

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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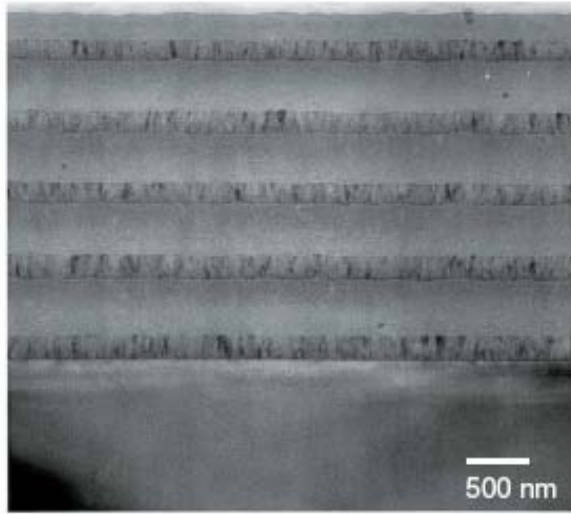
Please see Fig. 3.31 in Porter, David A., and
Kenneth E. Easterling. *Phase Transformations in
Metals and Alloys*. 2nd ed. New York, NY: Chapman & Hall, 1992.

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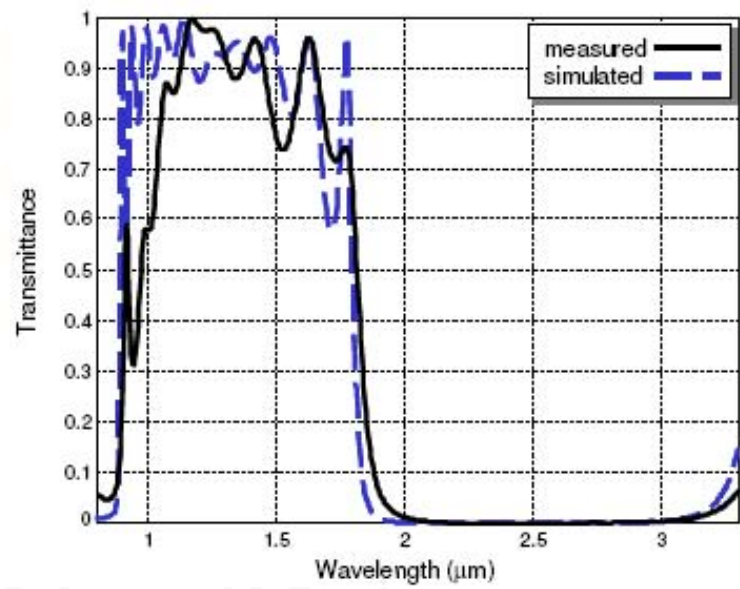
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Review of Lecture 11

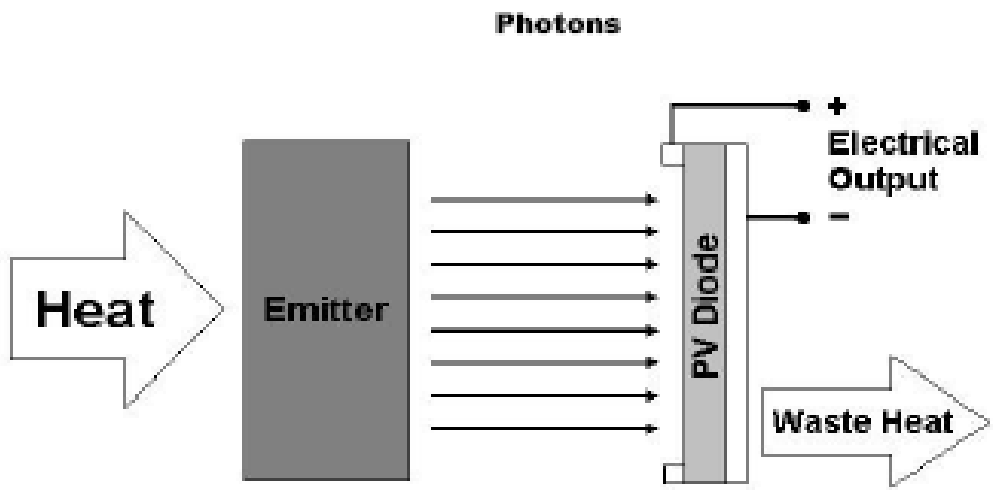
By I. Celanovic



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



	<p>Prototype 1 Sample area: ~175mm² Period: 1000nm Hole diameter: 910nm Hole depth: 550nm Wall aspect ratio: 0.05</p>
	<p>Prototype 2 Sample area: ~175mm² Period: 1000nm Hole diameter: 820nm Hole depth: 315nm Wall aspect ratio: 0.09</p>
	<p>Prototype 3 Sample area: ~225mm² Period: 1000nm Hole diameter: 720nm Hole depth: 600nm Wall aspect ratio: 0.04</p>



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Lecture 12 Solid-State Solar-Thermal Energy Conversion

- Solar thermophovoltaics
- Solar thermophotonics
- Solar thermoelectrics

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For 2.997 Direct Solar-Thermal to
Electrical Energy Conversion

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.

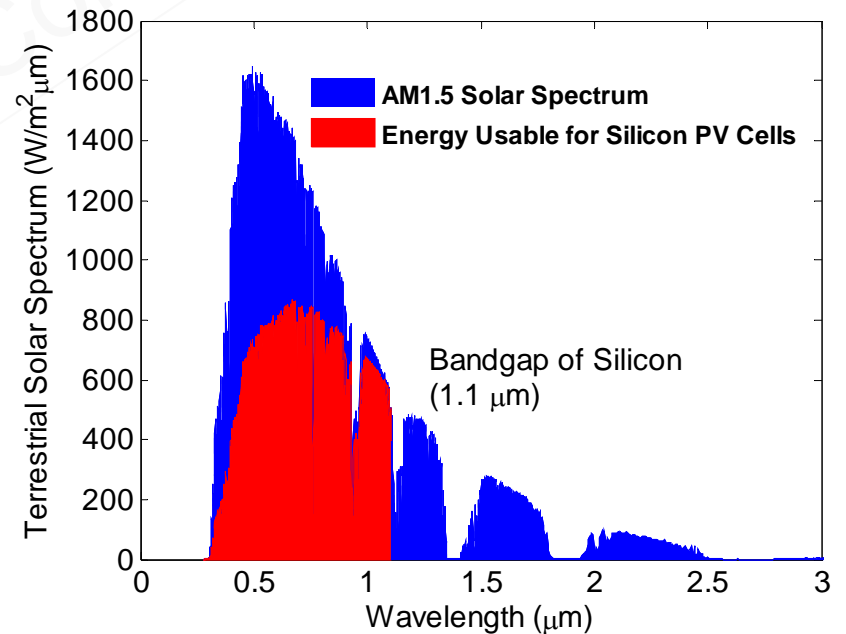
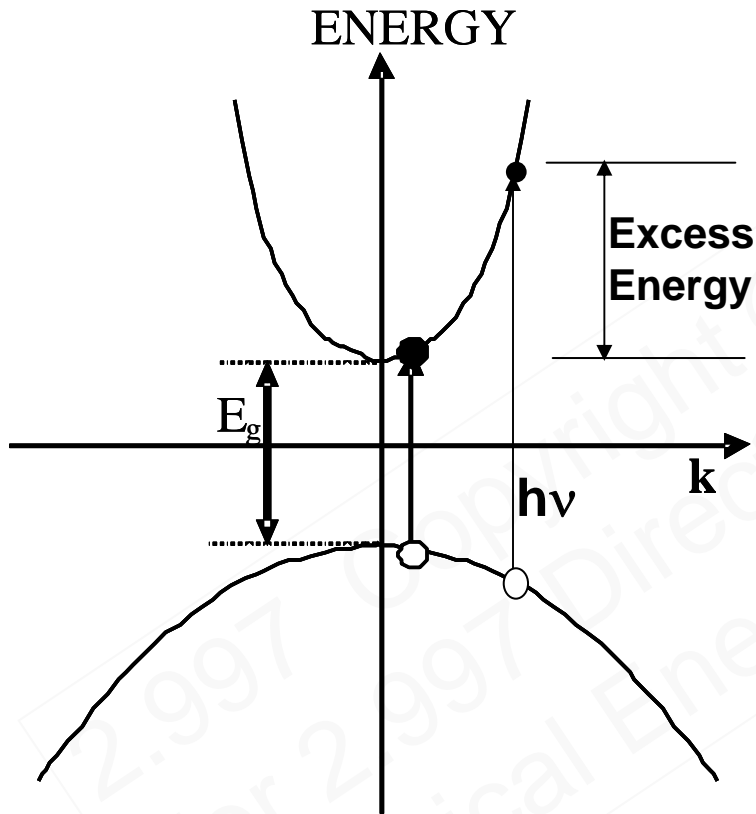
Shockley, W. and Queisser, H.J., *Journal of Applied Physics*, 32, 510 (1961).
Henry, C.H., *Journal of Applied Physics*, 51, 4494 (1980).

Where is energy lost?

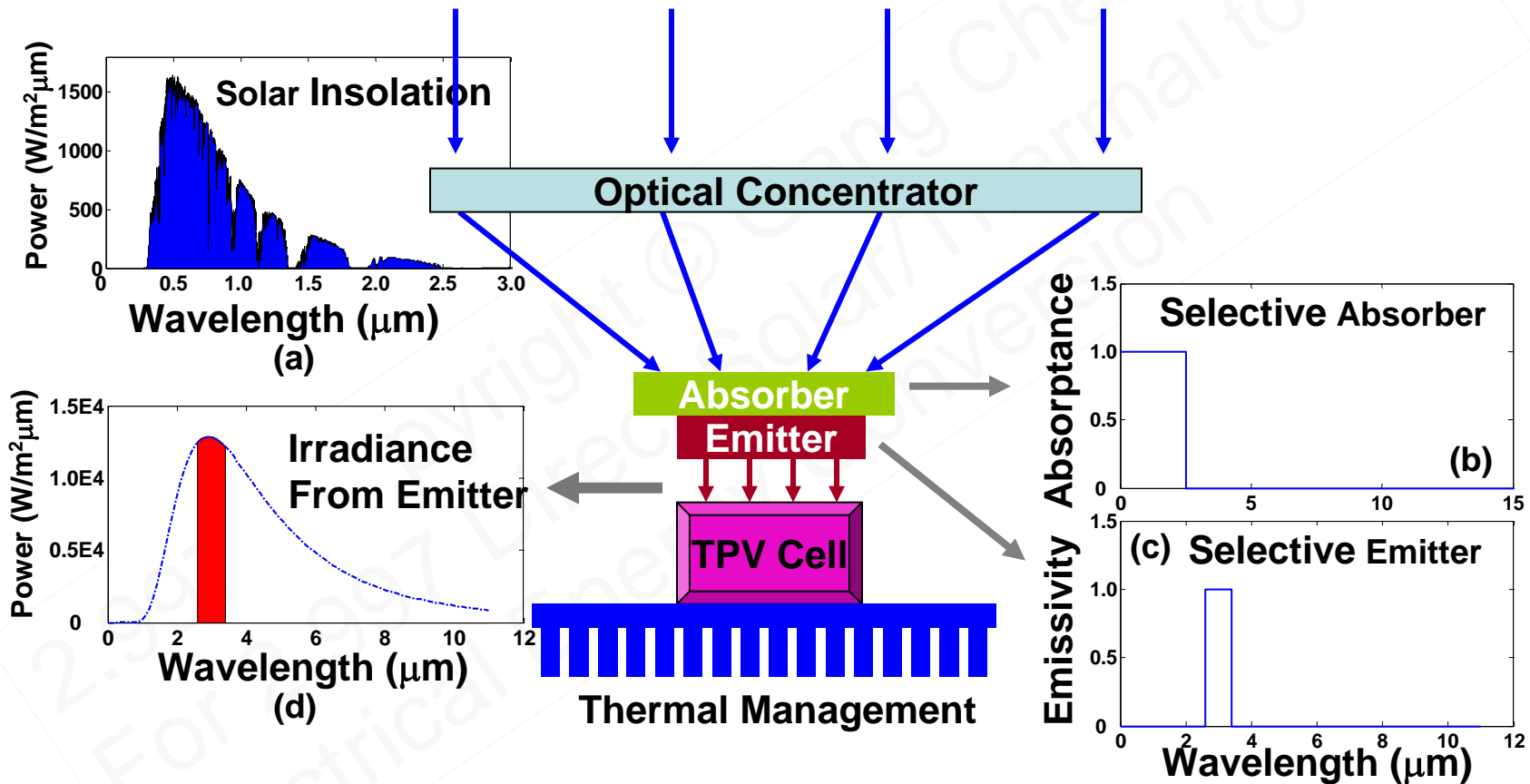
For $E_g=1$ eV

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

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



Solar Thermophotovoltaics



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

Blackbody At
Sun's
Temperature T_s

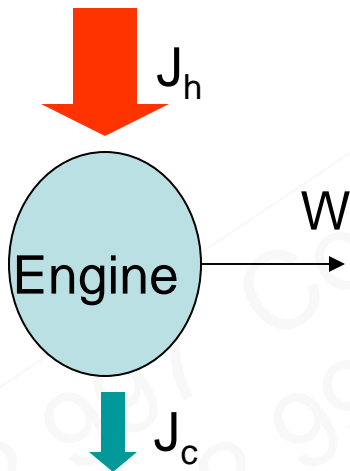
Heat Transferred to Absorber

$$Q_h = \sigma(T_s^4 - T^4)$$

Blackbody
Absorber at T

Thermal Efficiency

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



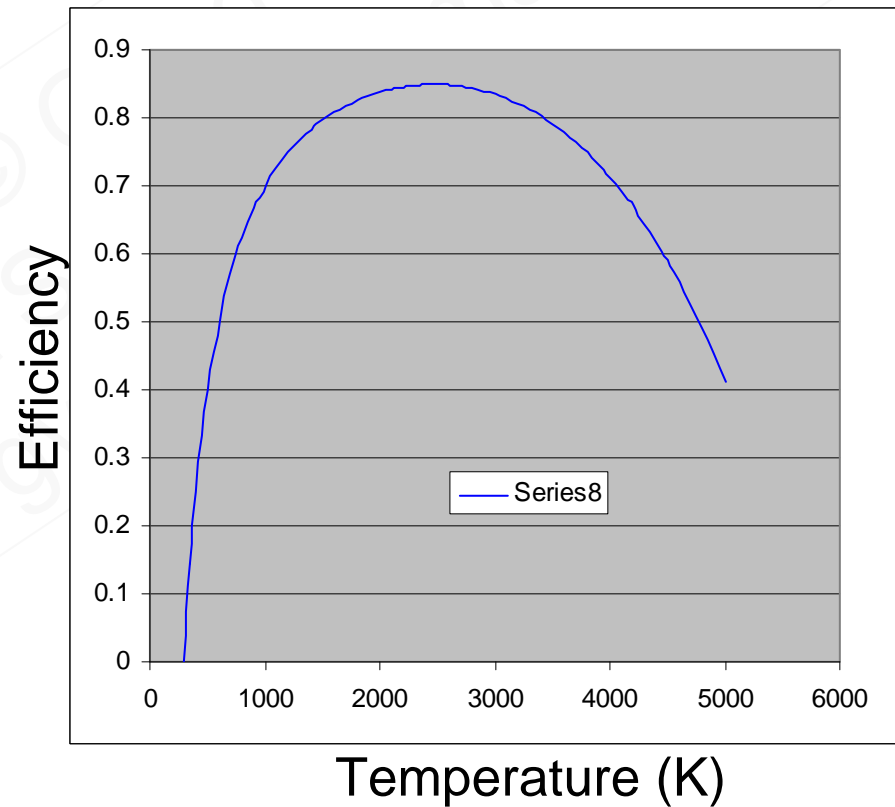
Carnot Efficiency

$$\eta = 1 - \frac{T_a}{T}$$

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.

Wuerfel and Ruppel Analysis – Black Absorber

Images removed due to copyright restrictions.

Please see Fig. 1, 3, 4 in Würfel, Peter, and Wolfgang Ruppel.

"Upper Limit of Thermophotovoltaic Solar-Energy Conversion."

IEEE Transactions on Electron Devices ED-27 (April 1980): 745-750.

Wuerfel and Ruppel, IEEE Trans. Elec. Devices, ED-27, 745, 1980

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."

IEEE Transactions on Electron Devices ED-27 (April 1980): 745-750.

Wuerfel and Ruppel, IEEE Trans. Elec. Devices, ED-27, 745, 1980

Wuerfel and Ruppel Analysis – Selective Absorber + Filter

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Please see Fig. 9-11 in Würfel, Peter, and Wolfgang Ruppel.

"Upper Limit of Thermophotovoltaic Solar-Energy Conversion."

IEEE Transactions on Electron Devices ED-27 (April 1980): 745-750.

Wuerfel and Ruppel, IEEE Trans. Elec. Devices, ED-27, 745, 1980

Optimal Bandgap & Temperature

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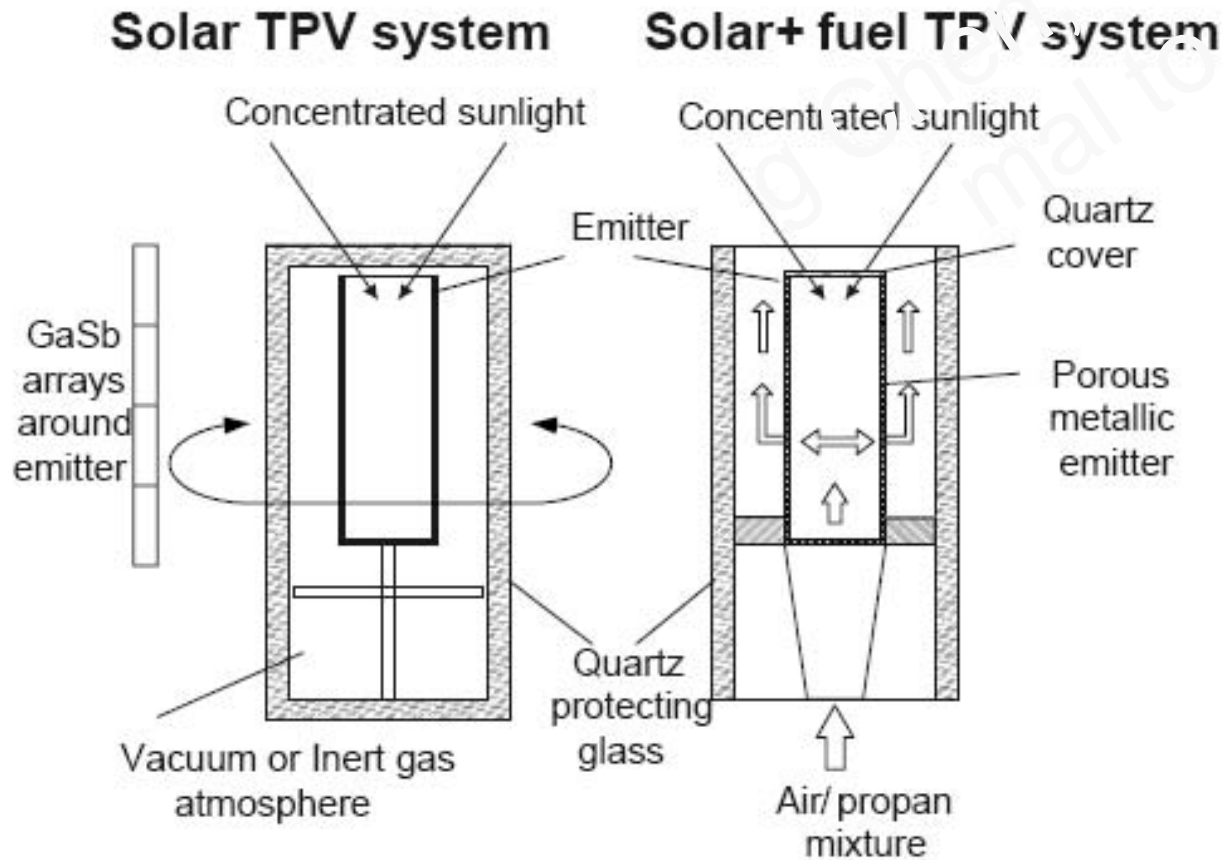
Please see Fig. 5 in Tobias, I., and A. Luque.

"Ideal Efficiency and Potential of Solar Thermophotonic
Converters Under Optically and Thermally Concentrated Power Flux."

IEEE Transactions on Electron Devices 49 (November 2002): 2024-2030.

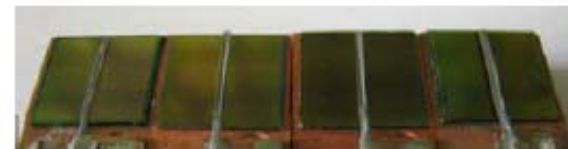
Tobias and Luque, IEEE Trans. Electron Dev. 49, 2024 (2002)

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."

IEEE Transactions on Electron Devices 49 (November 2002): 2024-2030.

Tobias and Luque, IEEE Trans. Electron Dev. 49, 2024 (2002)

TPH---Monochromatic Limit

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

$$i_{CEL} = i_{LED} = i = \frac{2q\pi A}{h^3 c^2} \left(\frac{E_G^2}{\exp\left(\frac{E_G - qv_{LED}}{kT_{LED}}\right) - 1} - \frac{E_G^2}{\exp\left(\frac{E_G - qv_{CEL}}{kT_{CEL}}\right) - 1} \right) \Delta E = \frac{qPRAD}{E_G} \quad (8)$$

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

$$\eta_{TPH} = \frac{(v_{CEL} - v_{LED})i}{PRAD - v_{LED}i} = \frac{v_{CEL} - v_{LED}}{E_G/q - v_{LED}} = 1 - \frac{T_{cell}}{T_{LED}}$$

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."

IEEE Transactions on Electron Devices 49 (November 2002): 2024-2030.

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STPH---With Filter

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Please see Fig. 4 in Tobias, I., and A. Luque.

"Ideal Efficiency and Potential of Solar Thermophotonic

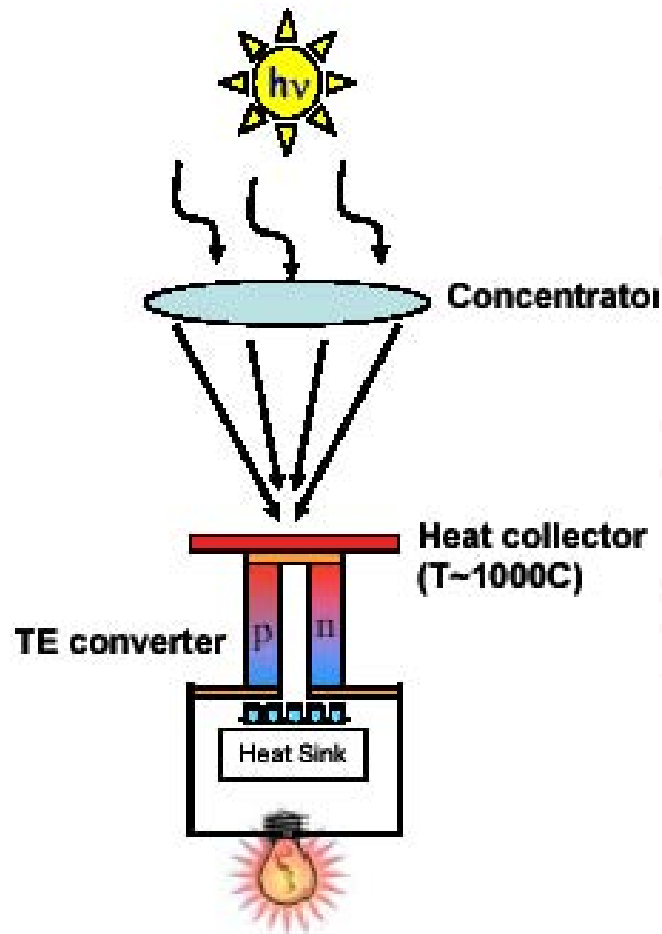
Converters Under Optically and Thermally Concentrated Power Flux."

IEEE Transactions on Electron Devices 49 (November 2002): 2024-2030.

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Solar Thermoelectrics



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

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Please see Fig. 6 in Telkes, Maria. "Solar Thermoelectric Generators."

Journal of Applied Physics 25 (June 1954): 765-777.

Efficiency: 0.63%

Solar Thermoelectrics – Flat Panel Prototypes

Image removed due to copyright restrictions.

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

Solar Thermoelectric Generator ---Concentrated Prototypes

Images and text removed due to copyright restrictions.

Please see Fig. 3, 10 and Table III in Dent, C. L., and M. H. Cobble.

"A Solar Thermoelectric Generator Experiment and Analysis."

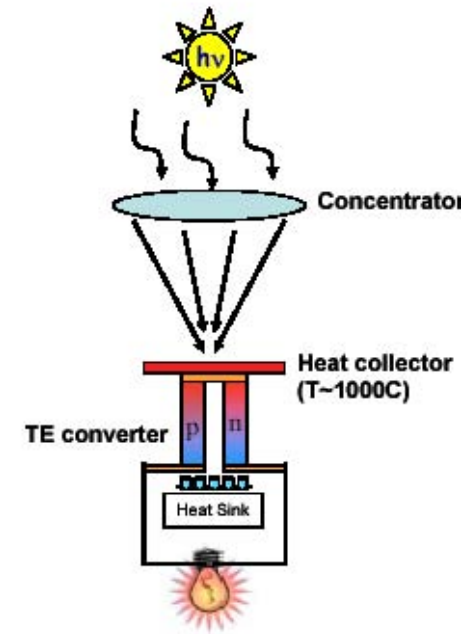
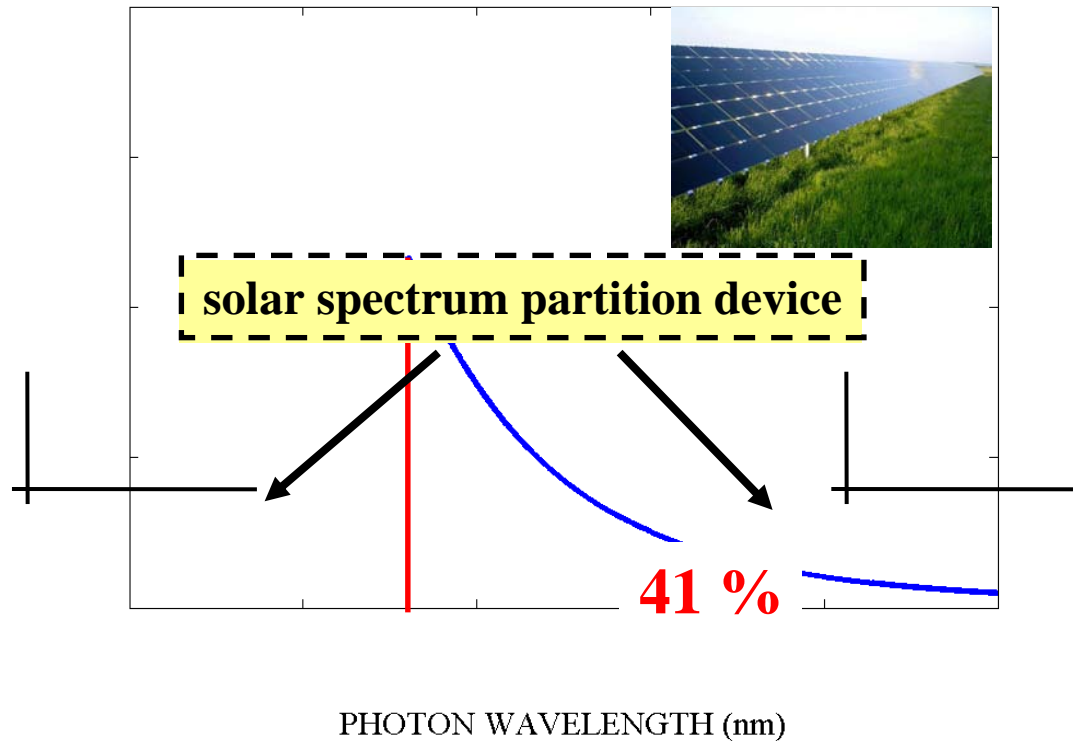
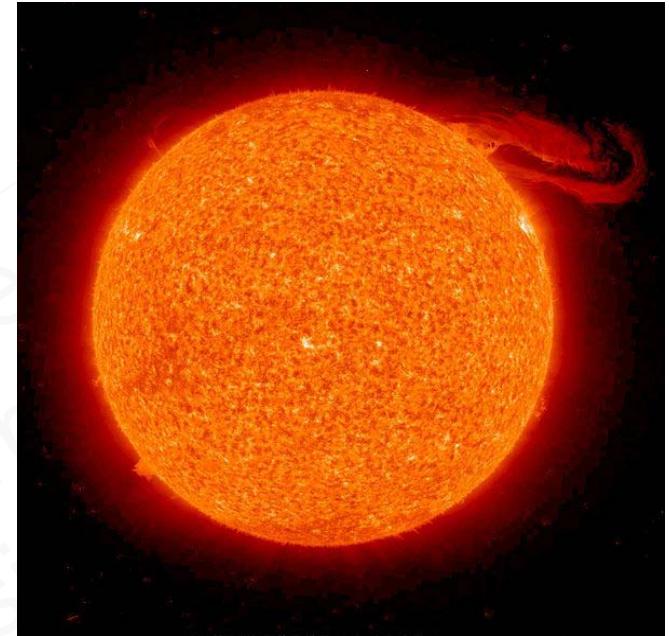
Proceedings of the International Conference on Thermoelectric Energy Conversion 4 (1982): 75-78.

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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Please see Fig. 1 in Vorobiev, Y. V., et al. "Analysis of Potential Conversion Efficiency of a Solar Hybrid System with a High-Temperature Stage." *Journal of Solar Energy Engineering* 128 (May 2006): 258-260.

Vorobiev et al., J. Solar Energy Eng., 128, 258, 2006.

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2.997 Direct Solar/Thermal to Electrical Energy Conversion Technologies
Fall 2009

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