Review of Lecture 9

- Solar hot water systems
- Maximum solar concentration
- Methods for concentration
- Nontracking and tracking
- Solar thermal-mechanical energy conversion
- EM wave calculation of surface properties
Review of Lecture 10

By C. Schuh

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Review of Lecture 11
By I. Celanovic

TEM cross section of LPCVD® grown quarter-wave stack filter with half-layer at the top

Prototype 1
Sample area: ~175nm²
Period: 1000nm
Hole diameter: 610nm
Hole depth: 550nm
Wall aspect ratio: 0.05

Prototype 2
Sample area: ~175nm²
Period: 1000nm
Hole diameter: 820nm
Hole depth: 315nm
Wall aspect ratio: 0.09

Prototype 3
Sample area: ~225nm²
Period: 1000nm
Hole diameter: 720nm
Hole depth: 600nm
Wall aspect ratio: 0.04

Photons
Heat

Electrical Output
Waste Heat

Courtesy of Ivan Celanovic. Used with permission.
Lecture 12  Solid-State Solar-Thermal Energy Conversion

- Solar thermophovoltaics
- Solar thermophotonics
- Solar thermoelectrics
Shockley-Queisser Limit of Solar Cells (Lec.7)

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Please see Fig. 3 in Henry, C. H. "Limiting Efficiencies of Ideal Single and Multiple Energy Gap Terrestrial Solar Cells." *Journal of Applied Physics* 51 (August 1980): 4494-4500.

Where is energy lost?

For $E_g = 1$ eV

- Energy below the gap: 20%
- Average photon energy above gap: 1.9 eV
- Chemical potential: 0.7 eV

$$\eta = 0.8 \times \frac{1eV}{1.9eV} \times \frac{0.7eV}{1eV} = 0.3$$
Solar Thermophotovoltaics

(a) Solar Insolation

(b) Selective Absorber

(c) Selective Emitter

(d) Irradiance From Emitter

TPV Cell

Optical Concentrator

Absorber

Emitter

Emissivity

Absorptance

Thermal Management

Power (W/m²μm)

Energy Conversion
Maximum Efficiency of a Solar Thermal Engine (Lec.8)

Heat Transferred to Absorber

\[ Q_h = \sigma(T_s^4 - T^4) \]

Thermal Efficiency

\[ \eta_{th} = \frac{\sigma(T_s^4 - T^4)}{\sigma T_s^4} = 1 - \frac{T^4}{T_s^4} \]

Carnot Efficiency

\[ \eta = 1 - \frac{T_a}{T} \]
Maximum Efficiency of a Solar Thermal Engine (Lec.8)

\[
\eta = \eta_{th} \eta_C = \left(1 - \frac{T^4}{T_s^4}\right) \left(1 - \frac{T_a}{T}\right)
\]

Maximum: 85% @ T=2450K
For \(T_a=300\) K
Problems

- Needs very narrow bandwidth to achieve Carnot efficiency solar cells.
- Solar absorption and radiation from absorber does not balance at 2450 K.
- Difficult to operate at 2450 K.
- Ideal selective surfaces do not exist.
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Please see Fig. 1, 3, 4 in Würfel, Peter, and Wolfgang Ruppel.
"Upper Limit of Thermophotovoltaic Solar-Energy Conversion."
Wuerfel and Ruppel Analysis – Selective Absorber

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Please see Fig. 6 and 7 in Würfel, Peter, and Wolfgang Ruppel.
"Upper Limit of Thermophotovoltaic Solar-Energy Conversion."

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Please see Fig. 9-11 in Würfel, Peter, and Wolfgang Ruppel.
"Upper Limit of Thermophotovoltaic Solar-Energy Conversion."

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Optimal Bandgap & Temperature

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Please see Fig. 5 in Tobias, I., and A. Luque.
"Ideal Efficiency and Potential of Solar Thermophotonic Converters Under Optically and Thermally Concentrated Power Flux."

Andreev et al.,

Courtesy of Viacheslav Andreev. Used with permission.
Some Examples

GaSb Cell

pvlab.ioffe.ru/technology/tpv.html

Courtesy of Viacheslav Andreev. Used with permission.
Solar Thermophotonics

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Please see Fig. 1 in Tobias, I., and A. Luque.
"Ideal Efficiency and Potential of Solar Thermophotonic
Converters Under Optically and Thermally Concentrated Power Flux."

TPH---Monochromatic Limit

\[
\frac{i_{EMI}(v, T, E_G, E_{SUP})}{q} = \frac{2\pi A}{\hbar^3 c^2} \int_{E_G}^{E_{SUP}} \frac{E^2 dE}{\exp \left( \frac{E - qv}{kT} \right) - 1}
\]

(1)

\[
i_{CEL} = i_{LED} = i = \frac{2q\pi A}{\hbar^3 c^2} \left( \frac{E_G^2}{\exp \left( \frac{E_G - qv_{LED}}{kT_{LED}} \right) - 1} \right)
\]

\(- \frac{E_G^2}{\exp \left( \frac{E_G - qv_{CEL}}{kT_{CEL}} \right) - 1} \right) \Delta E = \frac{qPRAD}{E_G}
\]

(8)

\[
i = 0 \Rightarrow \frac{E_G - qv_{LED}}{kT_{LED}} = \frac{E_G - qv_{CEL}}{kT_{CEL}} \Rightarrow v_{CEL}
\]

\[
\eta_{TPH} = \frac{(v_{CEL} - v_{LED})i}{p_{RAD} - v_{LED}i} = \frac{v_{CEL} - v_{LED}}{E_G/q - v_{LED}} = 1 - \frac{T_{cell}}{T_{LED}}
\]
STPH---No Filter

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Please see Fig. 3 in Tobias, I., and A. Luque.
"Ideal Efficiency and Potential of Solar Thermophotonic
Converters Under Optically and Thermally Concentrated Power Flux."
STPH---With Filter

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Please see Fig. 4 in Tobias, I., and A. Luque.
"Ideal Efficiency and Potential of Solar Thermophotonic Converters Under Optically and Thermally Concentrated Power Flux."
Solar Thermoelectrics

- US Patent No. 389124: E. Weston in 1888
- M. Telkes, JAP, 765, 1954

Efficiency: 0.63%

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Please see Fig. 6 in Telkes, Maria. "Solar Thermoelectric Generators." Journal of Applied Physics 25 (June 1954): 765-777.
Solar Thermoelectrics
– Flat Panel Prototypes

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Please see Fig. 6 in Telkes, Maria. "Solar Thermoelectric Generators."
Solar Thermoelectric Generator
---Concentrated Prototypes

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Please see Fig. 3, 10 and Table III in Dent, C. L., and M. H. Cobble.
"A Solar Thermoelectric Generator Experiment and Analysis."
Proceedings of the International Conference on Thermoelectric Energy
Hybrid PV and TE

Solid-State Solar-Thermal Energy Conversion Center (S³TEC Center)

Gang Chen (Director)  http://s3tec.mit.edu/
Kraemer et al.
APL, June 2008

Courtesy of DOE/NREL, Credit - Beck Energy.

 Courtesy of NASA.
Two Configurations

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