Lecture 19: Thermodynamic model of photovoltaic energy conversion

Ideal photovoltaic solar energy converter:

- Absorbs all photons with $E > E_g$
- Emits like black body with chemical potential $\Delta\mu > 0$
- Every net absorbed photon → one electron in external circuit (QE = 1)
- Delivers power through flux of photogenerated electrons with $\Delta\mu > 0$ (c.f. $W = \mu dN$)

Analysis of ideal PV converter:

Emitted photon flux density by black body with $\Delta\mu > 0$: $b(E,T,\Delta\mu) \approx e^{\Delta\mu/kT} b(E,T,0)$

Conservation of particle flux: $j(E) = Xf_s b(E,T_{sun}) + (1 - Xf_s) b(E,T_p) - e^{\Delta\mu/kT} b(E,T_p)$

Net current density produced J:

$$\frac{1}{e}J = \int_{E_g}^{\infty} j(E)dE = Xf_s \int_{E_g}^{\infty} b(E,T_{sun})dE + (1 - Xf_s)\int_{E_g}^{\infty} b(E,T_p)dE - \int_{E_g}^{\infty} e^{\Delta\mu/kT} b(E,T_p)dE$$

$$J = J_{SC} - J_0\left(e^{eV/kT} - 1\right)$$

where output voltage is: $V = \Delta\mu / e$

Power produced: $P = \frac{J}{e}\Delta\mu = JV$

Power conversion efficiency: $\eta = \frac{JV}{Xf_s \sigma T_{sun}^{\ 4}}$

Quantum efficiency: $QE(E) = \frac{\text{electron flux density collected}}{\text{incident photon flux density}} = \frac{j(E)}{Xf_s b(E,T_{sun})}$

Performance of ideal solar photovoltaic converter:

For a given spectrum and intensity, performance is maximised at some optimum E_g
For unconcentrated blackbody sun (X = 1) η has maximum of 31% at E_g = 1.4 eV
Low efficiency results from poor match of broad solar spectrum to single energy E_g