Lecture 22: Practical photovoltaic solar energy conversion

Performance characteristics

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

Photocurrent J_{SC} depends on light intensity ($J_{SC} \propto X$) but not V
Dark current J_0 ($e^{eV/kT} - 1$) depends on V but not intensity

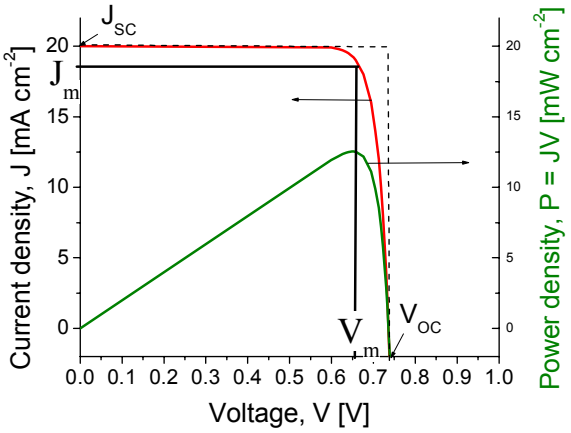
Short circuit current density $\mathbf{J_{SC}}$
Open circuit voltage $\mathbf{V_{OC}}$ [$J(V_{OC}) = 0$]

Maximum power point: V_m, J_m

Maximum power conversion efficiency

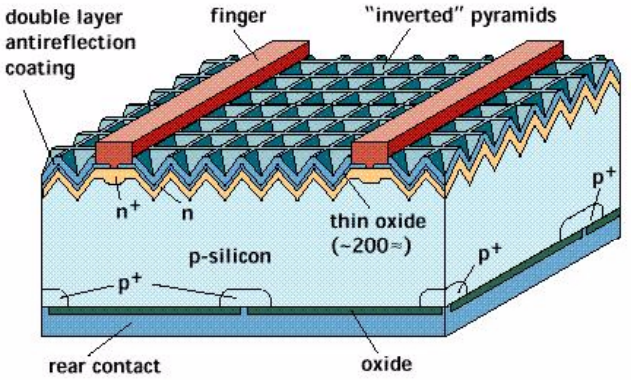
$$\eta = \frac{J_m V_m}{P_{sun}} \quad \text{or} \quad \eta = \frac{J_{sc} V_{oc} FF}{P_{sun}}$$

where 'fill factor' FF = $J_m V_m$ / $J_{SC}V_{OC}$



Cell Type	Area (cm^2)	V_{oc} (V)	J_{sc} (mA /cm^2)	FF (%)	η (%)
c-Si	4.0	0.706	42.2	82.8	24.7
c-GaAs	3.91	1.022	28.2	87.1	25.1
poly-Si	1.0	0.664	37.7	80.9	20.3
a-Si	1.0	0.887	19.4	74.1	12.7
$CuInGaSe_2$	1.04	0.669	35.7	77.0	18.4
Cd Te	1.032	0.845	25.9	75.5	16.5
P3HT / PCBM	0.1	~0.6	~12	~60	4 - 5

Solar Cell Efficiency Tables, Vers 27. M. A. Green et al., *Progress in Photovoltaics* **14**, p.45-51 (2006).



Crystalline Si PERL cell (24% efficient)

Sources of loss:

Unavoidable:

Photons of energy $E < E_g$ not absorbed
Electrons excited by photons of $E > E_g$ lose some energy to heat
Some electrons recombine to emit light (required for equilibrium with ambient)

Avoidable:

Problem	*Solution*
Reflection by surface and contacts	Antireflection coat, narrow metal fingers
Incomplete of light absorption	Textured surfaces, thick active layer
Non-radiative charge recombination	High purity crystal, low doping in bulk of cell, surface passivation
Resistive losses	High doping near contacts, deep metal fingers