Lecture 19

- Ideal solar photovoltaic converter :
  - Absorbs all photons with E > Eg
  - Emits like black body with chemical potential $\Delta\mu > 0$
  - Every net absorbed photon $\rightarrow$ one electron in external circuit (QE = 1)
  - Delivers power density P = JV for $\Delta\mu = eV > 0$

- J-V characteristic $J = J_{sc} - J_o(e^{eV/kT} - 1)$

- Efficiency depends (only) on E_g and concentration X
  - Max 31% at Eg = 1.4 eV for X = 1

- To generate electric power from solar radiation we need:
  - An energy gap (to keep photo-generated electrons at high $\Delta\mu$)
  - A preferred direction for electron extraction

Lecture 20

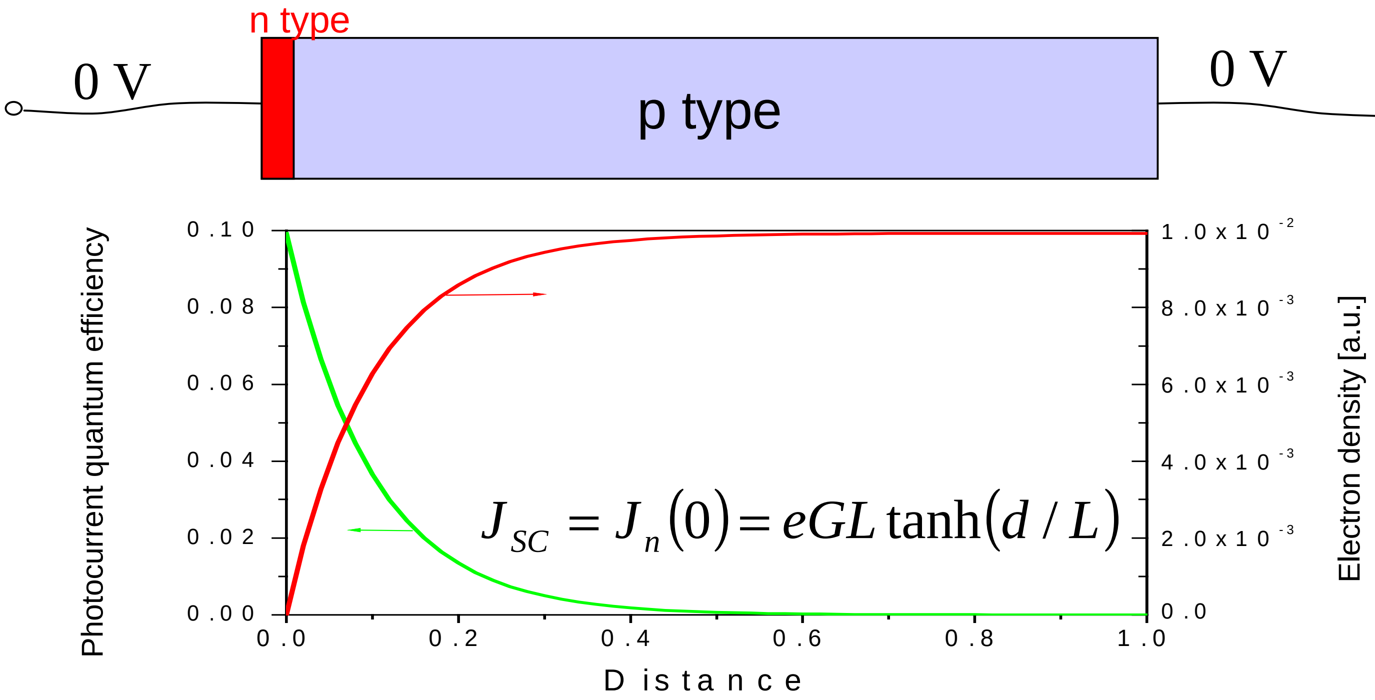
- A semiconductor provides the energy gap
- For electrons in p-type semiconductor:
  - absorption coefficient α
    - » Photogeneration rate $G = \int \alpha\, b\, dE$
  - lifetime t_n
    - » Recombination rate $R = n / t_n$
  - Diffusion coefficient D_n
    - » diffusion current density $J_n = e\, D_n\, dn/dx$
- Continuity equation

$$\frac{1}{e}\frac{dJ_n}{dx} + G - R = 0$$

Lecture 21

- A *pn* or *np* junction provides the preferred direction

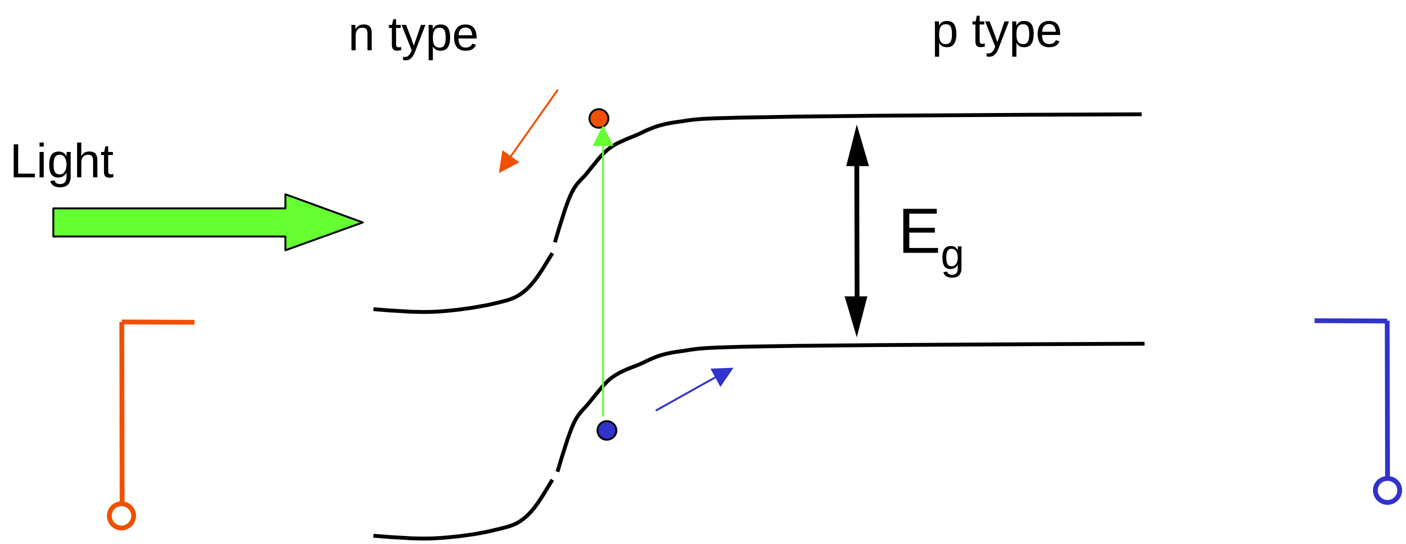
- Solved continuity equation for ideal boundary conditions



$$J_{SC} = J_n(0) = eGL \tanh(d/L)$$

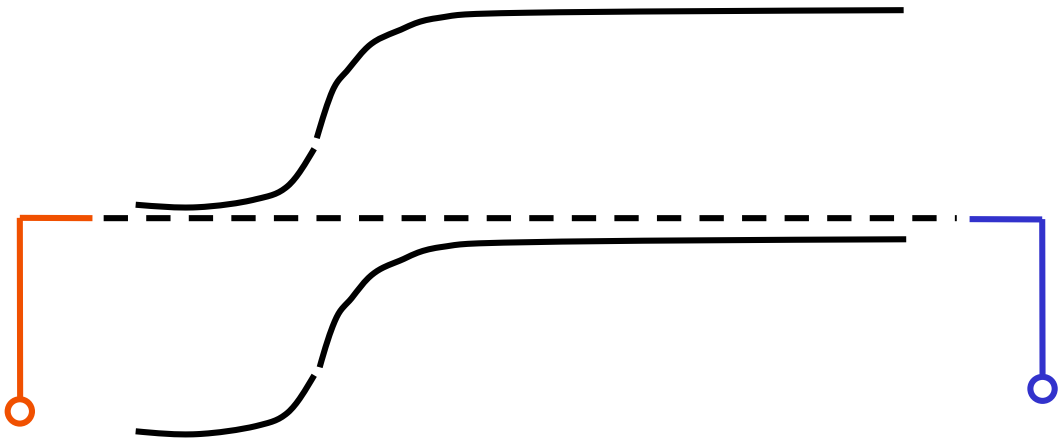
- J_{SC} depends on optical depth, reflection, electron diffusion length $L = (t\ D)^{1/2}$

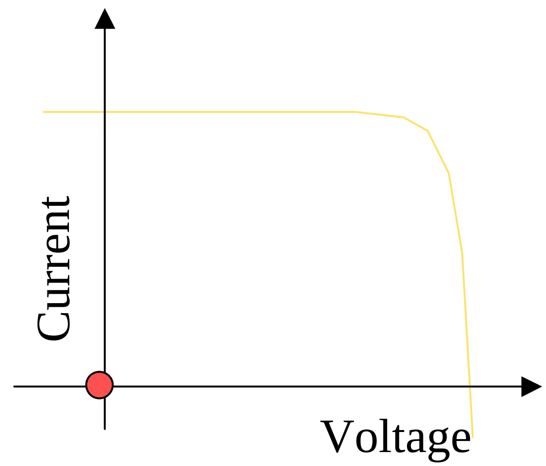
Semiconductor p-n junction



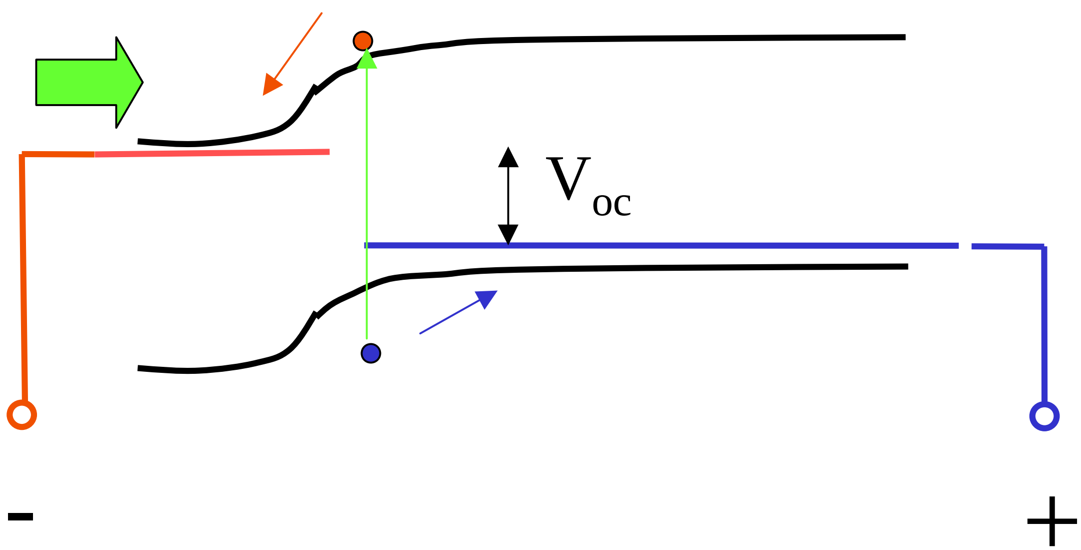
- Band gap enables photogeneration
- n and p type doping $\Rightarrow$ asymmetric electrodes

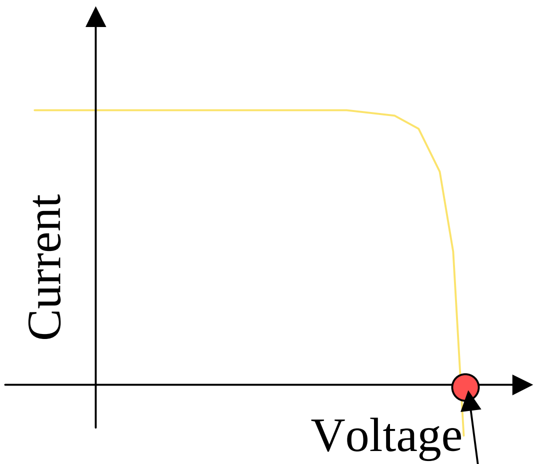
In the dark





Open circuit

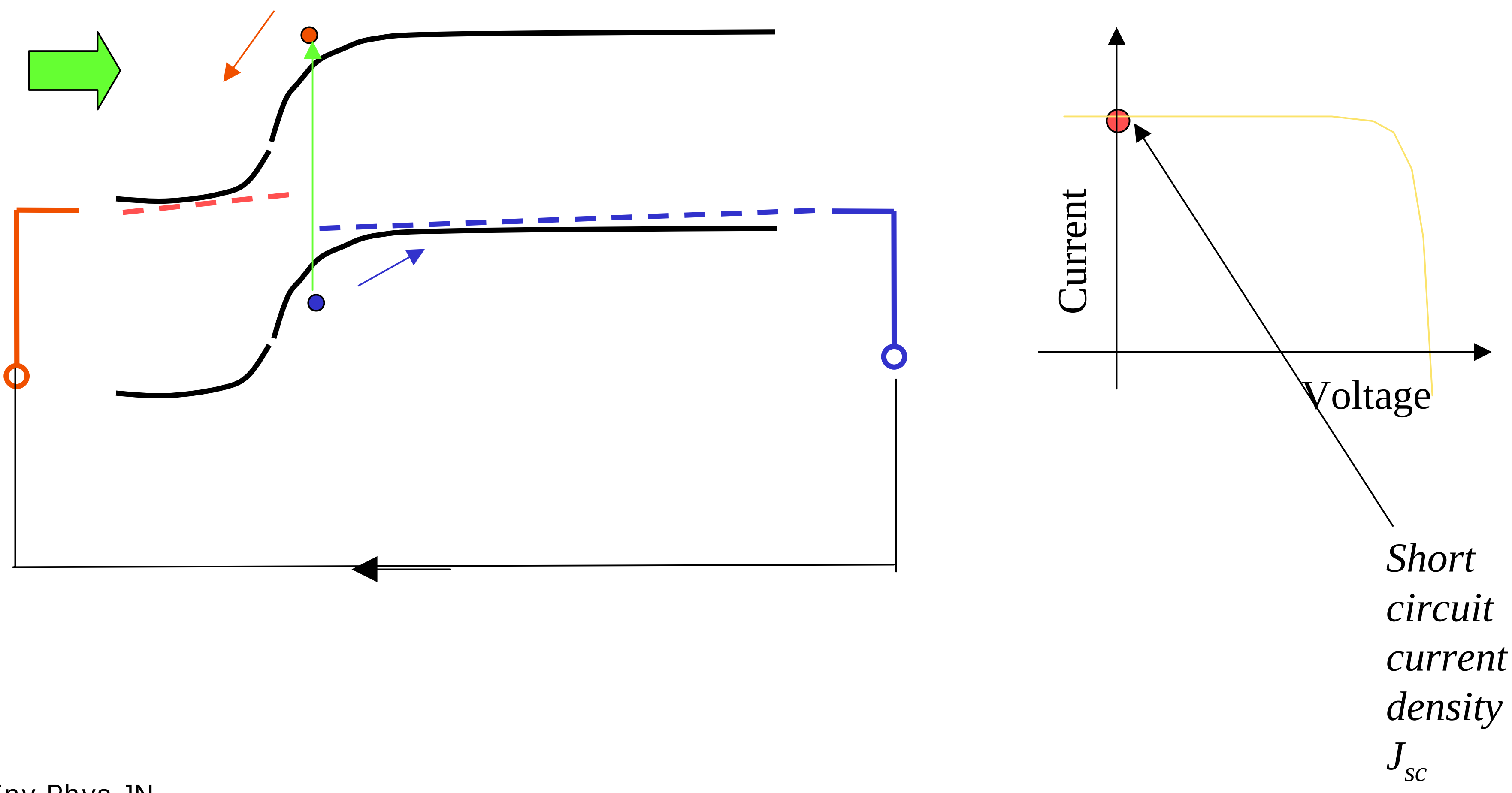




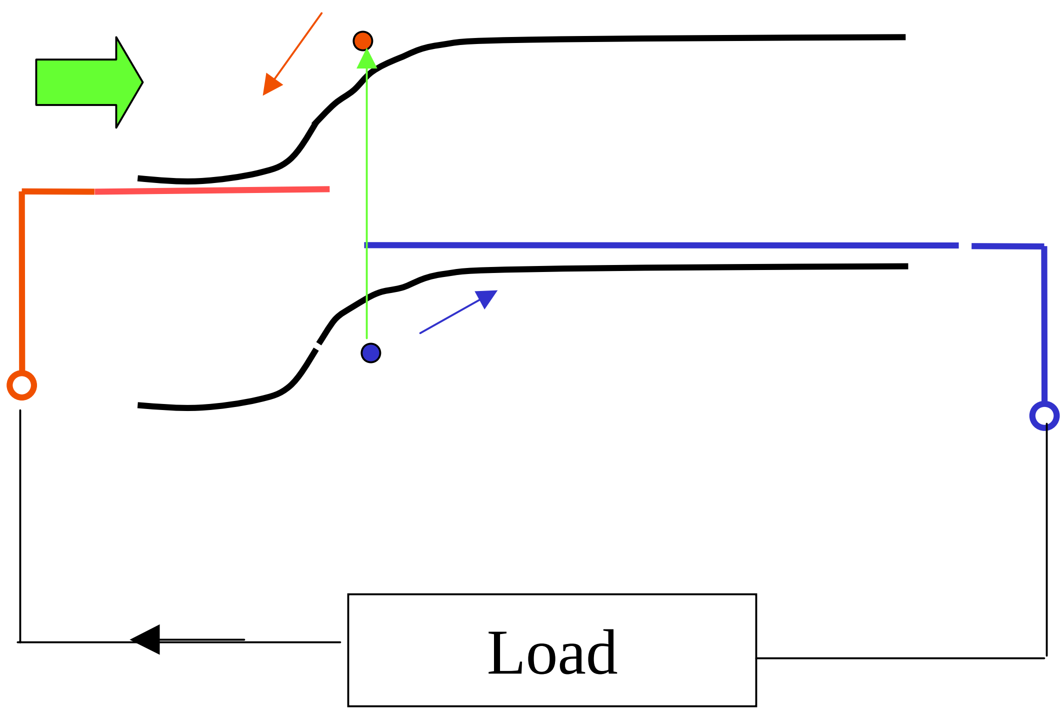
Open circuit voltage V_{oc}

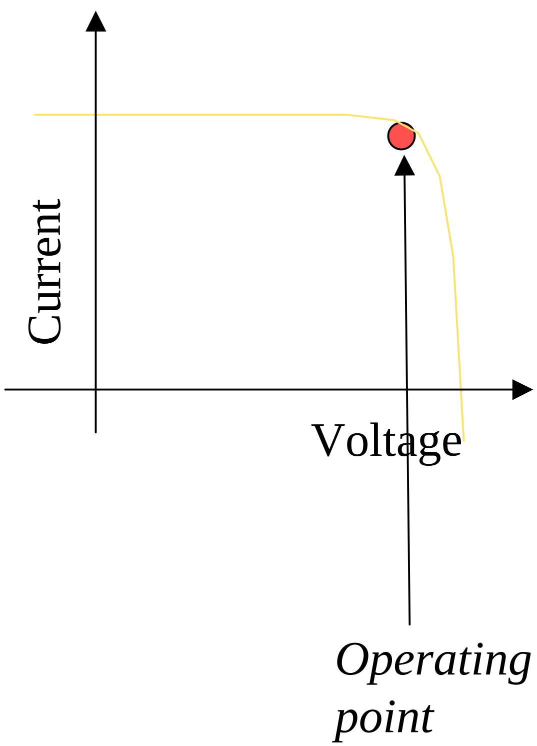
+

Short circuit



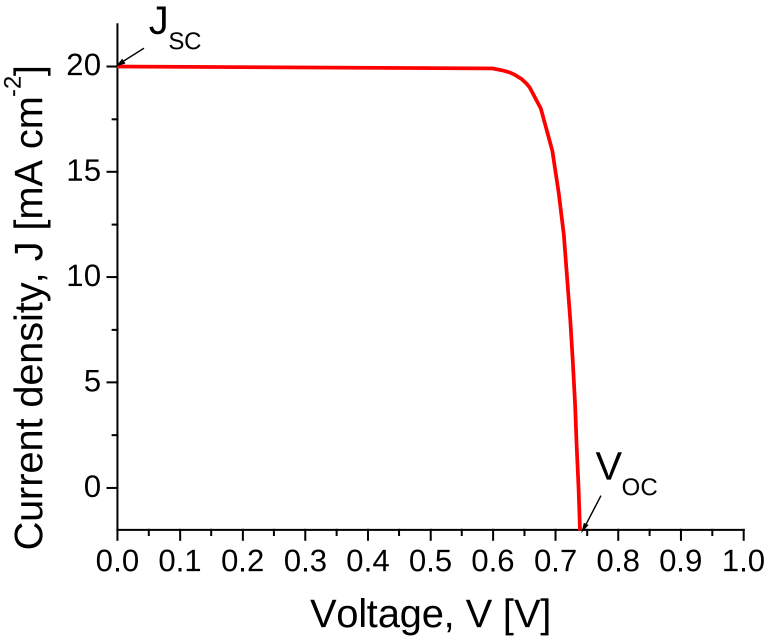
Operating: photovoltage x photocurrent = electric power





Solar cell characteristics

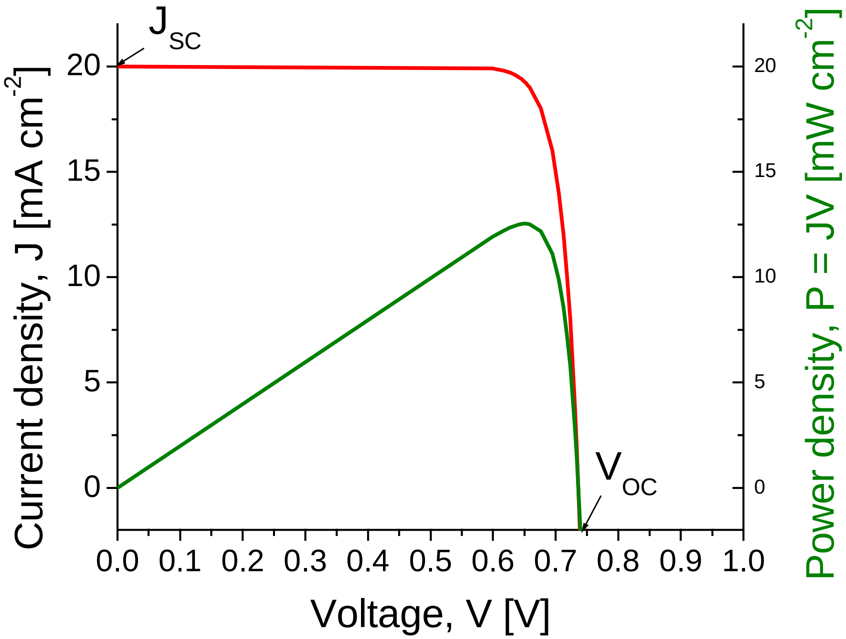
- *Short circuit current density* J_{sc},
- *Open circuit voltage* V_{oc}



- Measured under Standard Test Conditions (AM1.5, 1000 Wm^{-2}, 25°C)

Solar cell characteristics

- *Short circuit current density* J_{sc},
- *Open circuit voltage* V_{oc}
-

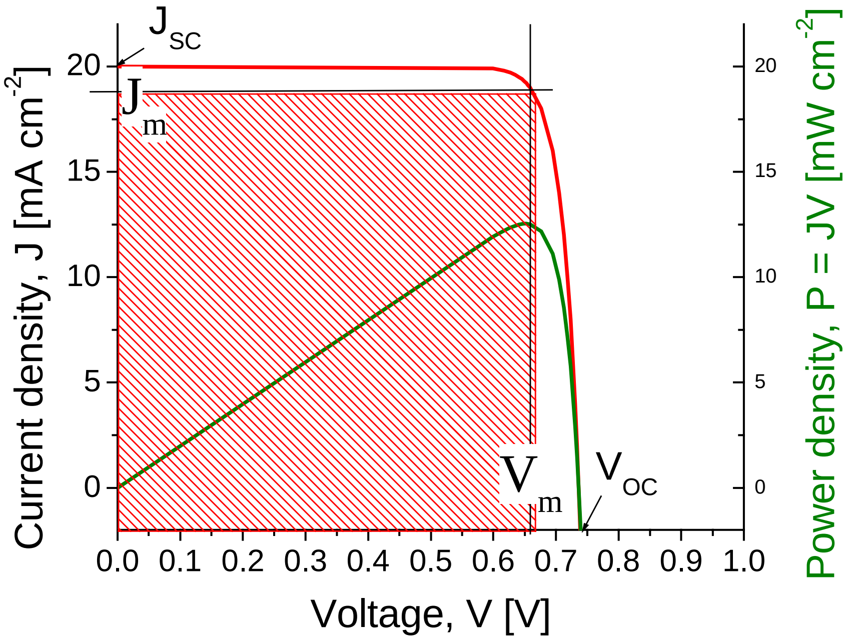


- Measured under Standard Test Conditions (AM1.5, 1000 Wm^{-2}, 25°C)

Solar cell characteristics

- *Short circuit current density* J_{sc},
- *Open circuit voltage* V_{oc}
- *Power conversion efficiency*

$$\eta = \frac{J_m V_m}{P_{sun}}$$

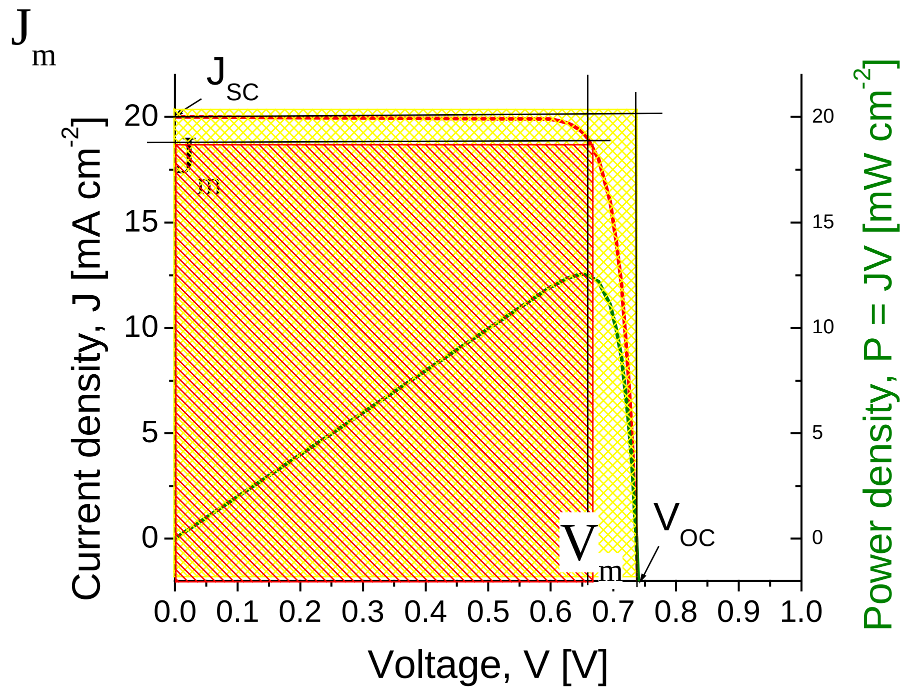


- Measured under Standard Test Conditions (AM1.5, 1000 Wm^{-2}, 25°C)

Solar cell characteristics

- *Short circuit current density* J_{sc},
- *Open circuit voltage* V_{oc}
- *Fill factor* FF $FF = \frac{J_m V_m}{J_{sc} V_{oc}}$
- *Power conversion efficiency*

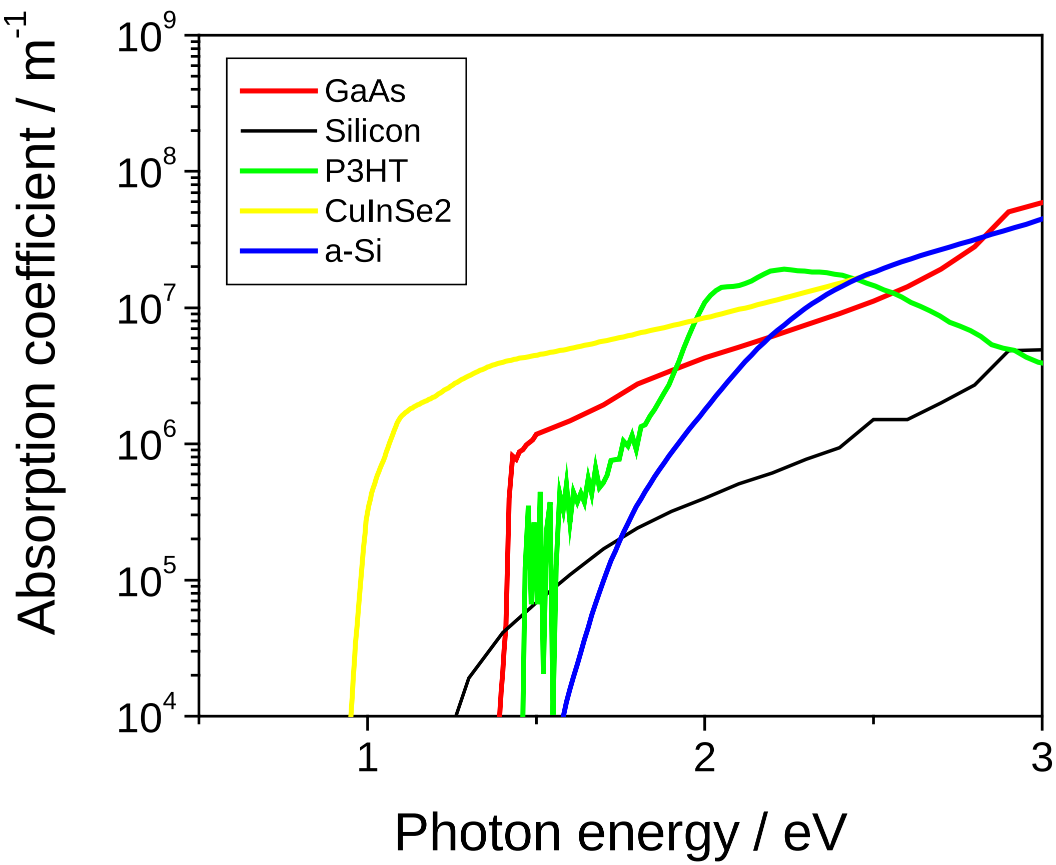
$$\eta = \frac{J_{sc} V_{oc} FF}{P_{sun}}$$



- Measured under Standard Test Conditions (AM1.5, 1000 Wm^{-2}, 25°C)

PV materials

- Monocrystalline silicon
- Multicrystalline silicon
- GaAs
- Amorphous silicon
- CdTe
- $CuInGaSe_2$
- Molecular materials



PV materials

- Crystalline Silicon
  - 90% of terrestrial market
  - Mature technology, close to optimum performance. Aim to reduce production costs

- Monocrystalline III-V semiconductors (e.g. GaAs)
  - Only for space or future use with concentrators
  - High efficiency but expensive

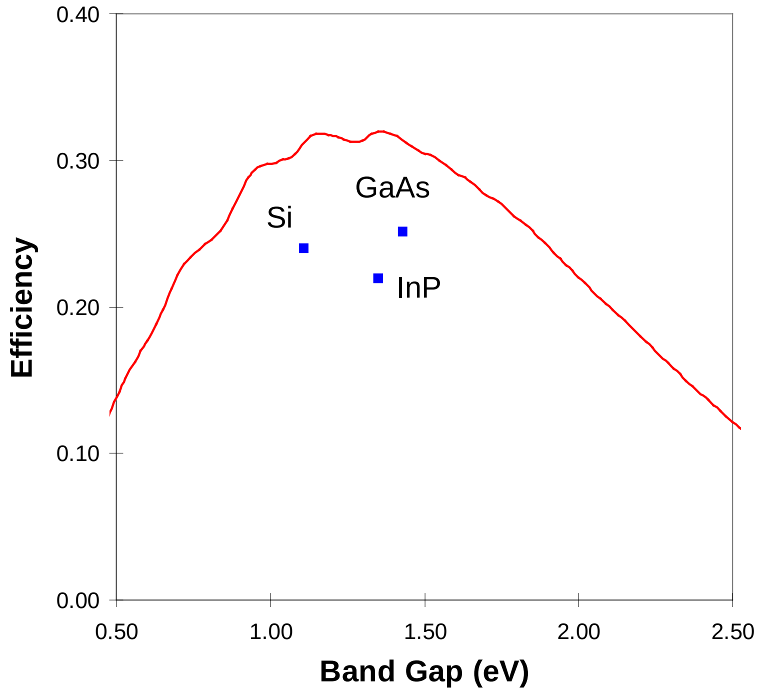
- Thin films
  - amorphous silicon, CdTe, $CuInGaSe_2$
  - Higher absorption than silicon, so less material needed
  - Lower cost production, performance still improving

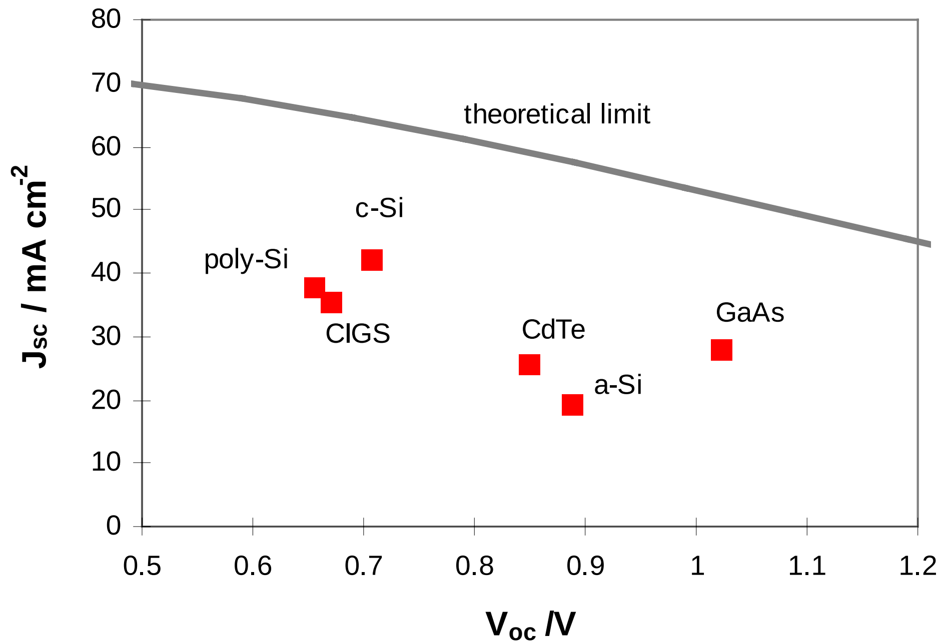
- Molecular photovoltaic materials
  - Potentially very cheap
  - Materials and devices still need to be understood

PV materials

Cell Type		**Area (cm^2)**	**V_{oc} (V)**	**J_{sc} (mA /cm^2)**	**FF (%)**	Efficiency (%)
c-Si	UNSW PERL	4.0	0.696	42.0	83.6	24.9
c-GaAs	Kopin	3.91	1.022	28.2	87.1	25.1
poly-Si	UNSW/ Eurosolare	1.0	0.628	36.2	78.5	19.8
a-Si	Sanyo	1.0	0.887	19.4	74.1	12.7
$CuInGaSe_2$	NREL	1.04	0.669	35.7	77.0	18.4
Cd Te	NREL	1.131	0.848	25.9	74.5	16.4
P3HT / PCBM	ICL (and others)	0.1	~0.6	~12	~60	4 - 5

Actual versus ideal PV performance





An exercise for the student….

- A highly energy efficient London home consumes 2 kWh per day, and receives solar radiation with mean intensity of 1.67 Peak Sun Hours per day.

  Using PV modules of efficiency 15% (rated at STC) and assuming all generated electricity can be used, what is the area of PV modules needed to meet the household's consumption?

Summary of Lecture 22

- A PV cell is equivalent to a diode in parallel with a current generator
- Performance characteristics:
  - J_{sc} (increases with reducing Eg or increasing X)
  - V_{oc} (increases with increasing Eg, increases logarithmically with X)
  - FF (convenient indicator of operating point)
- Real materials limited by
  - incomplete light absorption
  - (non-radiative) recombination
  - series resistance
- Thin film materials pursued for low cost (outweighs lower efficiency)
- PV systems designed for wide variety of applications: versatile, modular, decentralised