Investigating Effects of Non-idealities in Thermophotovoltaics System Performance

*Chidubem Dimukeje, [1] Zunaid Omair, [1,2]Eli Yablonovitch

*Department of Engineering and Aviation Sciences University of Maryland Eastern Shore

[1] Department of Electrical Engineering and computer sciences, University of California, Berkeley

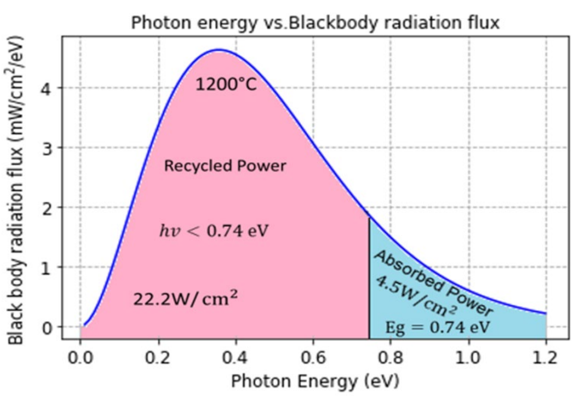
[2]Center for Energy Efficient Electronics Science, University of California, Berkeley

Email: cbdimukeje@umes.edu

***Abstract* — Thermophotovoltaics (TPVs) are heat engines that convert thermal radiation from a local hot body to electricity. A basic thermophotovoltaics system consists of a thermal emitter and a photovoltaic cell. In an effort to achieve a high thermophotovoltaic efficiency with a 0.74eV band gap InGaAs cell and a 96% high-reflectivity back mirror using a 1200°C thermal emitter in a vacuum chamber, we must understand the effect of non-idealities in thermophotovoltaic system conversion, and perform Calorimetry experiments to determine the source of leakage in the thermophotovoltaic chamber and calibrate future experiments with the photovoltaic cell**

I. INTRODUCTION

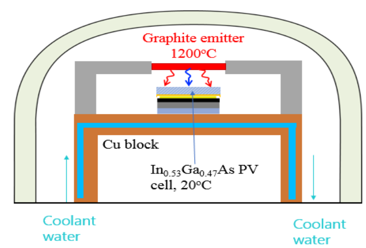
Thermophotovoltaics (TPVs) convert thermal radiation from a local hot body to electricity. A basic thermophotovoltaics system consists of a thermal emitter and a photovoltaic cell which convert this infrared wavelength of thermal radiation to electricity. Thermophotovoltaics is distinguished from solar photovoltaics by the nature of the sun primarily because the sun is a 5800K blackbody at distances up to 1.5 x 10^8 km whereas TPV is from a local hot body, thus it has a different incident spectra and illumination intensities than that of the sun. In this paper, we present the goals of achieving high TPV efficiency by recycling thermal radiation back to the source, and then we present research experiments done in an optical cavity of a TPV system to understand how fundamental non-idealities may affect the TPV efficiency in our chamber.



II. Benefits of a high-back reflectivity mirror

Fig. 1 Black body radiation flux showing benefit of high-back reflectivity mirror

This figure shows the blackbody power spectrum using a 0.74 eV bandgap photovoltaic cell. The Band-gap energy is determined by measuring light absorption by the semiconductor as a function of photon energy. Using a 0.74 eV bandgap photovoltaic cell for blackbody sources at 1200°C, power absorbed in the blackbody spectrum is indicated in the blue region power recycled back to the hot source is indicated in the pink region. At 1200 degree Celsius, for a 0.74 eV bandgap PV cell there is 27 W/cm^2 of black body radiation, 4.5W/cm^2 is absorbed, approximately 22.2 W/cm^2 is reflected back to the hot source and not counted as a loss. High-efficiency in thermophotovoltaics are proposed as achievable due to this advances in photon extraction and light management.



The experimental proving ground for the proposed TPV system is pictured above. It is enclosed in a vacuum chamber. The TPV system will be used to ascertain the achievable TPV efficiency. The TPV cavity is enclosed in a vacuum bell jar equipped with a turbomolecular pump and a cryogenic trap, which provide a vacuum of 10^{-5} torr. This level of vacuum is sufficient to minimize heat loss to the surrounding media by conduction and convection. A reflective chamber surrounds the emitter, which consists of a strip of resistively heated graphite. The chamber sits on a reflective, water-cooled copper block. Photovoltaic samples can be placed along the walls of the reflective chamber, facing either side of the emitter, and are maintained at room temperature to avoid open-circuit voltage degradation. The relative positions of the emitter and photovoltaic samples can be adjusted. Graphite emitter at 1200°C and 20°C are shown. 0.74 eV $In_{0.53}Ga_{0.47}As$ photovoltaic cells, will be used in this experiment. The system's TPV efficiency will be evaluated using Equation: the electrical power output from the photovoltaic cell will be compared with the optical power incident upon the cell that is not reflected back.

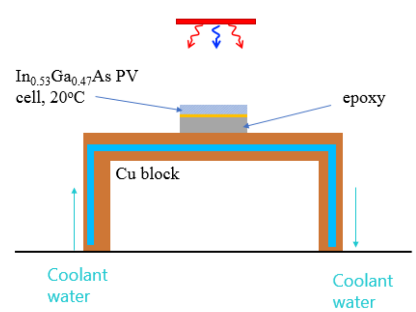


Diagram 2: Epoxy in thermophotovoltaic experimental chamber showing possible overheating

Prior to the implementation of high thermophotovoltaics efficiency, we use an epoxy to glue the PV cell onto the copper block to cool the photovoltaic cell, there is a need to understand the effect of temperature rise on the efficiency of the TPV heat to electricity conversion, thus we model the theoretical calculation to see how much cell rise affects the efficiency. We find that photovoltaic cell temperature affects the efficiency below. The need to understand how cell temperature affects the efficiency is because the epoxy can have a thickness of up to 100 microns so the cell temperature could rise up to 68^{o}C. Prior to implement this high efficiency we must understand the effect of cell temperature rise on the heat to electricity conversion efficiency.

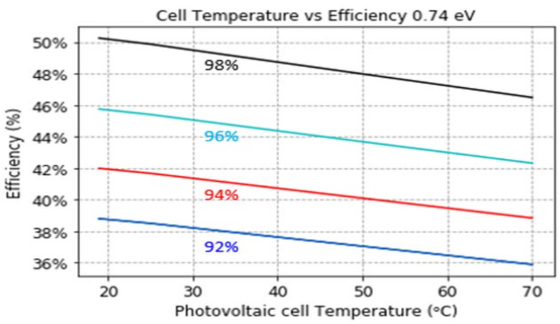


Fig 2. Cell temperature vs. Efficiency

Calorimetry in the thermophotovoltaic chamber was conducted the experimental setup consist of instruments we use to measure pressure, Voltage, Current power, emitter mount temperature, Copper base, temperature of water in, and temperature of water out. The procedure for Calorimetry begins with: First, turning on the faucet and ensuring the water flow rate has become steady, we use a 100 ml graduated cylinder and allow water to continuously drop in the graduated cylinder until the water reaches the 100 ml mark, we use a stopwatch to calculate the time it took for the water to fill the 100 ml graduated cylinder. We repeat the test again to ensure that the time it takes to fill the 100-ml graduated cylinder is consistent. We repeat the test a third time to ensure a consistent water flow rate. When the time it takes to fill the 100ml graduated cylinder becomes more consistent we begin our experiment in the TPV chamber. We put a tint of copper in the blackbody emitter which has a melting point of 1085 degree Celsius. We collect data on the pressure, Voltage, Current power, Emitter mount temperature, Pyrometer, Copper base, Temperature of Water in, and Temperature of water out when we begin the experiment on the TPV chamber at base pressure. We collect data when the copper melts on the blackbody emitter. We heat the blackbody emitter ideally to 1200 degree Celsius. After the copper melts, we collect data on the pressure, Voltage, Current power, Emitter mount temperature, Pyrometer, Copper base, Temperature of Water in, and Temperature of water out, at every minute for the next length of minutes we conduct the experiment. The equation of the power absorbed is calculated using the formula $\frac{dQ}{dt} = \frac{dm}{dt} C_p (T_{out} - T_{in})$, C_p is the specific heat of water, T_{out} is the temperature out of the chamber, T_{in} is the temperature in the chamber, $\frac{dm}{dt}$ is the water flow rate. We obtain the power absorbed below.

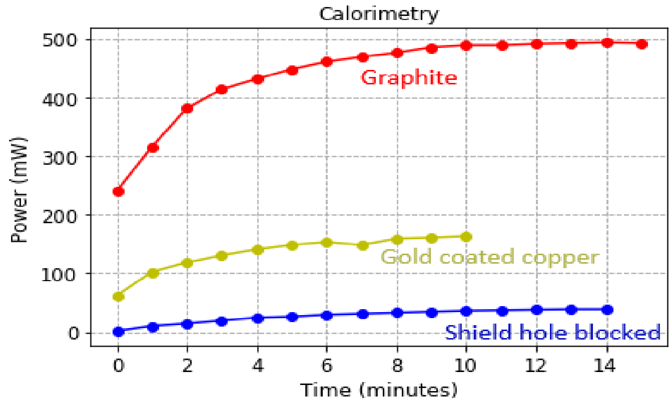


Fig 3. Calorimetry using materials with different thermal conductivity

Calorimetry allows us to understand how much energy will be absorbed by the photovoltaic cell. Coating the copper with gold to substitute for the photovoltaic cell for a calorimetry test allows us to understand how heat is exchanged with the surroundings, which we compare with graphite in place of the photovoltaic cell. Calorimetry experiments are done before conducting experiments with the actual photovoltaic cell to observe the effects of heat in the thermophotovoltaic chamber. Ideally with the shield block we would expect zero reading power out of the calorimeter. The calorimetry reading was not zero, this means we have a source of excess heat in our calorimeter. Further experiments will be conducted with calorimetry for adequate calibration or finding the source of excess heat.

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[5] In this paper, we learn the concept of a TPV system and how reflectivity can have a significant effect on the thermophotovoltaic efficiency. We also learn the derivation of efficiency calculation in thermophotovoltaics similar to the TPV system we use. https://arxiv.org/pdf/1611.03544.pdf