# Ultra High Efficiency Thermo-Photovoltaic Solar Cells Using Metallic Photonic Crystals As Intermediate Absorber and Emitter

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## B. Abstract

Our team aims to combine large-scale numerical simulations, with nanofabrication and characterization to develop the efficient intermediate absorbers and emitters that enable high efficiency solar thermo-photovolatic systems. In this year, continued progress has been made in developing designs that enable high efficiency TPV cells, as well as in experimental setup for fabricating and measuring of such devices.

## C. Introduction

Thermal Photovoltaic (TPV) solar cells, where solar radiation is absorbed by an intermediate, which then emits thermal radiation towards a solar cell, is capable of achieving an extremely high efficiency using single-junction solar cells. The theoretical efficiency of 85% far exceeds the Shockley-Queisser limit. In order to approach such efficiency, however, there are very important constraints on the properties of the intermediate absorber and emitter. Until now, there is no known way to meet the requirements on the intermediate that are needed in order to reach efficiency beyond 30%.

The aim of our project is to exploit emerging opportunities in the area of nanophotonic structures such as photonic crystals for TPV applications. It has been recently shown that both the absorption and thermal emission properties of nanophotonic structure can be tailored with appropriate design. Here, we aim to show that such structures can indeed be designed to enable ultra-high efficiency TPV solar cells. Specifically, we will demonstrate that crystal structures can be produced with low-cost self-assembly fabrication techniques using abundant materials such as Tungsten, that the crystals can provide broad-band absorption over the entire solar spectrum, and that the intermediate can be designed to enhance overall cell efficiency.

## D. Background

This project builds upon significant expertise and previous accomplishments that this group has in the design of nanophotonic structures (Fan), low-cost fabrication techniques (Braun).

## E. Results

### E.1. Experimental Demonstration of Solar-Selective Absorbers

We have set up a vacuum emissometer capable of measuring thermal emission properties of nanophotonic structures at elevated temperatures (see Fig 1.). We have optimized, fabricated and tested multilayer-dielectric stacks as solar-selective coatings for the intermediate absorbers in TPV systems. These stacks were designed to have high solar absorptivity while maintaining low spectral emissivity in the NIR and IR, thus suppressing low-energy thermal emission.

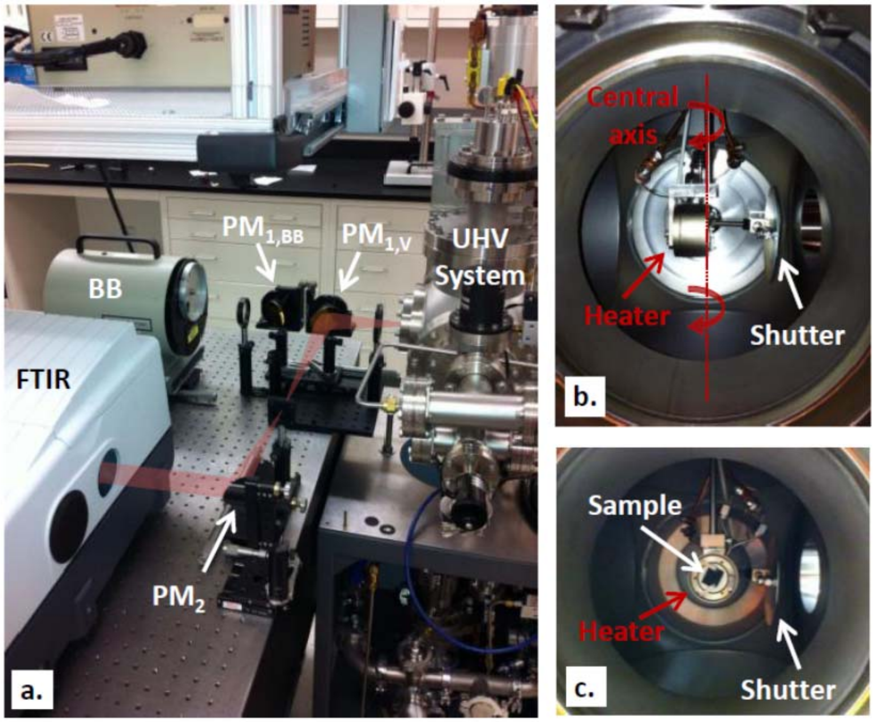

Figure 1. Pictures of the custom built vacuum emissometer. a) External imaging and collimating optics towards entry port of FTIR spectrometer. The configuration is shown for collection from the vacuum emissometer side. (b) High temperature heater centered in vacuum chamber (Viewed from loading door). (c) High temperature heater inside vacuum chamber rotated 90 degrees towards camera (Viewed from loading door).

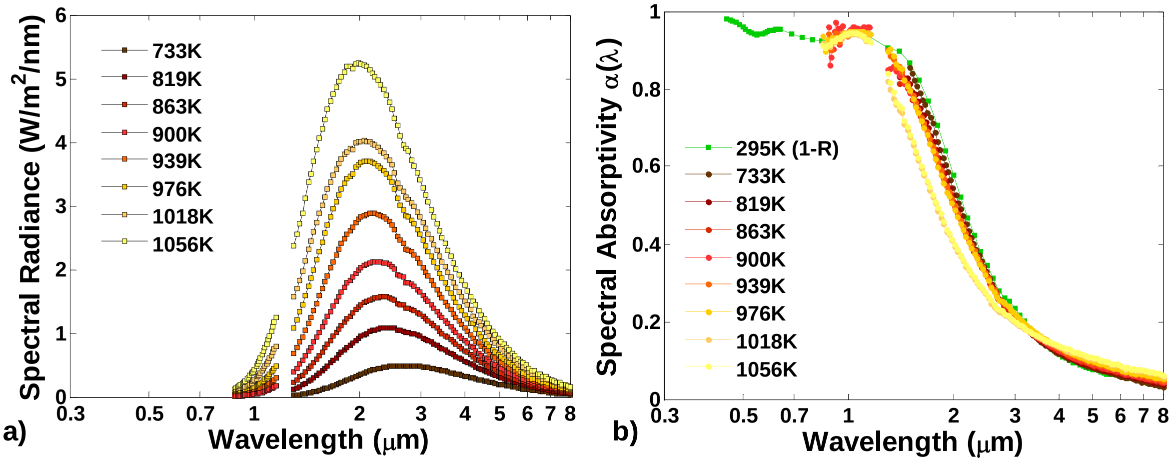

Figure 2. (a) Vacuum emissometer measurement of the spectral radiance of an aperiodic 5-layer coating at various temperatures. (b) Spectral directional absorptivity (emissivity) at normal incidence for the aperiodic 5-layer coating measured at various temperatures and compared to the indirect radiometric measurement (1-R), at room temperature (295K).

The experimental results for the multilayer-dielectric stacks are shown in Figure 2. Excellent spectral-selectivity was measured, with absorptance surpassing 90% within the solar frequency range, and emissivity dropping below 20% outside the solar frequency range. These measured results hold for a wide range of temperatures, thus demonstrating the robust optical properties of the multilayer stack under high temperatures. In addition, the coatings show thermal stability up to 1056K.

## E.2. Experimental Demonstration of Selective TPV emitters

We have optimized multilayer-dielectric stacks as selective intermediate emitters for TPV systems. These stacks were designed to have high spectral emission above the bandgap of a Ge TPV diode (0.667eV), while limiting thermalization losses in the TPV diode and suppressing below-bandgap thermal emission. These multilayer stacks are predicted to have spectral efficiency above 60%, which would lead to TPV conversion efficiency of up to 16.7%, using a Ge TPV diode (L=4). The modeling results are shown in Figure 3.

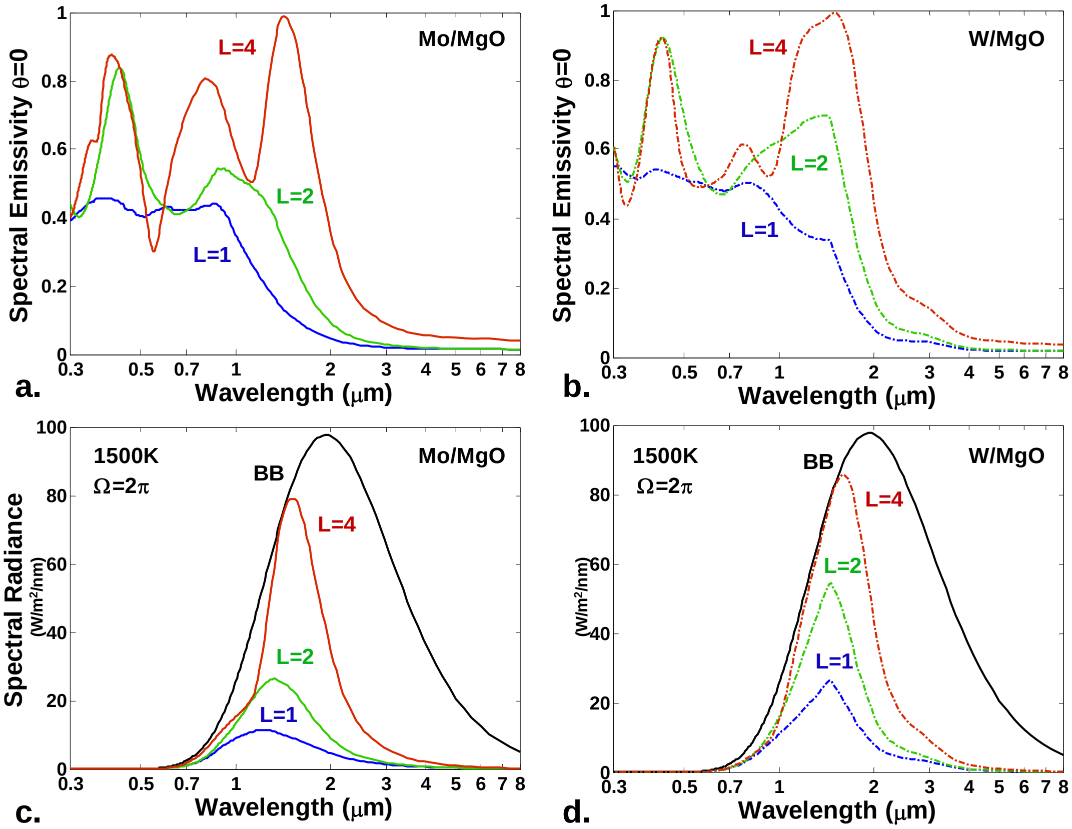

Figure 3. (a-b) Modeled spectral emissivity and (c-d) modeled spectral radiance of multilayer metal-dielectric stacks as selective emitters for the intermediate in a TPV system. The stacks are composed of (a,c) MgO/Mo or (b,d) MgO/W. The optimized designs are shown for a fixed number of layers L, varying from L=1 (bulk metal) to L=4 layers.

We have also fabricated and tested multilayer metal-dielectric stacks for selective emitters in TPV systems. The experimental results based on an indirect radiometric reflection measurement are shown in Figure 4. Excellent agreement is obtained between the theoretical and experimental demonstration. The EQE of a Ge diode optimized for use in TPV systems is shown for comparison in Figure 4 [1-2]. In combination with the Ge diode, this selective emitter would achieve TPV conversion efficiency up to 13.3%.

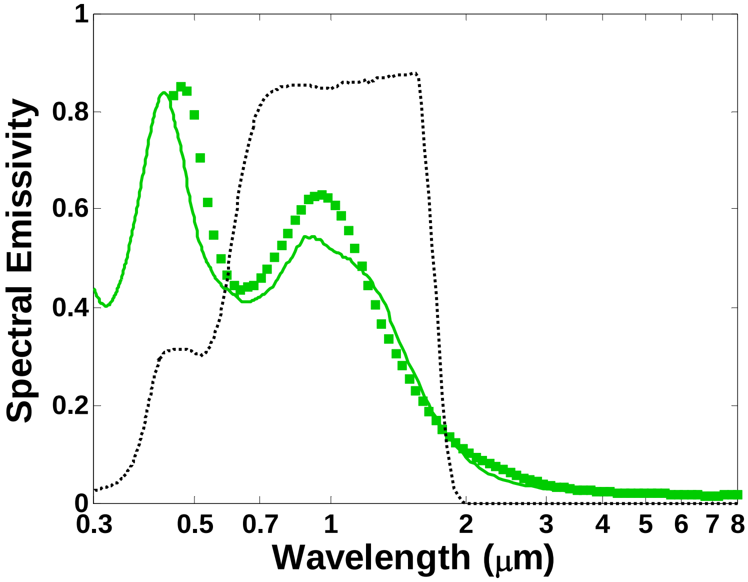

Figure 4. (a-b) Modeled (full) and measured (squares) spectral emissivity of a multilayer metal-dielectric stack (L=2) as selective emitters for the intermediate in a TPV system. The stacks is composed of a thin layer of MgO on top of Mo. The EQE of a Ge TPV diode is shown for comparison.

## F. Progress and future plans

The team plans to further improve the fabrication processes and measurements of the optical properties of nanostructured surfaces at high temperature. The team will then start assembling these materials and coatings into practical TPV devices.

## G. Publications

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## H. Contacts

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## I. References

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[2] J. van der Heide, \Cost-e_cient thermophotovoltaic cells based on germanium," Ph.D. Thesis, Department of Electrical Engineering (ESAT), KULeuven, Belgium (2009).