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Edited by Timothy P. Hogan, Jihui Yang, Ryoji Funahashi and Terry M. Tritt

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## **Thermoelectric Power Generation**

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**MATERIALS RESEARCH SOCIETY  
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# Thermoelectric Power Generation

Symposium held November 26–29, 2007, Boston, Massachusetts, U.S.A.

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## PREFACE

Symposium U, “Thermoelectric Power Generation,” held November 26–29 at the 2007 MRS Fall Meeting in Boston, Massachusetts, was the eighth in a series of thermoelectric materials research symposia related to new thermoelectric materials and devices [see MRS Proceedings volumes: 234, 478, 545, 626, 691, 793, 886]. In this symposium there were 135 contributed presentations including 11 invited talks and 63 posters. A steady and growing interest in the field of thermoelectric materials is evidenced by the continual increase in the number of submitted abstracts throughout the series of symposia. Even with the narrowed focus on thermoelectric power generation, this symposium was no exception having the highest number of contributions in the series.

The efficiency,  $\eta$ , of a thermoelectric power generator can be written as the product of a Carnot efficiency component,  $\eta_c$ , given as the ratio of the temperature gradient over the hot side temperature, and a thermoelectric component,  $\eta_{ZT}$ , such that  $\eta = \eta_c \cdot \eta_{ZT}$ . The thermoelectric component,  $\eta_{ZT}$ , is a function of the unitless figure of merit,  $ZT$ , and rapidly increases at low  $ZT$  values then asymptotically approaches a value of one in the limit. Higher efficiencies can therefore be achieved with large temperature gradients, and through improvements in  $ZT$  (commonly used materials have  $ZT \approx 1$ ). This figure of merit is based on the material properties as  $ZT = \alpha^2 \sigma T / \kappa$ , where  $\alpha$  is the thermopower,  $\sigma$  the electrical conductivity, and  $\kappa$  is the thermal conductivity of the material. It is a challenging task to find materials with high electrical conductivity while simultaneously exhibiting high thermopower, and low thermal conductivity. Promising materials are often brittle and significant research in the processing of these materials is also of interest. Some results of current research in these areas are contained in these proceedings, and it is the hope of the organizers of this symposium that these proceedings will provide a concise reference for the current state of the field of thermoelectric materials research and development.

Within this symposium, there were sessions on nanocomposite materials including an excellent overview given by Millie Dresselhaus (MIT) on the use of “self assembled,” and “force-engineered” nanocomposites in bulk samples. Jian He (Clemson) described the coating of pulverized  $p$ -type  $\text{Bi}_2\text{Te}_3$  powders followed by hot pressing into bulk samples. Mercouri Kanatzidis (Northwestern U.) showed  $ZT > 1.4$  for self assembled nanostructured  $\text{PbTe}$ -based bulk materials. George Nolas (U. of South Florida) described efforts in material systems including group IV clathrates, nanostructured chalcogenides, and antifluorite compounds and the use of powder processing techniques for the fabrication of bulk samples. Thallium telluride, and gallium telluride materials with extremely low thermal conductivity of below  $0.5 \text{ (W/m}\cdot\text{K)}$  were presented by Shinsuke Yamanaka (Osaka U.). Theoretical studies of oxide thermoelectrics were presented by David Singh (ORNL) using conventional Boltzmann transport and showing the origin of the desired bandstructures coming from the bonding topology. Wataru Koshibae (Sendai National College of Technology) presented theoretical analysis on strongly correlated electron systems, and S.D. Mahanti (Michigan State U.) presented theoretical studies of the  $\text{AgPb}_m\text{SbTe}_{m+2}$  material system. Mahanti showed self assembled nanostructuring in these materials can be understood through clustering and ordering of Ag, Sb, and Pb ions, and the temperature dependent electrical conductivity is dominated by the temperature dependence of the relaxation time rather than its energy dependence. Qiang Li (Brookhaven National Lab) described modeling and fabrication efforts toward materials with high power factors, and Holger Kleinke (U. of Waterloo) presented several new interesting compounds including  $\text{Mo}_3(\text{Sb,Te})_7$ ,  $\text{Nb}_3(\text{Sb,Te})_7$ , and  $\text{Re}_3(\text{E,As})_7$  (with  $\text{E} = \text{Si, Ge, Sn}$ ). Filling of the voids with nickel gave the compound  $\text{Ni}_{0.06}\text{Mo}_3\text{Sb}_{5.4}\text{Te}_{1.6}$  as a degenerate  $p$ -type semiconductor that reaches  $ZT = 0.96$  at  $750^\circ\text{C}$ . The symposium focused not only on the preparation and properties of new materials, but also included several talks on the processing of these new materials into devices, and the mechanical properties of thermoelectric compounds. In addition, the development status for the use of several advanced thermoelectric materials in radioisotope thermal generators for space applications was given by Thierry Caillat (JPL). Continued interest in the area of thermoelectrics was evidenced by the

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number of outstanding presentations received, and the excellent level of attendance throughout the symposium.

The greatest returns come from investments in human capital through training and research of future scientists. As with previous thermoelectrics related symposia, there were a large number of graduate student presentations. Through the generous support of sponsors for this symposium, six graduate student oral presentation awards, and five graduate student poster awards were given. These students included:

#### Oral Presentations

**Xiaofeng Qiu** (Case Western Reserve University) "Synthesis and Characterization of Novel Thermoelectric Nanomaterials"

**Bo Zhang** (Clemson University) "PbTe Nanocomposites Fabricated by a Nano Surface Coating Technique"

**Fei Ren** (Michigan State University) "Mechanical Characterization of PbTe-based Thermoelectric Materials"

**Vladimir Jovovic** (Ohio State University) "Galvanomagnetic Measurements of Neodymium Doped Lead Telluride"

**Matt Beekman** (University of South Florida) "Synthesis and Characterization of Inorganic Clathrate-II Materials"

**Joseph R. Sootsman** (Northwestern University) "Transport Behavior, Thermal Conductivity Reduction, and Improved Thermoelectric Performance in the Composite System PbTe – Pb – Sb"

#### Poster Presentations

**Ann I. Persson** (University of Oregon) "Thermal Conductivity Measurements of Epitaxially Grown Nanowire Arrays Using TDTR"

**Sabah Bux** (University of California) "Synthesis and High Temperature Thermoelectric Properties of Nano Bulk Silicon and Silicon-Germanium Semiconductors"

**Masataka Fukano** (Tokyo University of Science) "Crystal Growth of Mg<sub>2</sub>Si by the Vertical Bridgman Method and the Doping Effect of Bi and Al on Thermoelectric Characteristics"

**Yoriko Mune** (Nagoya University) "Origin of Giant Seebeck Coefficient for High Density 2DEGs Confined in the SrTiO<sub>3</sub>/SrTi<sub>0.8</sub>Nb<sub>0.2</sub>O<sub>3</sub> Superlattices"

**Yohei Oguni** (Tokyo University of Science) "Formation of Transition-metal-based Ohmic Contacts to n-Mg<sub>2</sub>Si by Plasma Activated Sintering"

The organizers are most grateful for the very gracious support of the Science and Technology Division of the Office of Naval Research, General Motors Corporation, Marlow Industries, Quantum Design Incorporated, Tellurex Corporation, ULVAC Technologies Incorporated, and the Materials Research Society. Their support enabled the large number of student awards and allowed for travel funds to help support contributing presenters.

Timothy P. Hogan  
Jihui Yang  
Ryoji Funahashi  
Terry M. Tritt

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