



Report on
Energy

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5 Energy

5.3 Thermoelectricity

5.3.1 Definition

Thermoelectricity is the conversion of heat into electricity or of electricity into heat or refrigeration. This conversion is called the Peltier-Seebeck effect. This comes from the name of the 2 physicians who discovered each effect. On one hand, the Prussian physicist Thomas Seebeck discovered, in 1821, that if one placed a temperature difference across a junction of two different conductors, an electrical current would flow. On the other hand, the French physicist Jean Peltier found, in 1834, that if you run a current into two different electrical conductors, connected at two junctions, one junction will heat up whereas the other one will cool down. It was later demonstrated by Lenz that it was possible by circulating a current, to freeze a drop of water at a BiSb junction and melting ice by reversing the current. The realisation of practical applications for thermoelectric devices appears only recently (last century).

5.3.2 Short description

The thermoelectric effect can therefore be used in solid-state systems to generate electrical power from heat, to cool or heat objects, to measure temperature. As the heating or cooling direction is defined by the sign of the applied voltage, the thermoelectric effect can also be used to realise precise temperature control.

A thermoelectric couple consists of 2 legs, one made of p-type materials where the charge carriers are holes and the other one made of n-type material where the charge carriers are electrons.

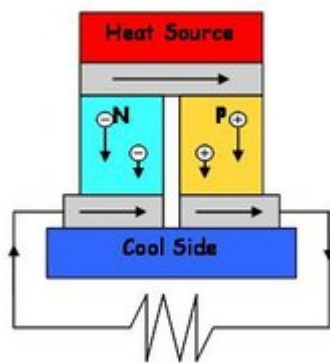


Figure 1: Working principle of a electric generator module

To generate electricity, thermocouples are assembled in modules. They are arranged electrically in series and thermally in parallel.

The performances of these devices are characterised thanks to the figure of merit $ZT = (\sigma S^2/\kappa)T$ where σ is the electrical conductivity, S the Seebeck coefficient and κ the thermal conductivity. The Seebeck coefficient is defined as the ratio of the generated

voltage difference ΔV to the temperature difference ΔT . As ZT increases, the conversion efficiency of the system increases. The limit is the Carnot efficiency.

Thermoelectricity is a promising source of electric power, thanks to its ability to locally scavenge energy by converting a heat flow in electricity. Indeed, by placing thermoelectric devices in a persistent thermal gradient, it is possible to save energy that would be lost otherwise. Even with a modest conversion yield, this would represent huge stakes. For instance, the power lost by heat leaks in devices powered by thermal engines, like automotive, is estimated among 30 to 40 % of the total power produced by the engine. Another field of application for thermoelectricity is the scavenging of the heat sent out by the human body. As a consequence, many applications are being imagined for local electricity production by thermoelectric effect, thanks to local heat leakages. Since this energy is available anyway, it is possible to estimate the interest of this solution depending on the price of the thermoelectric device vs. benefits like local needs in energy, wires dispense... The main other features of these devices is the lack of mechanical parts and therefore their silence, their small size, their light weight, their reliability, their lack of toxic gas emission and their low maintenance.

The problem remains the poor performance indeed nowadays thermoelectric materials are stuck to a ZT value around 1 and below (for $ZT=1$, the conversion yield is 8% for a temperature difference of 300°C). The increase of performances has been very slow since the 1950s.

A good thermoelectric material must have a high Seebeck coefficient to produce the required voltage, a high electrical conductivity to reduce thermal noise and a low thermal conductivity to reduce thermal losses.

However, on one hand, the increase of the Seebeck coefficient generally leads to a decrease of the electrical conductivity. On the other hand, the increase of the electrical conductivity leads to an increase of the electronic contribution to the thermal conductivity and then to an increase of this last one. The improvement of the figure of merit is therefore a question of compromise.

At first, let note that the best thermoelectric materials are semiconductors. Indeed, on one hand, metal have a low Seebeck coefficient due to their large electronic contribution to thermal conductivity. On the other hand, insulators have a low electrical conductivity due to their lack of charge carriers.

The improvement of nanotechnology process techniques offers possibilities to enhance the materials performances.

5.3.3 State of R&D

5.3.3.1 Nanostructures

Theoretical works have proven that small, dimensionally-confined material can exhibit figure of merit better than 1^{1,2}. ZT values of 2 or 3, i.e. 30% of Carnot efficiency are supposed to be reached, which will allow thermoelectric devices to be competitive with other electric generators.

2D structures such as superlattices^{3,4} have a better figure of merit than bulk materials. $ZT=2.4$ has been theoretically reported by A. Shakouri⁵. 1D structures such as nanowires^{6,7,8} have an even greater figure of merit. Indeed, on one hand, quantum confinement enhances Seebeck coefficients. The energy spectrum of the charge carriers

can be modified thanks to the structure change due to small dimensions or to dispersions interaction with ions and phonons. On the other hand, the surface area increase improves the boundary phonons scattering and therefore reduces the thermal conductivity: the boundaries can be considered as a selective filter of the phonons wavelength. Moreover, when the film thickness is closed to the phonons wavelength, destructive interferences appear (for a review, read⁹).

This predicted ZT enhancement has been experimentally demonstrated¹⁰. But for the moment, it seems that the theoretical value of $ZT = 3$ or more has never been reached.

These results have led to research on 0D structures such as nanoparticles. First it was proposed to embed nanoparticles and nanowires in a host matrix material¹¹ or to mix two different kinds of nanoparticles¹². These nanocomposites exhibit reduced thermal conductivity. The challenge was to properly choose electronic properties of the materials used so that the electron transport properties are maintained¹³. More recently works on pressed Bi nanoparticles have been carried out.¹⁴

Last results concerned the nanostructuring of materials. Grinding BiSb telluride alloys into fine nanopowers and then pressing them into nanocrystalline ingots allows to increase the figure of merit to a value around 1.2 at room temperature and 1.4 at 100°C.¹⁵

5.3.3.2 Materials

Concerning the materials, the most appropriate to low temperature uses are for the moment those based on group-IV tellurides. The matter is that these materials are noxious. So studies have been carried out to use other material such as those based on silicon. The problem remains that the best performance are obtained at high temperature (around 1200°K) as is shown on the Figure 1.

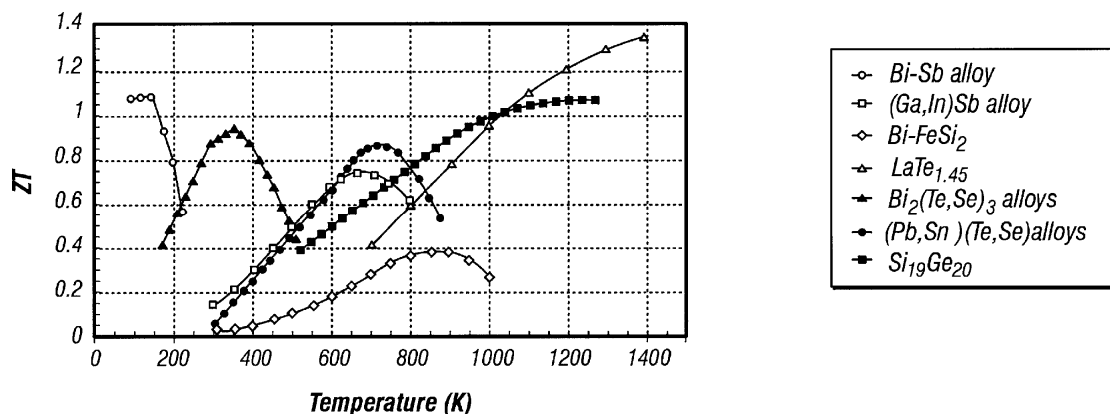


Figure 1: Figure of merit vs. temperature for different alloys¹⁶

For the moment, those materials are laboratories ones and some are even just at modelling level. So the great challenge is to get to an industrial level and sometimes even to a lab prototype first. Another point is that most advances have been achieved at high temperature and that some low temperature improvements need to be studied.

Non toxic materials, like alloys of strontium titanate, are now intensely studied, particularly by Japanese research teams¹⁷.

5.3.4 Additional demand for research

5.3.5 Applications and perspectives

Electrical generation from waste heat sources:

- burning oil lamp driving a wireless receiver
- automobile engines heat driving air conditioner

Body heat to run some small electronic devices:

- digital watch
- pulse meter
- GSM/GPS chip
- MP3 player

Body heat to run medical electronic devices:

- Sensors and power supplies embedded in band aids

Electrical generation in hostile place:

- Spatial: radioactive isotopes used as heat sources (PV not useful)

5.3.6 Current situation within the EU

5.3.7 References and literature

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