

Thermoelectric energy conversion

Objective

The objective of this laboratory is for you to explore the physics and practical aspects of solid-state heat pumps, the direct conversion of thermal-to-electrical energy using thermoelectric materials, and the thermodynamic limits to the efficiency of heat engines.

Preparation

Read the article, “Simple experiments with a thermoelectric module,” that is posted at the Compass web-site.

Equipment and samples

- Peltier device with integrated air heat exchanger
- Two dc power supplies; power supply for running the cooling fan
- Thermocouples, heaters, load resistors or decade box, hook-up wire, breadboard
- Hand-held multi-meter
- Computer, data acquisition board, plotting software

Introduction

Most large-scale conversion of thermal-to-electrical energy uses a gas cycle of some type. For example, heat generated by burning coal is used to vaporize water that drives a turbine and generator. And the air conditioner in your apartment uses electrical energy to run a compressor to condense a refrigerant. The electrons and holes in a semiconductor can also be used to convert heat to electrical power or the electrons and holes can be used to move heat against a temperature gradient. Semiconductors that do this relatively efficiently are referred to as “good thermoelectrics”. The best thermoelectric material for use near room temperature is Bi_2Te_3 and related alloys; for many decades, researchers have been looking for something better without success. In this lab, you will measure the efficiency of a Bi_2Te_3 -based thermoelectric module and compare this efficiency of the module to the theoretical limit, i.e., the efficiency of the Carnot cycle.

Session 1: Peltier current and solid-state heat pumps

- Explore heat Peltier cooling and heating by applying current to the thermoelectric module in both directions, i.e., measure the steady-state temperature drop across the module as a function of electrical current. Keep in mind that the Peltier heat current is linear in the electrical current but Joule heating due to the finite resistance of the thermoelectric materials is quadratic in the current. You will want to use the fan-driven heat exchanger to

keep one side of the module near room temperature. Make sure that you find the minimum cold-side temperature so that you can estimate the effective value of the thermoelectric figure-of-merit for this module from the maximum cooling.

- Measure the Peltier coefficient of the module by balancing the Peltier current against the heat dissipated by the planar heater that is attached to the module. In other words, apply a current to the module so that the heated side of the module stays at room temperature. Think about what values of the heater power—and therefore what values of the electrical current applied to the module—are needed for this measurement to be accurate and mostly free of the effects of Joule heating within the module. Another option is to measure the current for a large range of heater powers and use a fit to the data to determine the linear term that gives the Peltier coefficient. Take note of the resistance of the module; you will need that resistance in the second session.

Session 2: Seebeck coefficient and thermoelectric power generation

- Measure the Seebeck coefficient of the module by using the heater to create a temperature drop across the module. You will want to measure the voltage as a function of the temperature drop; the slope of that curve is the Seebeck coefficient. Is the Seebeck coefficient constant, i.e., independent of the size of the temperature drop? Does the Seebeck coefficient agree with the Peltier coefficient? Recall that $\Pi = ST$.
- Use the thermoelectric module to generate power from the heat dissipated by the planar heater. Leave the fan off for this part of the experiment. You will need to pick an appropriate load resistance to maximize the power generation. (Recall that you measured the resistance of the module in the first session.) Measure the power generated by the thermoelectric module as a function of heater power and compare the result to the Carnot efficiency. (To make that comparison, you will need to record the hot-side and cold-side temperatures of the module.) If you have time, repeat the experiment with the fan turned on and measure the power required to operate the fan. How large of a temperature drop is needed just to run the fan?