Nano-engineering for efficient energy conversion systems

Thermoelectric (TE) materials have a unique position for their dual purpose: electrical generation on one side and cooling/heating on the other side. Power generation is achieved by applying a temperature difference between two ends of the TE material, while cooling or heating is obtained by applying electrical current. Thermoelectrics have very attractive features, such as small size, simplicity, and reliability, and have important applications for power generation or cooling both for terrestrial and space applications. With state-of-the-art research and development, it is clear that new generation TE materials and devices are expected to play an important role in the development of clean and efficient energy conversion systems.

There is actually the need for the development of novel methods for the fabrication of high performance TE materials for several devices and systems. Improvement of the materials performance can be achieved through "nanostructuring" and the introduction of structural modifications of TE materials. This includes developing a technology for the different steps in processing the materials to devices (compacting, shaping, sintering, electrical contact, etc.). In this context, the project also deals with the evaluation of prototype devices for electrical energy generators, coolers, and thermal sensors.

The Market

Thermoelectric (TE) materials offer several opportunities for an economic recovery of low-grade thermal energy in several applications, thus increasing the overall operation economy. An increase in TE energy-conversion efficiency of a few percent in power production would translate into large sums of money on a European scale. For terrestrial applications, energy recovery in industrial processes has huge economic prospects. Cars, as an example, loose about 1/3 of the energy directly as heat in the exhaust, which can partly be recovered with an efficient TE device and converted to usable electricity resulting in overall vehicle operation economy and sizable impact on CO_2 emission. This is especially important for other electrically driven crafts, such as trains, tramways, etc. There are several billions euros worth of products per year, only in this area.

There is an enormous potential for European and world markets in cooling applications, varying from water coolers, air-conditioners, etc. to applications in space for both cooling and power generation systems.

For space applications, satellites and spacecrafts, TE materials are indispensable power generators that constitute very high value products. Although there is no accurate estimate for this market volume, it is expected to be in the order of few billions euros/year.

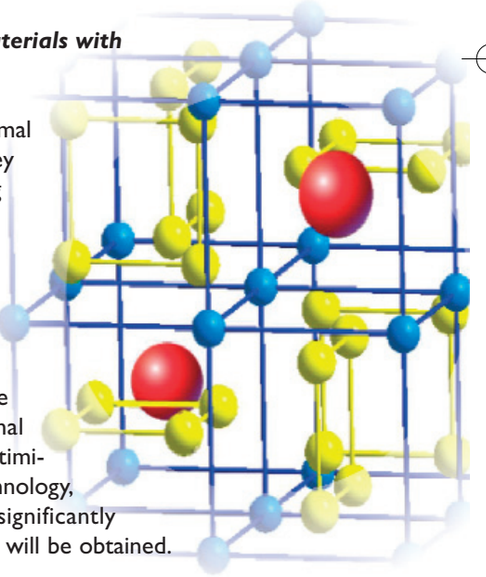
Innovations

The project has developed a viable strategy for the improvement of the performance of TE materials based on the use of nanotechnology as well as on the introduction of structural modifications of novel "Host-Guest" configurations.

- ***Theoretical modelling of TE materials***
  First principle (ab-initio) computations of several crystal structures were performed to evaluate the feasibility and limitation of TE materials.

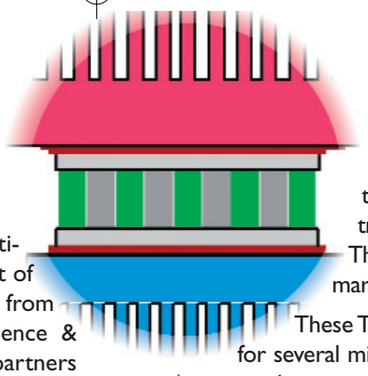
- ***Novel concepts for the fabrication of nanostructured TE materials***
  Current technology does not permit the fabrication of nanophase TE materials. In this project, novel chemical methods have been developed for the fabrication of nano-engineered thermoelectric materials. These methods allow the preparation of several TE materials at relatively low temperatures and short processing time. Nanostructured bismuth telluride, zinc antimonides, and skutterudite TE materials have been prepared using these methods.

- ***Development of TE materials with extremely low thermal conductivity***
  The reduction of thermal conductivity is a key parameter for increasing the materials TE properties. We have fabricated nano-structured skutterudite with a dramatic decrease of thermal conductivity, one order of magnitude lower than conventional materials. By proper optimisation of processing technology, TE materials with significantly improved figure of merit will be obtained.



- ***Structural modifications of TE materials with "Host-guest" configuration***
  In this project, a new concept of modifications of "Host-Guest" structures is used. Doping atoms are substituted into the "Host" structure or introduced as "filling (guest)" atoms inside the main structure. Theoretical predications are used for system selection. Novel TE-materials (skutterudite, clathrates) have been prepared.

- ***Development of Standardized TE evaluation techniques***
  Methods for the measurements of different TE related properties have been optimised and standardized for a wide temperature range (175-575 K). Novel methods for mapping the homogeneity of selected areas of TE samples were developed.



The Project Team

The project Team is structured to include the multi-disciplinary competence necessary for the development of fabrication and processing technology with expertise from theory, experiments, chemistry, physics, materials science & engineering, and processing technology with industrial partners for power generation and cooling applications.

The Kungliga Tekniska Högskolan, University of Aarhus, and Chalmers Tekniska Högskola play the role of developing innovative synthesis methods for TE materials as well as chemical and structural/microstructural characterisation. The Istituto di Scienze e Tecnologie Molecolari is supplying basic data by theoretical modelling of selected systems.

NEDO Centre for Thermoelectric Engineering has a world-class experience in thermoelectrics as well as a special competence in the electrical engineering and design of thermoelectric devices. NEDO Centre for Thermoelectric Engineering and Deutsches Zentrum für Luft- und Raumfahrt share the responsibility of thermoelectric characterization of prepared materials. Standardization of thermoelectric characterizations is another aspect these two partners are currently working on. Design, production and testing of thermoelectric elements and devices will be performed by NEDO Centre for Thermoelectric Engineering, CIDETE Ingenieros, Termo-Gen AB and Deutsches Zentrum für Luft- und Raumfahrt. CIDETE Ingenieros (SME) is a commercial producer of thermoelectric materials, elements and devices for cooling applications. CIDETE shall exploit the results of new TE materials developed for more efficient cooling devices. Termo-Gen AB/Legelab and ST Engineering AB (SME) is involved in developing applications for power generation from waste heat. Term-Gen AB shall exploit the developed TE materials for the fabrication of devices for the recovery of waste energy from car gas exhaust.

An application example

Cooling: this conventional application of TE materials and devices lies within their use as Peltier elements for cooling purposes. Improving the figure of merit for these materials opens the doors for several novel applications. TE offers a reliable low volume, low-noise cooling device. It can be applied as a thick or thin film.

Industrial cooling is an important application with a large market volume. Car air conditioners are a new area for TE materials. Other important applications are active cooling of electronic printed-integrated circuits, radio transmitters and PC processors, etc. These applications can have a very high market volume worth several billion euros.

These TE materials are also of special interest for several military uses. Light weight power generation (power gadgets, sensors, communication systems, etc.) and cooling devices (IR detectors, etc.) are important applications.

Glossary

Thermoelectric (TE) material: *A material capable of converting heat to electrical energy and electrical energy to heat.*

ZT: *Figure of merit of thermoelectric material that is the measure of materials efficiency.*

Nano-engineering of high performance thermo-electrics

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Useful links

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