Visitor Research Report

Visitor Name: **Dr. Hyun Jung Kim**

Area of Research: **Advanced Materials for Energy Harvesting**

Period of Visit: **April 6, 2009 – December 31, 2010**

Goal:

The goal is to develop new thermoelectric materials that will be used for advanced thermoelectric power generator. Thermo-Electric (TE) materials are important elements to generate electric power directly from thermal energy. NASA's deep space explorers, such as Voyager and Galileo, require long-lifetime power generators that can operate several decades of space travel time without dependence on solar energy because the distance from the Sun is very far. TE power generators satisfies this requirement and have become very important power sources for NASA's deep space exploration. TE materials have variety of applications such as TE cooling device and power generator from wasted heat from engine and house/factory-heating system. However, the efficiency of TE modules was only 6~8% so far due to the low figure of merit of TE materials. To give a visible benefit, the figure of merit of TE materials must be greater than 1.5 or higher (figure of merit 1≈7% thermal efficiency). To enhance the figure of merit of TE materials, it is necessary to reduce thermal conductivity while keeping or increasing electrical conductivity and Seebeck coefficient. Low thermal conductivity of TE materials signifies that incoming thermal energy is kept for TE conversion. Our team has developed new material designs for TE applications which would give the figure of merit higher than 2. Materials development will be focused to achieve these goals with new innovative epitaxial growth technologies and characterization tools.

Strategy:

- SiGe (high temperature application): Our strategy is to develop crystal-atomic-lattice-controlled high ZT bulk TE materials using new innovative rhombohedral semi-bulk/epitaxial growth technology with advanced XRD methods. XRD method determines the best growth condition; shows full crystal structure electrically connected atomic structure/disordered enough to scatter phonons. Our SiGe samples have very high electrical conductivity, close to single crystalline materials, but disordered enough (stacking faults) to scatter phonons.
- BiTe (low temperature application): To use metallic nano-powder, which acts as bridges between BiTe grains, with dimensions comparable to the phonon mean free path reducing thermal conductivity by disrupting phonons without sacrificing electron transport.
- Thermoelectric properties usually varying with temperature and thermoelectric devices are designed to operate at a determined temperature range. Temperature-dependent measurement is necessary. Some thermoelectric characterization systems have

been commercialized for temperature up to 1000^{o}C, but there is no system that measures all three parameters simultaneously, in such a temperature range. A high temperature characterization system that measures Seebeck coefficient, and thermal conductivity at temperature up to 1000^{o}C has been demonstrated.

Accomplishments:

- We have developed a method to grow twin-lattice SiGe structure in our laboratory. We developed crystal atomic lattice controlled bulk TE materials using our new innovative rhombohedral semi-bulk/epitaxial growth technology with advanced XRD methods. When cubic semiconductor materials are aligned along <111>-orientation, i.e. rhombohedral direction, they can form two identical twin crystal structures, only rotated by 60° from each other. These twin crystals are formed by stacking faults. We could control the formation of twin crystals and stacking faults and characterize the materials.

- We fabricated advanced bulk-type TE material of BiTe by metallic nanopowder-decorate technology
- A refined measurement technique at elevated temperatures is imperative to verify thermoelectric properties. So we established a new thermoelectric characterization system that measures all three parameters nondestructively, in high temperature range.

Future Work: Thick-films of rhombohedrally grown lattice-controlled TE materials will be fabricated with negative ion beam growth system. Future work will require fabrication of multi-element TE modules for TE power generator, TE cooling device, and high temperature TE characterization system. Future work will also involve the fabrication of prototype high efficiency TE power generator and performance test.

Pending Publications: None

Seminar Presented: (Oral presentation) "Enhanced thermoelectric figure of merit in nanostructured SiGe alloys", Hyun Jung Kim, Yeonjoon Park, Glen C. King, Kunik Lee, Sang H. Choi, SPIE Smart Structures/NDE, 2010, San Diego, CA, USA