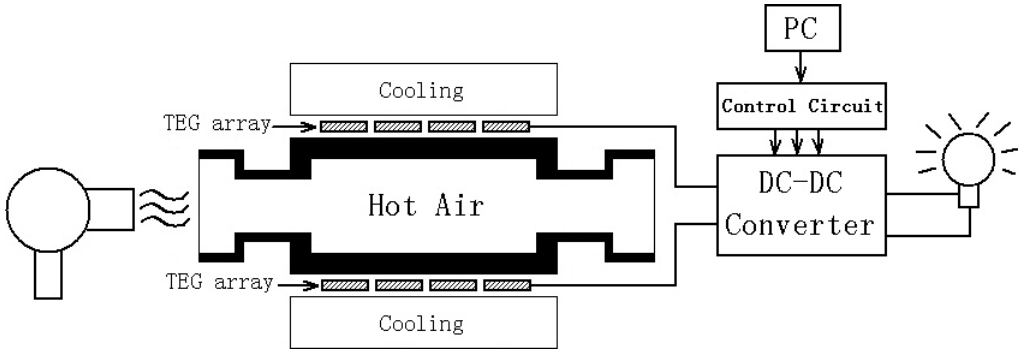
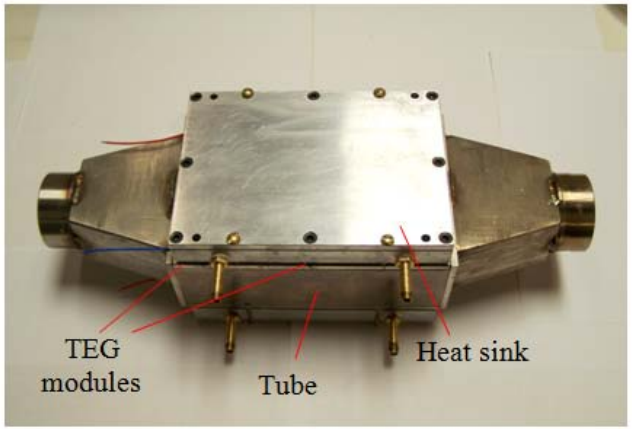
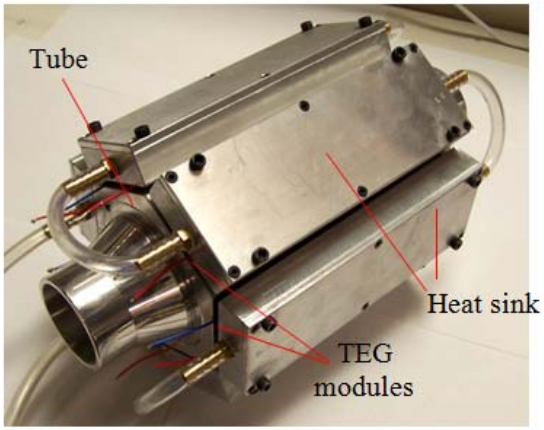
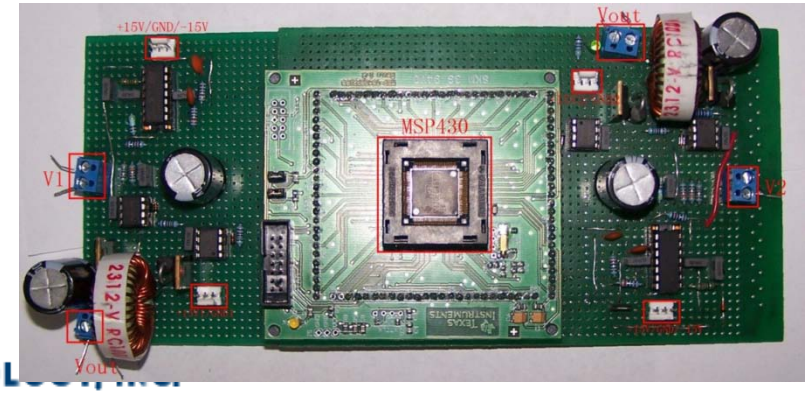


Diagram of waste heat recovery testing system



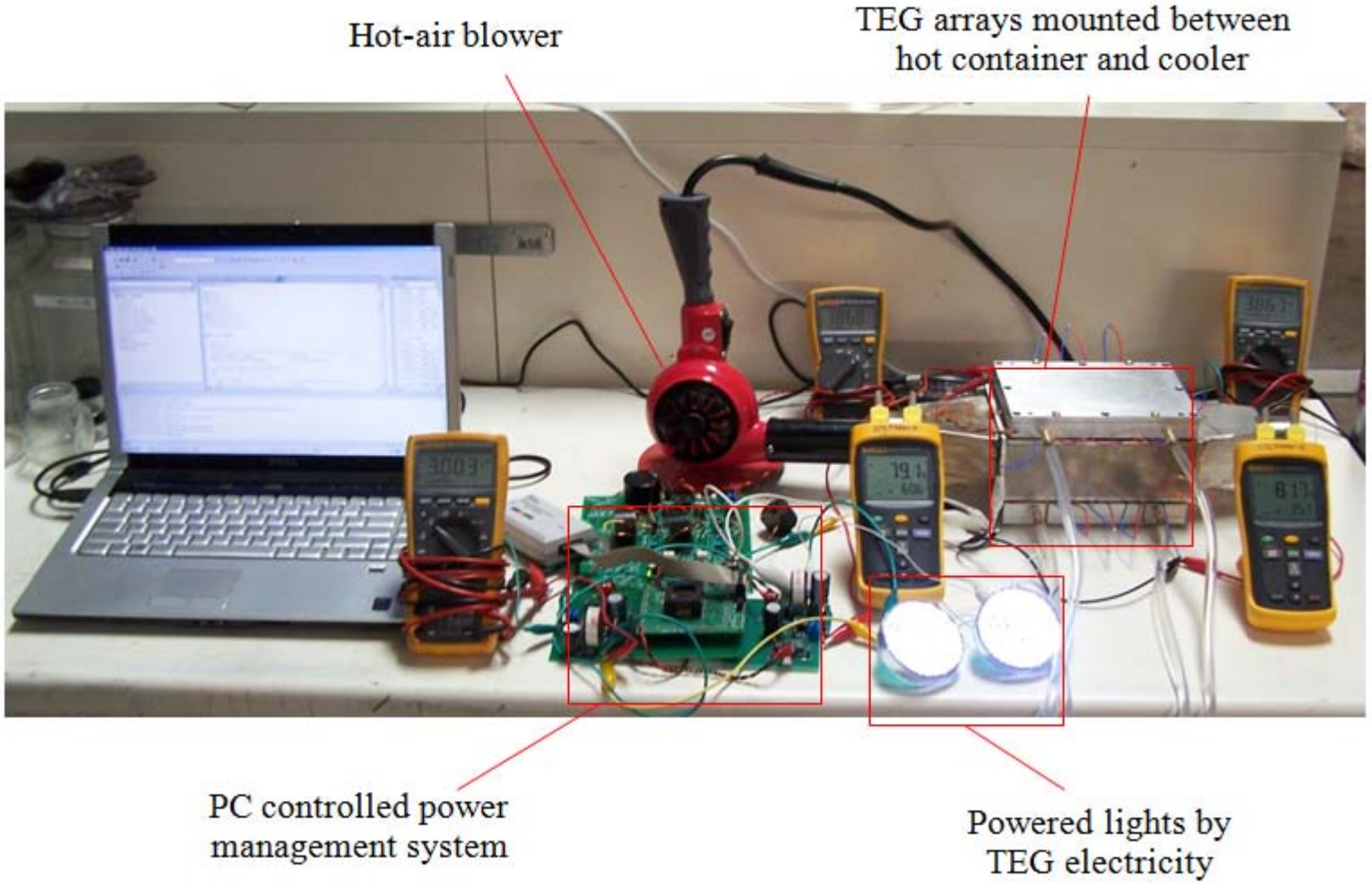


Units with rectangular and circular tubes



Power management system

Modules, Devices and Systems



Summary

- Achieved ZT of 1.15-1.25 for Bi2Te3-Sb2Te3 system and ZT of 1.45 for PbSe-PbTe system
- Developed synthesis method for 2 inch diameter bulk samples, which can be further scaled to 4 and 6 inches
- Fabricated evaluation TE modules and system for performance testing
- Presently the processing approach are being utilized for the synthesis of large-dimension Skutterrudite-based TE nanocomposites

Acknowledgement

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