Thermoelectric Generators

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Thermodynamics: The Governing Science of Thermoelectricity

Thermodynamics is the science of heat inside energy systems, most notably its transfer into neighbor systems or its conversion into other forms. This science provides bounds for the thermoelectric effect, which concerns itself with the creation of a temperature difference by way of moving charge carriers. The thermoelectric effect also states that the reverse action can occur: charge carriers can be set into motion inside a region if a temperature gradient is established across that region. The laws of thermodynamics limit the efficiency of both of these processes. For example, a refrigerator is a device that establishes a temperature difference between its interior and its surroundings. Because refrigerators accomplish this by way of electric power, a refrigerator is in a sense a thermoelectric device. The efficiency of a refrigerator is expressed by the coefficient of performance (COP), which is the amount of cooling divided by the electrical energy input needed to obtain that cooling. The laws of thermodynamics tell us that a maximum efficiency, called the Carnot efficiency, cannot be exceeded for this system or any system like it (DiSalvo 1999). Therefore, all thermoelectric devices-including thermoelectric generators-are limited by this single law.

The Seebeck Effect

Essentially, the Seebeck effect is the part of the thermoelectric effect that states that a temperature difference between two points in a conductor or semiconductor results in a voltage difference between these two points. Stated differently, a temperature gradient in a conductor or a semiconductor gives rise to a built-in electric field. The thermoelectric voltage developed per unit temperature difference in a conductor is called the Seebeck coefficient and is a gauge of the magnitude of the Seebeck effect (Kasap 1997). As heat flows from hot to cold, free charge carriers in the material are forced to traverse towards the cold end. This produces a voltage that is directly proportional to the temperature difference across the material and which can be driven through a load. This voltage can be given in terms of the temperature difference by the equation $V=\alpha Th\text{-}Tc$, where α is the Seebeck coefficient (Snyder 2008).

Thermoelectric Generators

Thermoelectric generators are solid-state devices that directly convert heat into electricity by making use of the Seebeck effect. The efficiency of a thermoelectric generator depends entirely on the materials used to construct the device. Good thermoelectric materials are typically heavily doped semiconductors that possess low thermal conductivity. These materials contribute to a high thermoelectric figure of merit zT, where z is defined as $z = \alpha 2\sigma/\kappa$, ($\alpha$ is the Seebeck coefficient, σ is the electrical conductivity, T is temperature and κ is the thermal conductivity). Heavily doped semiconductors provide a balance between the large $|\alpha|$ of lightly doped semiconductors and the high σ of metals. Today's thermoelectric generators are constructed by connecting P and N doped semiconductors electrically in series and thermally in parallel. These semiconductors are then usually placed in between two plates that electrically insulate the system. A thermoelectric generator converts heat into electricity with an efficiency η by the equation $P=\eta Q$, where P is the electrical power output and Q is the amount of heat that can be transferred through the thermoelectric material (Snyder 2008). Generally speaking, thermoelectric generators are relatively inefficient as compared with the modern heat engine. Because of this, most applications for these devices involve ultra-low power energy harvesting, where wasted energy that has been dissipated in the form of heat can be recaptured and converted into electricity. This electricity can then be used to either power some low energy device or to provide a “power boost” to some energy system.

Inside the Thermoelectric Generator: Thermocouples and Semi-conductors

Materials inside thermoelectric generators are paired off into thermocouples that are composed of two different semiconductors joined at one end by a metal junction and separated at the other end. Semiconductors are nonmetallic elements that contain both electrons and holes as charge carriers in contrast to the enormous number of electrons as in metals. A hole is essentially a "half-broken" covalent bond which has a missing electron and therefore behaves effectively as if positively charged. Under the action of an applied field, the hole can move by accepting an electron from a neighboring bond, thereby passing on the "hole". Electron and hole concentrations in a semiconductor are generally many orders of magnitude less than those of electrons in metals, leading to much smaller conductivities and thus the name semiconductor (Kasap 1997). In thermoelectric thermocouples, one semiconductor is p-type and the other is n-type. N-type semiconductors are characterized by the flow of negatively charged electrons through them, while p-type semiconductors are characterized by the flow of the positively charged holes. When a temperature gradient exists across the thermocouple junctions, the thermocouple experiences the Seebeck effect. By using the two different semiconductors, this effect is maximized, and the thermoelectric generator possesses a higher Seebeck coefficient-that is, it is more efficient, producing more voltage per increase in temperature.

Design Plan

The design process for the thermoelectric generator is fairly simple. Two basic circuits will be constructed in order to portray two of the possible commercial applications for this technology. The first circuit will use the thermoelectric generator to run some low power appliance, while the second circuit will implement the thermoelectric generator in with some other power source-most likely a AA battery- in order to “boost” the total voltage output and therefore power some device better or more efficiently.

Experimental Hazards

If any persons wish to imitate this experiment, two suggestions can be made as to what not to try. Firstly, do not under any circumstances microwave the thermoelectric generator. This results in an apocalyptic caliber battle between microwave and generator, and the microwave will always in. Secondly, do not believe any so-called friends who might suggest a rock as a heat source or who suggest the microwave as an efficient way to heat the stone. It will take hours to clean the pulverized rock dust from the corners and edges of your microwave. Otherwise, have fun! Thermoelectric generators are fun devices to fool around with.

<u>Schematic of Thermoelectric Generator</u>

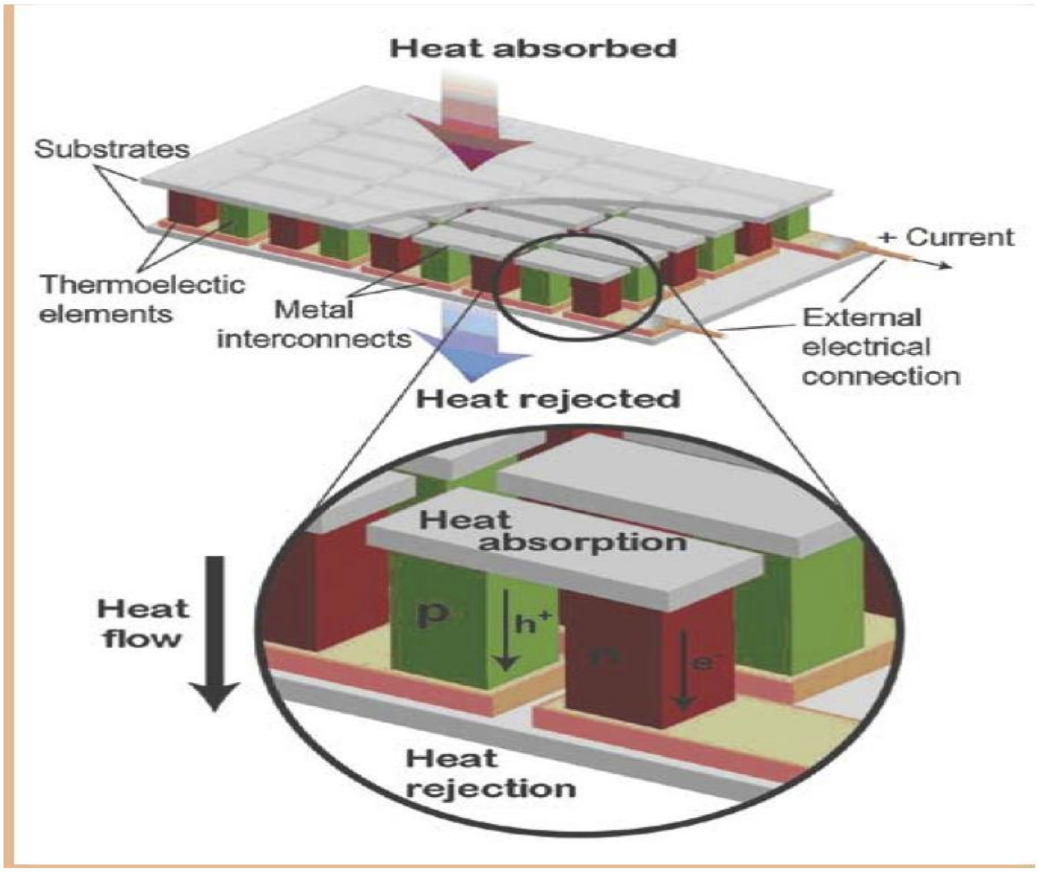

Figure 1: This thermoelectric generator consists of 27 junctions and each junction consists of two semiconductors, one n-type and one p-type.

Courtesy of Jeffrey Snyder

References

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