Photovoltaics

LECTURE 9

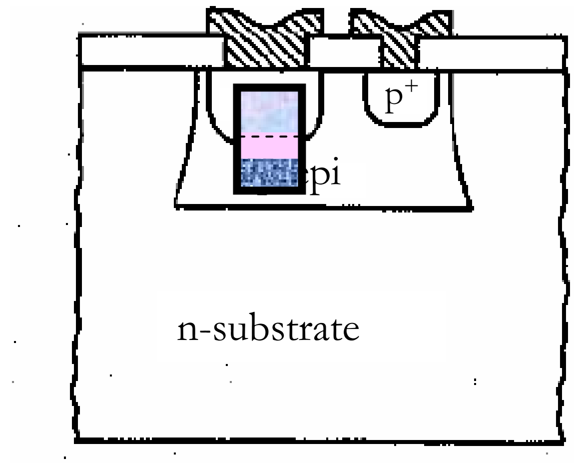
- Diode summary
- photovoltaic effect
- the Sun as a resource
- absorption of photons
- generation of electron-hole pairs

Practical np-junction diodes and our model

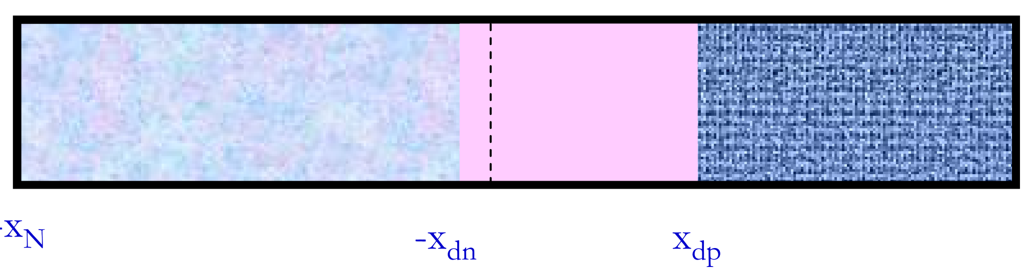
Discrete diode: 200V, 70A

IC diode: 1V, 1mA

np diode with ohmic contact to p-region

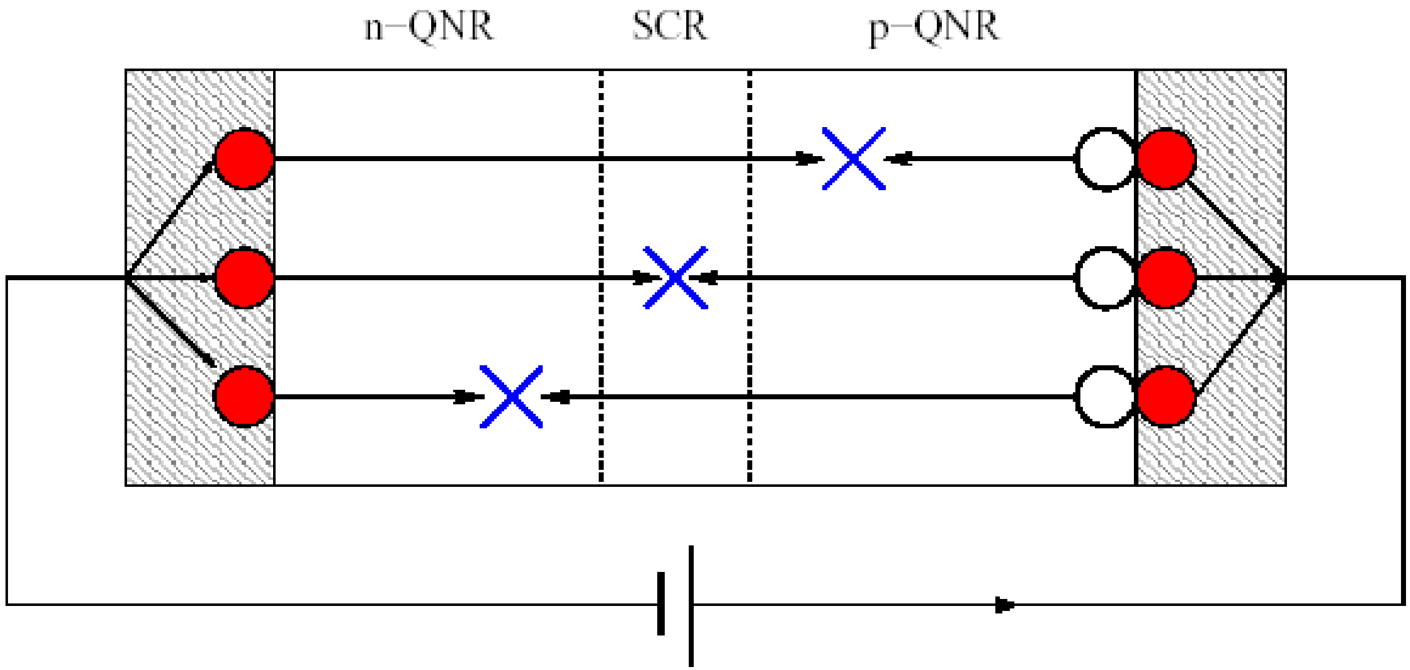


Our 1-D model



Sec. 6.6

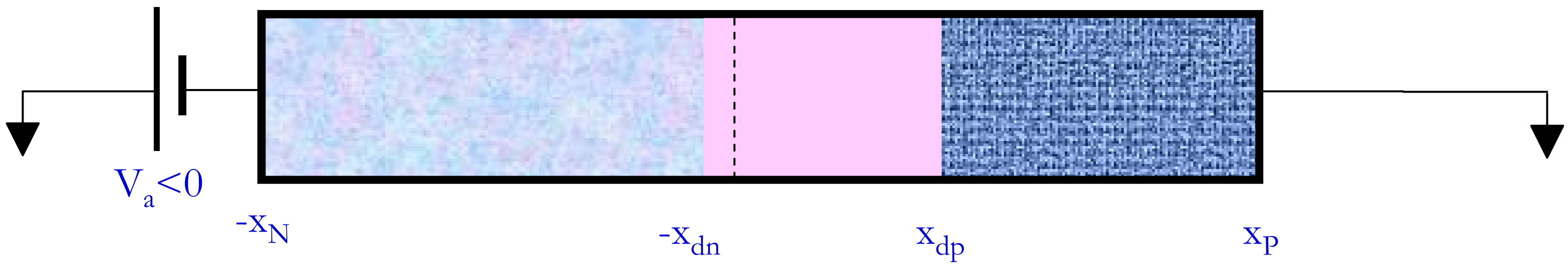
Bipolar conduction



What is going on here?

Sec. 6.6

Diode calculations



$$
\begin{aligned}
-\nabla^2\psi &= \frac{q}{\epsilon}[p - n + N_D - N_A] \\
J_e &= -qn\mu_e\nabla\psi + qD_e\nabla n \\
J_h &= -qp\mu_h\nabla\psi - qD_h\nabla p \\
\frac{\partial n}{\partial t} &= \frac{1}{q}\nabla\cdot J_e - \frac{n-n_0}{\tau_e} \\
\frac{\partial p}{\partial t} &= -\frac{1}{q}\nabla\cdot J_h - \frac{p-p_0}{\tau_h}\,.
\end{aligned}
$$

Pick a region, e.g., p-QNR for n and J_e

General solution: $$n(x) - n_{0p} = Ae^{x/L_e} + Be^{-x/L_e}$$

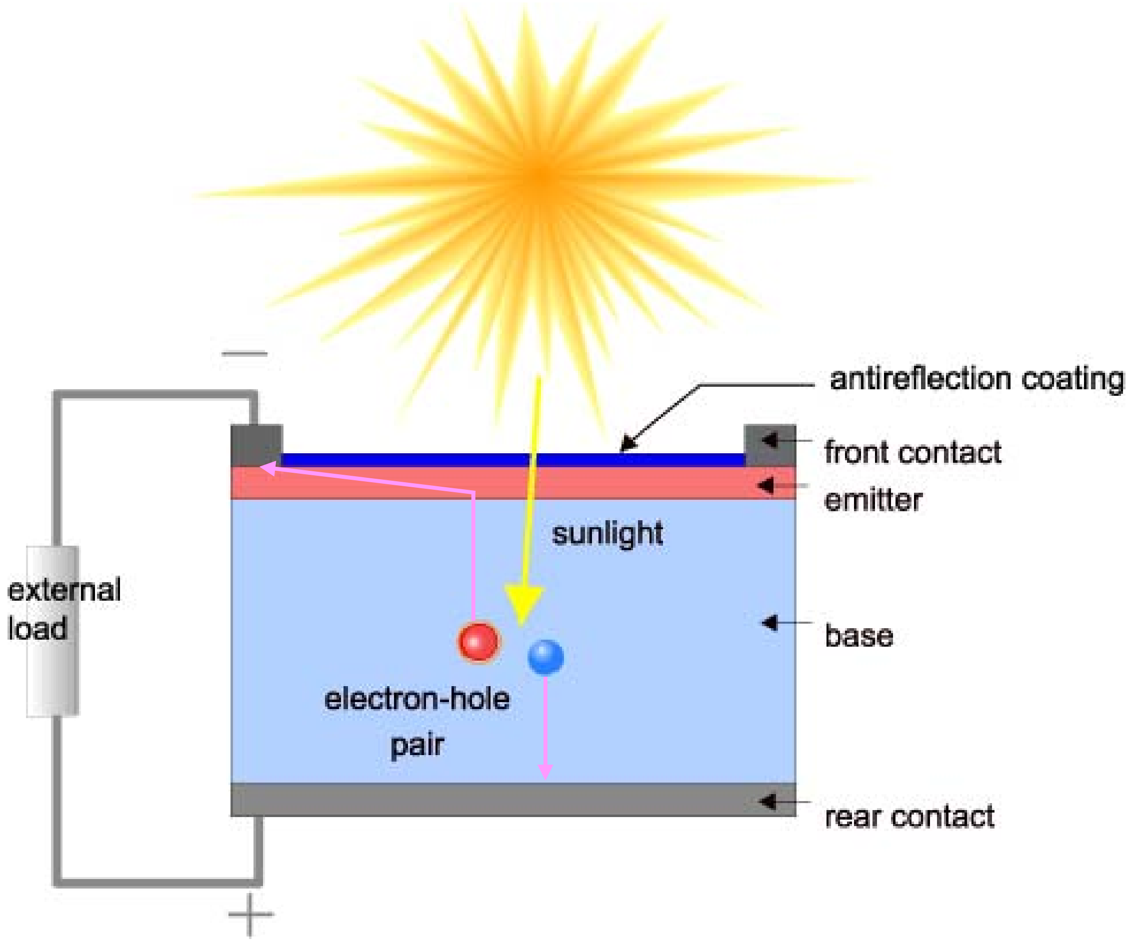
Boundary conditions:

$$n(x_P) \equiv n(\infty) = n_{0p}$$ if contact is?

$$n(x_{dp}) = n_{0p}e^{-V_a/V_{\text{th}}}$$

Sec. 7.0

The Photovoltaic Effect



We need to consider:

1.
2.
3.
4.

PV: large and small

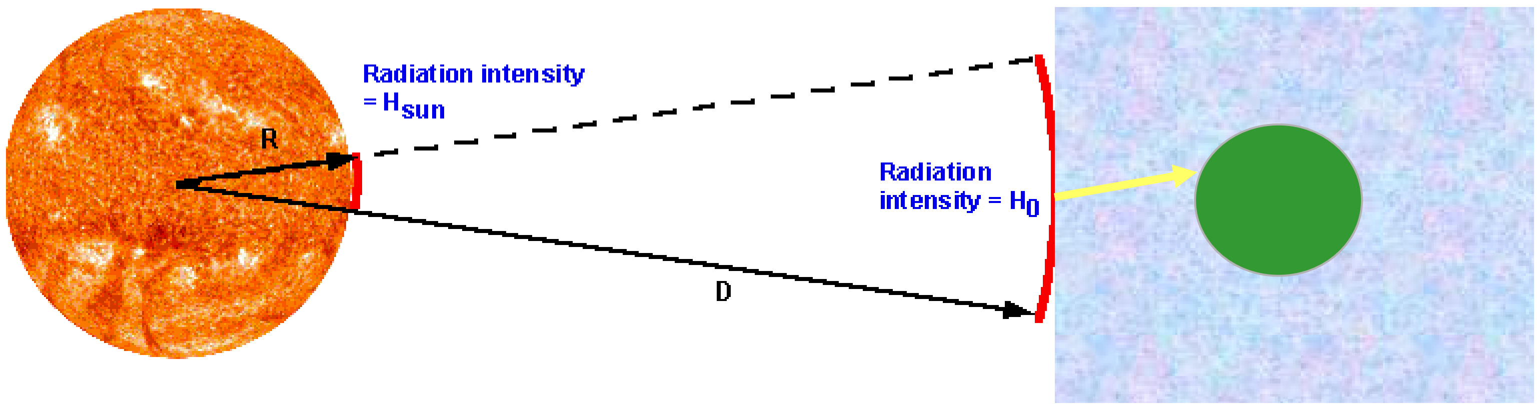
12 MW Arnstein, Germany

90 MW Sarnia, Ontario

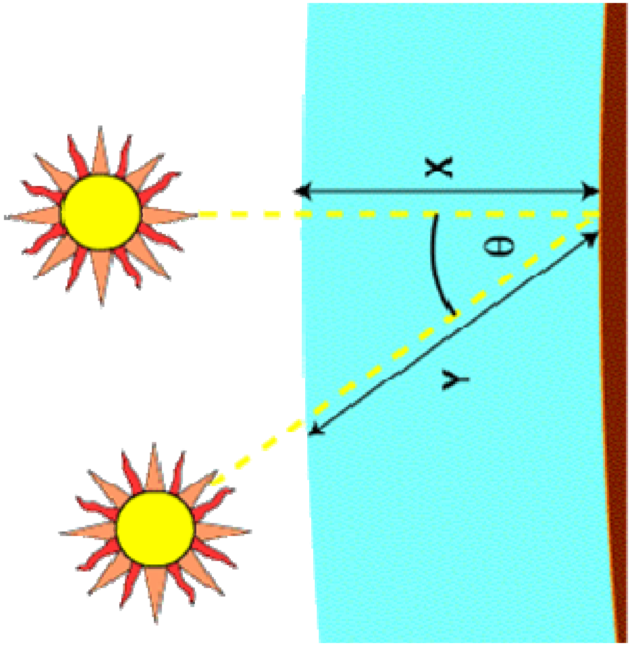
5kW Boston Massachusetts http://256.com/solar/

Sec. 7.1

The sun as a resource

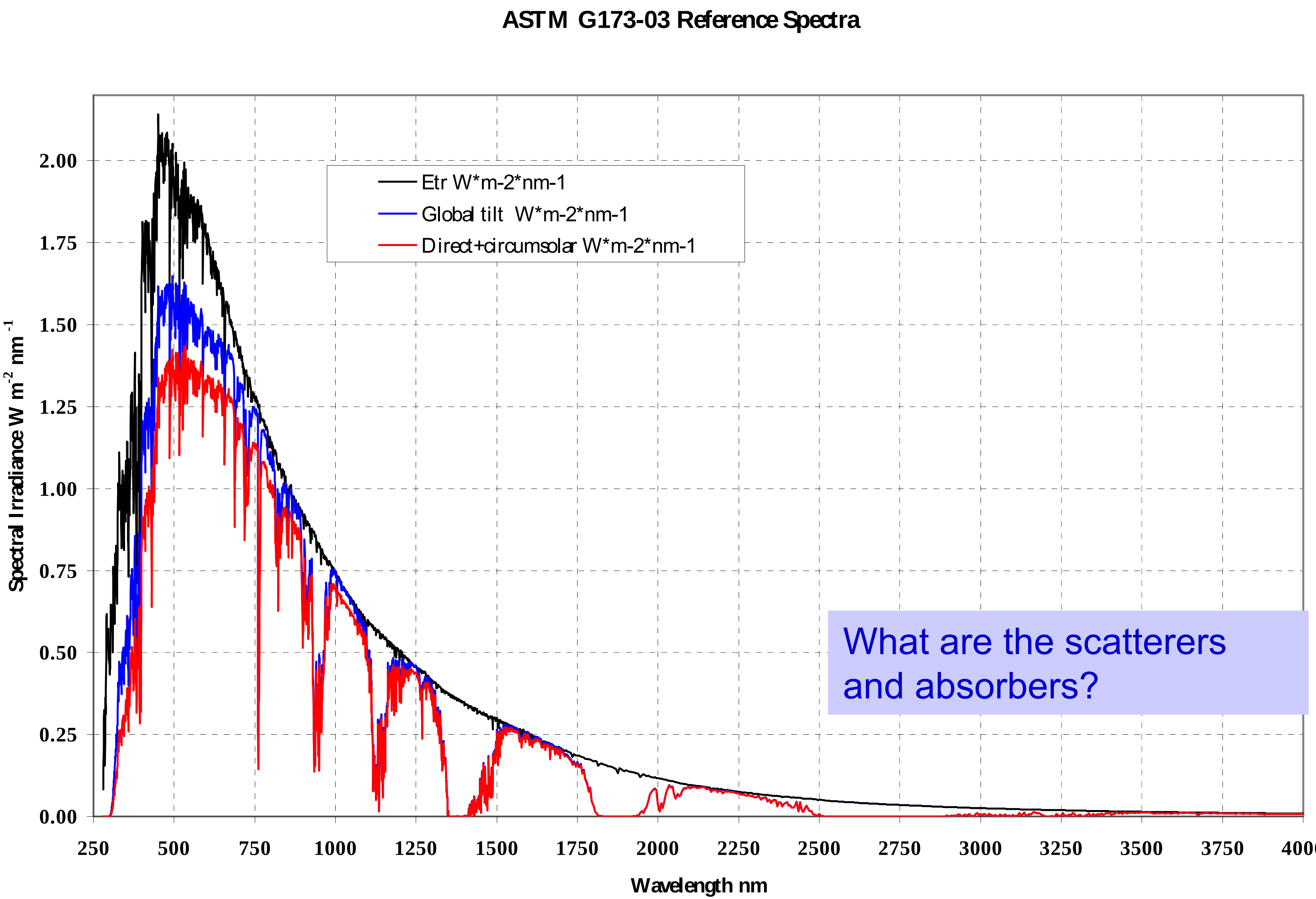


- Value for H_{sun} ?
- How is the energy generated ?
- Value for H_0 ?
- How much is lost in the atmosphere ?
- What is Air Mass ?



Sec. 7.1

Irradiance standards



What are the scatterers and absorbers?

Ref. 7.1

Sec. 7.2

Absorption

TEM plane wave

$$\mathcal{E}_y(x) = \mathcal{E}_0 e^{ikx}$$

Refractive index

$$k = \frac{\omega}{c/n^*} = \frac{\omega(n_r + ik_r)}{c} \equiv \frac{2\pi(n_r + ik_r)}{\lambda}$$

$$\mathcal{E}_y(x) = \mathcal{E}_0 e^{i2\pi n_r x/\lambda}\, e^{-2\pi k_r x/\lambda}$$

What's this?

$$\vec{S} = \vec{\mathcal{E}} \times \vec{H}$$

What characterizes the attenuation?

$$S_x = \mathcal{E}_y H_z = \sqrt{\frac{\epsilon}{\mu}}\left|\mathcal{E}_y\right|^2 = \sqrt{\frac{\epsilon}{\mu}}\mathcal{E}_y(x)\mathcal{E}_y^*(x) = \sqrt{\frac{\epsilon}{\mu}}\mathcal{E}_0^2 e^{-\alpha x}$$

What's this?

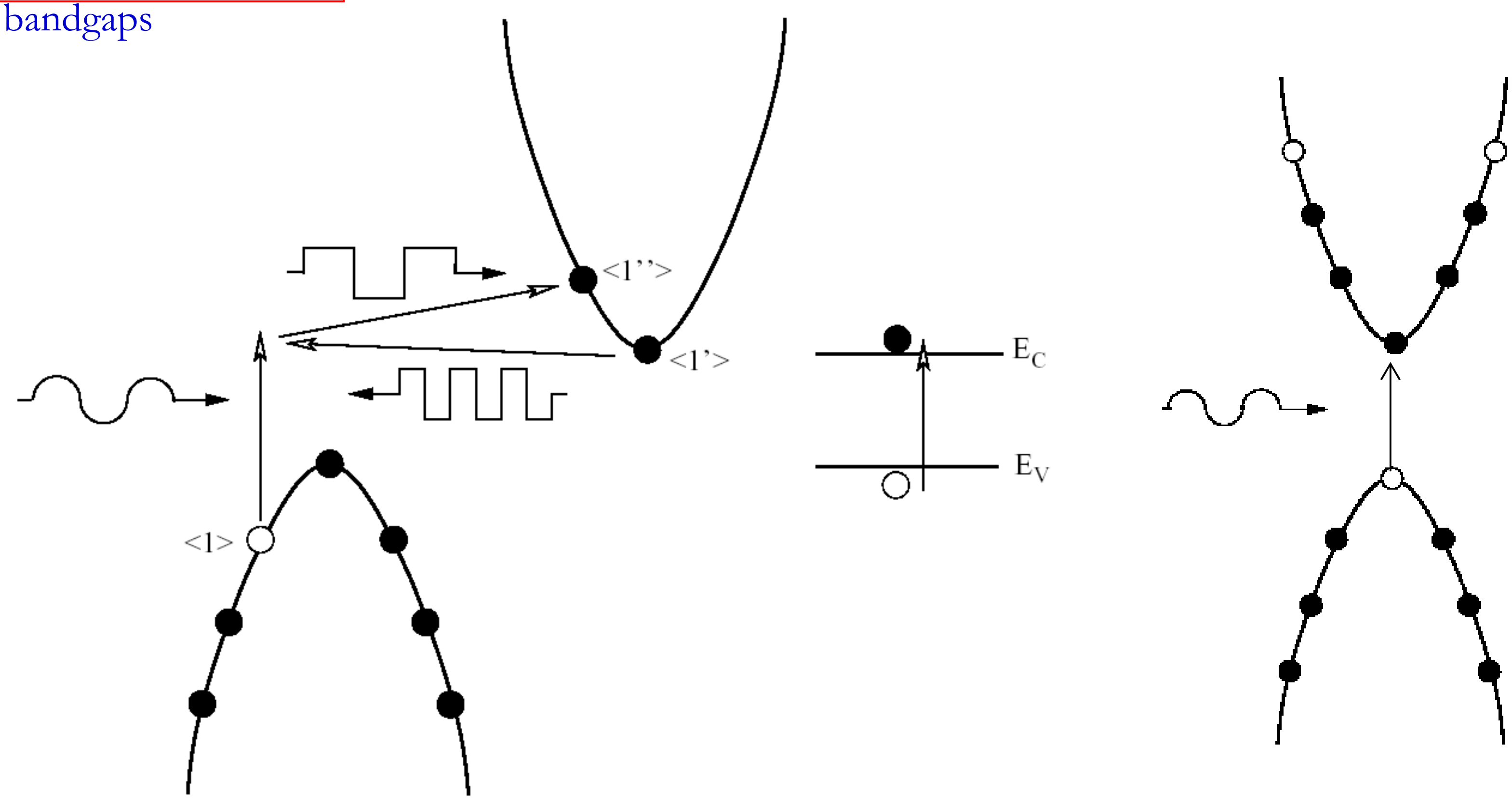
$$\alpha = \square \qquad \equiv \square$$

Sec. 7.3

Photogeneration

Consider materials with

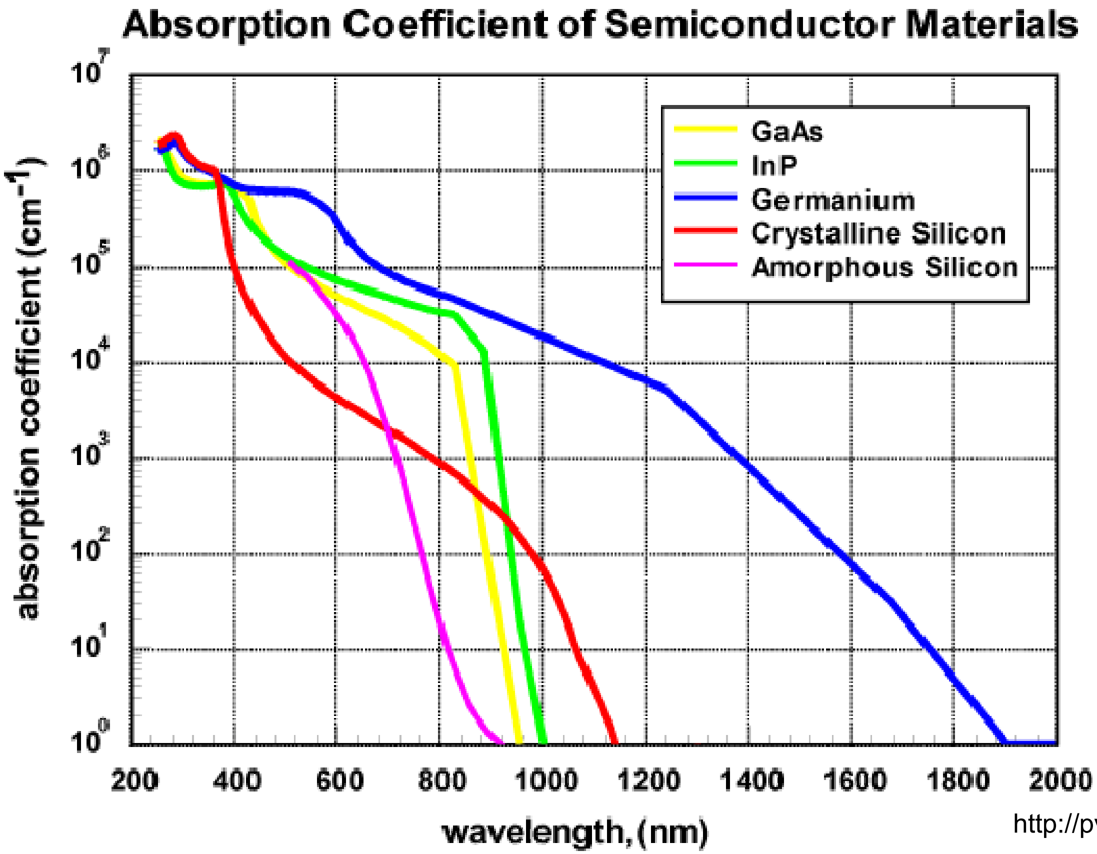
bandgaps



Which material is likely to have the higher absorption coefficient?

Sec. 7.2

Absorption coefficient



http://pvcdrom.pveducation.org/

What is the cut-off energy?

Which of these materials has a direct bandgap?

Secs. 5.2.1, 7.3

Derivation of Generation rate

$$
\begin{aligned}
-\nabla^2\psi &= \frac{q}{\epsilon}[p - n + N_D - N_A] \\
J_e &= -qn\mu_e\nabla\psi + qD_e\nabla n \\
J_h &= -qp\mu_h\nabla\psi - qD_h\nabla p \\
\frac{\partial n}{\partial t} &= \frac{1}{q}\nabla\cdot J_e - \frac{n-n_0}{\tau_e} \\
\frac{\partial p}{\partial t} &= -\frac{1}{q}\nabla\cdot J_h - \frac{p-p_0}{\tau_h}\,.
\end{aligned}
$$

Let p be photon density P photons/m^3s

Let J_h be photon flux F photons/m^2s

Let U be generation of EHPs G_{op} EHPs/m^3s

Write down the photon balance equation

$$\frac{\partial P(\lambda)}{\partial t} + \square$$

Express F in terms of S

Define $\Phi_0 = \square$

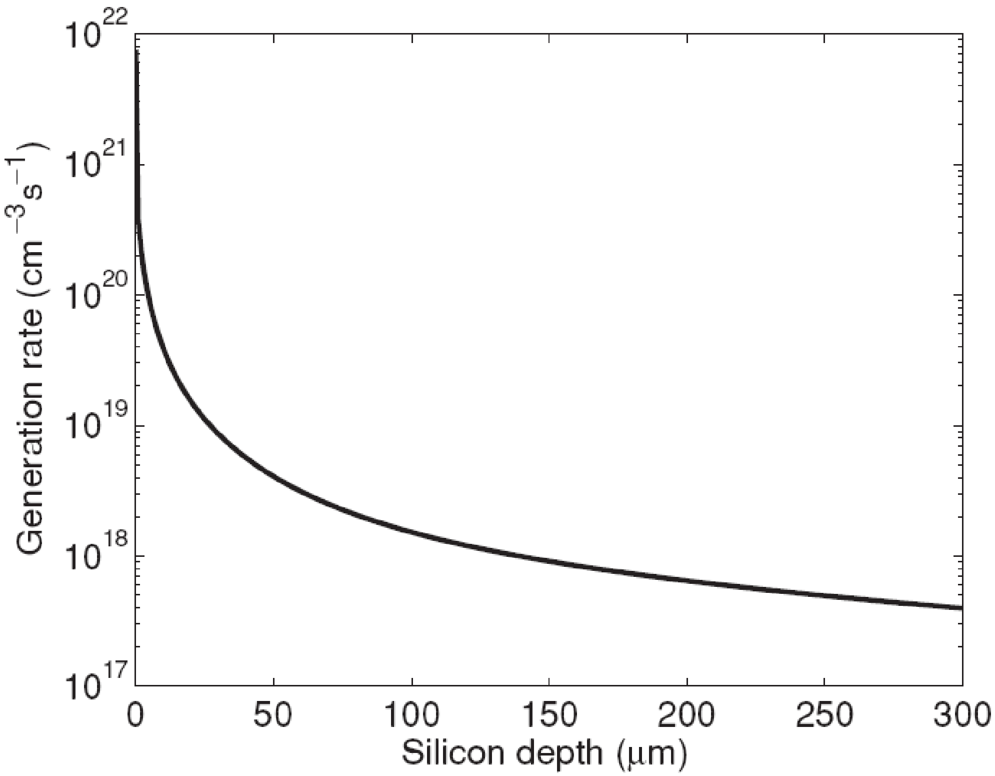
Solve for G_{op}

$$G_{op}(\lambda) = \square$$

Sec. 7.2

The generation rate

$$G_{\rm op}(\lambda) = \qquad \alpha(\lambda)\Phi_0(\lambda)e^{-\alpha x}$$



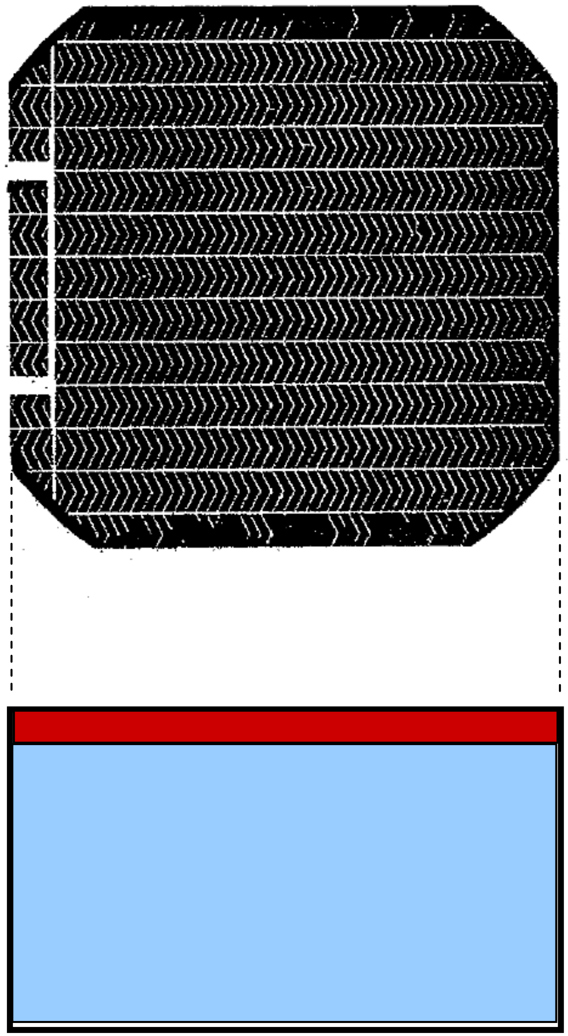
How does this curve help in the design of the solar cell?

Secs. 7.3, 7.4

Basic design issues resulting from $G_{op}(x)$

Plan view

Cross-section



- How deep should the junction be?
- Should the emitter be lightly or heavily doped?
- Should the emitter be *n*- or *p*-type?
- Should the base be thick or thin?
- Should the base be *n*- or *p*-type?