Thermophotovoltaic Back-Mirrored Cells as Spectral Filters

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Abstract:
The thermophotovoltaic cells convert thermal radiation from local 1500-1800 K hot sources to electricity. Obstacles to efficient photovoltaic energy conversion include sub-bandgap photon loss, carriers from high-energy photons thermalizing to the band edge, and low external luminescent efficiency. We propose that single-bandgap thermophotovoltaic cells can surpass the 23.8% efficiency record through the use of spectrum-appropriate semiconductors and a reflecting back mirror. Indium-gallium-arsenide (InGaAs) cells have a 0.74 eV bandgap optimal for spectral filtering at thermal radiation energies. Adding a gold back mirror to the cell reduces sub-bandgap photon loss, and increases operating power by boosting the external luminescent efficiency.

Background:

Semiconductor Thermophotovoltaics

Fig. 1: Thermophotovoltaic Semiconductor Technology for 1500-1800 K sources

Absorption and Loss:
- Bandgap energy: energy difference between the valence and conduction bands

Fig. 2: Thermophotovoltaic power losses from a blackbody emitter as determined by semiconductor bandgap

Thermophotovoltaic Losses

Fig. 3: Semiconductor absorption and losses as dependent on incident photon energy

Benefits of a High-Reflectivity Back-Mirror:

Fig. 4: Diagram of a high-reflectivity back-mirrored cell functioning as a spectral filter and accompanying black body curve recycling plot

Fig. 5: Effects of a high-reflectivity back-mirror on the cell photon concentration and resulting power output increase

Experimental Setup:

Efficiency Calculation:

 unfolds measured-\$V\$ curve

Sub-bandgap Loss (85\%)

Photon energy (eV)

Power (mW/cm² x eV)

0

0.2

0.4

0.6

0.8

1.2

Photovoltaic power from measured-V curve

Blackbody spectrum (1500 K)

-0.74 eV

Absorbed

Recycled power (85\%)

Fig. 6: Experimental setup of the power measurement

Vacuum Chamber

Wire Bonds

Cell Leads

Substrate at 293 K

Aluminum Mount

Water-Cooled Heat Sink

Pyrometer Channel

1500 K Graphite Hot Source

InGaAs Cells with High-Reflectivity Back Mirror

Source Current Leads

Experimental Work:

Results and Future Work:

Fig. 7: Reflectivity of the InGaAs Cell

Fig. 8: Efficiency of the InGaAs Cell

Example Application:

Photovoltaic Cells Lining Inner Chamber

Thermal Heat Reaction Chamber

Advanced Recuperator Manifold

Fuel

Air

Thermal Radiation

Dollar Bill for Scale

Fig. 9: Diagram of a thermophotovoltaic water heater and power source

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References