Moderate Temperature (300-500°C) Thermophotovoltaics

Improving Efficiency Using Anti-Reflective Coatings and Chemical Etching

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Introduction and Motivation

- Thermophotovoltaic (TPV) systems are static energy converters that convert waste thermal radiation into electricity by means of a photovoltaic (PV) cell.
- TPV systems include a high temperature source, an absorber/emitter infrared photon filter, and a PV cell.
- For ubiquitous use of TPV systems, system performance needs to be optimized at 300-500°C, where commercial ovens, furnaces, and other common waste heat sources operate at.
- This work focuses on the Absorber/Emitter portion of the TPV system, and investigates the use of 1D Photonic Crystals (PhC) and chemically etched nanostructures to improve the system efficiency.

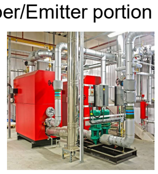

Fig. 2: Commercial heating system

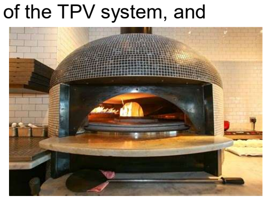

Fig. 3: Pizza oven at a pizzeria

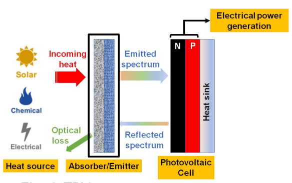

Fig. 1: TPV system structure

Fig. 4: Steel production line cooling zone

Experimental Setup

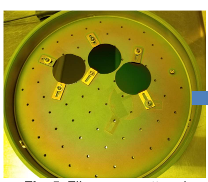

Fig. 5: Films are sputtered onto wafers

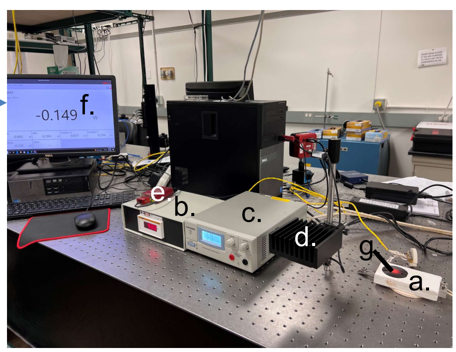

Fig. 6: Experimental setup for measuring system efficiency. The wafer (g) is placed on the HeatPad (a) with the film facing the heat source. The optical power monitor (d) is positioned above the wafer (**Fig. 7**) and sends data to the computer running Thorlabs Optical Power Monitor software (f) through the USB interface (e). The DC current source (c) powers the HeatPad, and the Temperature Indicator (b) displays the HeatPad temperature.

Components in experimental setup

a. Gen2-1.0 HeatPad
b. MHI TC-READ-110V Temperature Indicator
c. TekPower TP3030E DC Current Source, constant current mode
d. Thorlabs S442C Optical Power Monitor
e. PM102U thermal sensor interface (connects the optical power monitor to the computer for data collection
f. Thorlabs Optical Power Monitor measurement software
g. Wafer to be measured, film face down

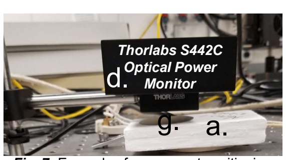

Fig. 7: Example of component positioning during measurements

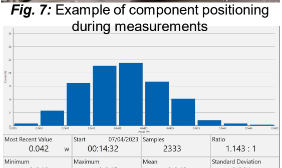

Fig. 9: Optical Power Monitor software (f). After stabilization, 10s of data is recorded.

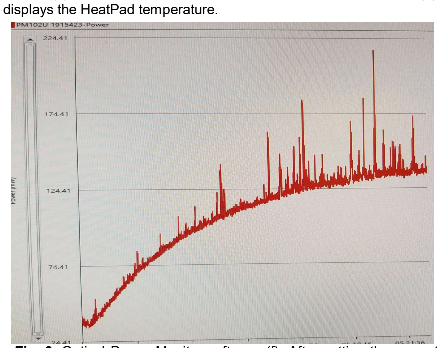

Fig. 8: Optical Power Monitor software (f). After setting the current on (c.), the temperature and power output stabilize after ~30 minutes.

Acknowledgements

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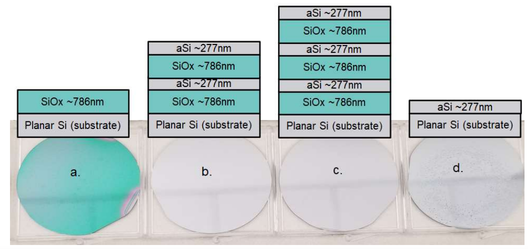
Early Results



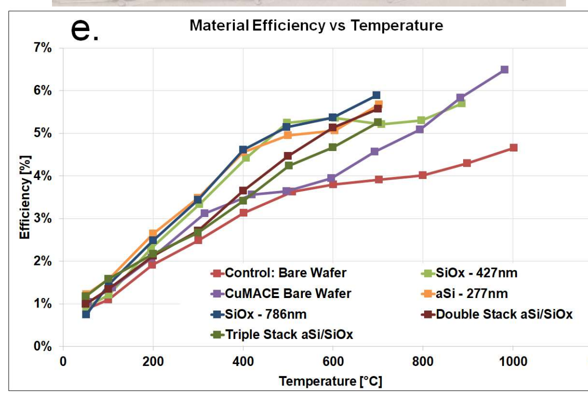


Fig. 9: (a-d) Four examples of 1D PhC design investigated. (e) Efficiency at different temperatures plotted. The control, an out-of-the-box, 275 micron, single-side polished Si wafer has the lowest efficiency. In the 300-500°C range, the single layer 786nm SiOx film, single layer 427nm film, and single layer 277nm aSi film, outperform the others. For all samples, efficiency increases with increasing temperature.

- **TPV system efficiencies demonstrated in this work are some of the highest observed for the 300-500°C temperature range.**
- A July 2021 Nature paper[1] demonstrates maximum efficiencies of 1.1% at 537°C, 3% at 657°C, and 5.9% at 777°C
- A January 2020 ACS Photonics paper[2] reports an efficiency of 11.2% at 1065°C, but drops to 1% by 700°C, and drops further by 500°C.
- In 2015, a group used nanostructures in a solar TPV system[3], but demonstrated only 2.2% at 750°C, and 3.8% at 1000°C
- In 2013, a group used Si and SiO2 1D photonic crystals[4], but demonstrated <2.5% efficiency below 600°C

Conclusions

- Single layer quarter-wavelength anti-reflective coatings dramatically increase the efficiency of the absorber within the region of interest (1.48% absolute, 47.3% relative increase at 400°C)
- Copper metal assisted chemical etching (CuMACE) can improve absorber performance within the region of interest (0.5% absolute, 13.7% relative increase at 400°C)
- Assuming an additive effect of CuMACE and thin films (future work), this would result in a dramatic improvement in efficiency (1.98% absolute, 61% relative increase at 400°C)

Future Work

- Investigate effects of combining CuMACE with thin dielectric films that form 1D photonic crystals
- Investigate alternate multi-layer stack structures that can improve system efficiency

References

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4. W.R. Chan et al., "Toward high-energy-density, high-efficiency, and moderate-temperature chip-scale thermophotovoltaics", Proc. Natl. Acad. Sci. U.S.A., 110 (2013), p. 5309