Photon-Enhanced Thermionic Emission for Concentrated Solar

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Photovoltaic Cells: Quantum-Based Conversion
Photovoltaic Cells: Quantum-Based Conversion

Absorption

Thermalization lost as heat

Charge extraction

Absorption
Solar Thermal: Classical Conversion

- Solar radiation as heat source
- High energy photons down-converted

5800° C

800° C

T_{\text{Sun}}

T_{\text{Hot}}

Heat Engine

Electrical Power

T_{\text{Cool}}

Power

Wavelength (nm)
Combined HT-PV/Solar Thermal?

- Backing thermal cycle harvests waste heat from high-temperature photovoltaic

Concentrated sunlight → photo-electricity → waste heat → thermo-electricity
Two devices with modest performance combine to form a very high efficiency device.

But photovoltaics lose efficiency at high temperature.

- **Combined HT-PV/Solar Thermal?**

  - **5800°C**
  - **600°C**

  - **Photo-electricity**
    - $\eta \sim 25\%$
    - $100\% \times (25\%) = 25\%$

  - **Thermo-electricity**
    - $\eta \sim 25\%$
    - $75\% \times (25\%) = 19\%$

  - **Total**: 44\%
Thermionic Emission

TOPAZ Satellite (circa 1980’s)

Nuclear decay-fueled, 5-10 kW power source for satellites or deep space missions

Test at NASA Marshall Space Flight Center

Thermally generated electrons

Solar Testing (circa 2005)
Thermionic Emission

- Work functions are too large
Photovoltaic + thermionic effect

Higher voltage at same temperature and current than in thermionic emission

PV-like efficiency at high temperatures: excess energy no longer “waste heat”
Theoretical Efficiency

- $\phi_A = 0.9 \text{ eV}$
  - [Koeck, Nemanich, Lazea, & Haenen 2009]
- $T_A \leq 300^\circ \text{C}$
- Detailed-balance limited recombination in cathode

Theoretical Efficiency

- **31.5%** Thermal to electricity conversion [Mills, Morrison & Le Lievre 2004]
- **285°C** Anode temperature [Mills, Le Lievre, & Morrison 2004]

From idea to ...

- Photon Absorption
- Surface Stability
- Surface Recombination

Surface Recombination

- High recombination velocity (~$10^6$ cm/s) in typical cathode materials
- Requirements on emissive surface of a PETE cathode can be difficult to simultaneously optimize at a single interface
“Emitter” between absorber and vacuum
Two interfaces

- Buried interface for PETE: optimized energy barrier and low recombination
- Vacuum interface: optimized for efficient emission into vacuum
Heterostructure Cathode

- Samples grown by Tomas Sarmiento
  - Student of Prof. James Harris at Stanford

- Absorber: GaAs 1 µm
  - $E_{g,\text{GaAs}} = 1.42\text{eV}$

- Emitter: Al$_{0.15}$Ga$_{0.85}$As 70 nm
  - $\Delta E_{CB} \approx \Delta E_{g} \approx 0.22\text{eV}$
Experimental Set-up

- Cs(-O) to lower the workfunction
- Quantum efficiency measurements (electrons out/photons in)
  - Incident photon energy
  - Sample temperature
Photon-Energy Dependence
Temperature Dependence

Improved yield from $10^{-4}$ to 1-2%!
Outlook

- Surface Recombination
- Photon Absorption
- Surface Stability
  - 5-10x predicted improvement from the same material!
Summary

- Combined cycles for high efficiency
- PETE for high-temperature solar
- Identified three key barriers to efficient PETE devices, creating exciting opportunities for rapid improvements in efficiency

Posters:
- **#14** Jared Schwede, “Photon-Enhanced Thermionic Emission for Concentrated Solar”
- **#16** Daniel Riley, “Optimization and Characterization of Nanostructured Surfaces for Photon-Enhanced Thermionic Emission and Photoemission Cathodes”
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