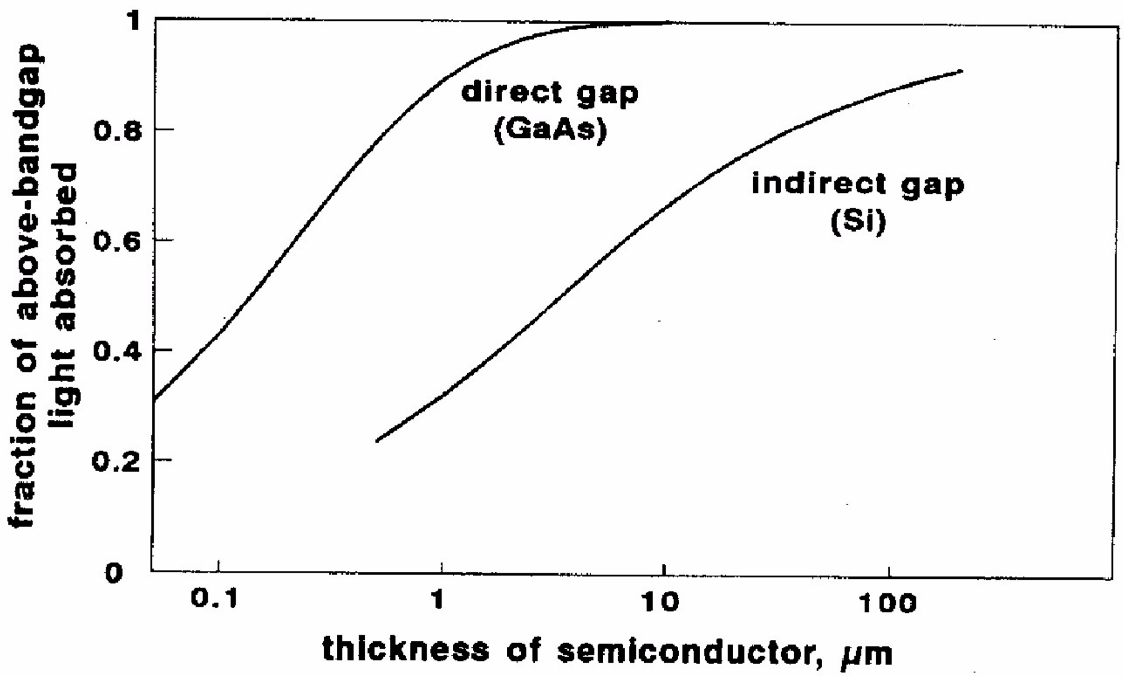
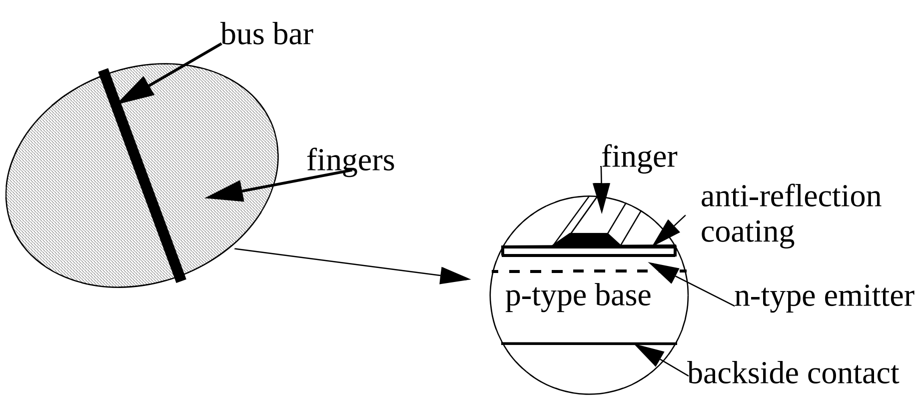
Lecture 14

Direct vs. indirect gap

Some semiconductors are good absorbers, and absorb all above-bandgap light in a layer of a few microns thick. These are called direct-bandgap semiconductors. In others, called indirect-gap semiconductors, which include crystalline silicon, the absorption process is weaker. In this case, a phonon (a quantum of the lattice vibration) is necessary to conserve momentum in the light absorption process. In silicon, a layer several hundred microns thick is required.



Solar cell structure

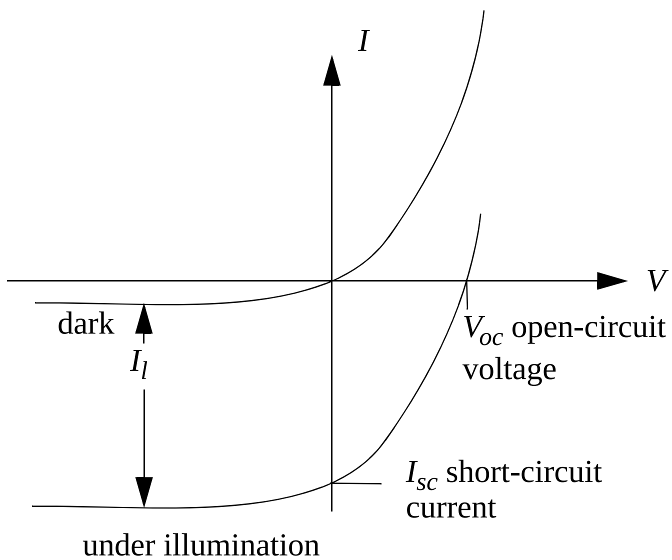


The top contact structure typically consists of widely spaced thin metal strips to allow the light to pass through, with a larger bus bar connecting them all to extract the current. An anti-reflection coating on top of the cell can be used to minimize reflection loss from the top surface.

The light generation current in the diode is in the reverse direction, so we can write to total current as the difference between the two:

$$\boxed{I = I_l - I_0 \exp\left(\frac{qV}{kT}\right)}$$

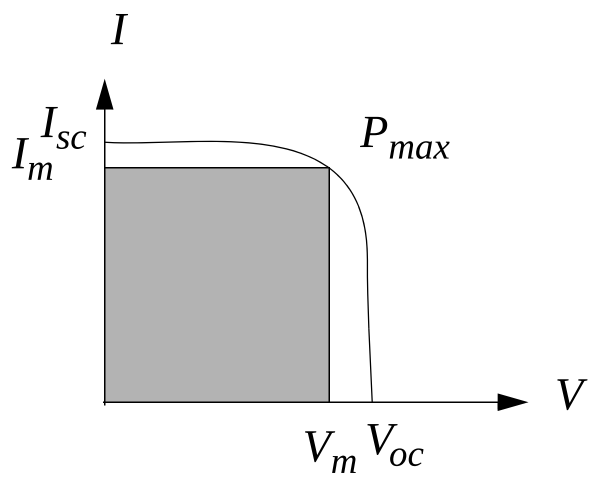
The I-V characteristic now looks like this:



Maximum power point

No power is generated under open or short circuit. The maximum power P_{max} is produced by the device at a point on the characteristic where the product IV is maximized. The position of the maximum power point represents the largest area of the rectangle shown in the figure below. The 'fill factor', FF is commonly defined by:

$$\boxed{P_{max} = V_m I_m = FF V_{oc} I_{sc}}$$



The efficiency of a solar cell, η, is defined as P_{max} produced by the cell under standard test conditions, divided by the power of the radiation incident. Usually, the standard conditions are: irradiance of 100 mW/cm^2, standard reference AM1.5 spectrum and temperature of 25C.

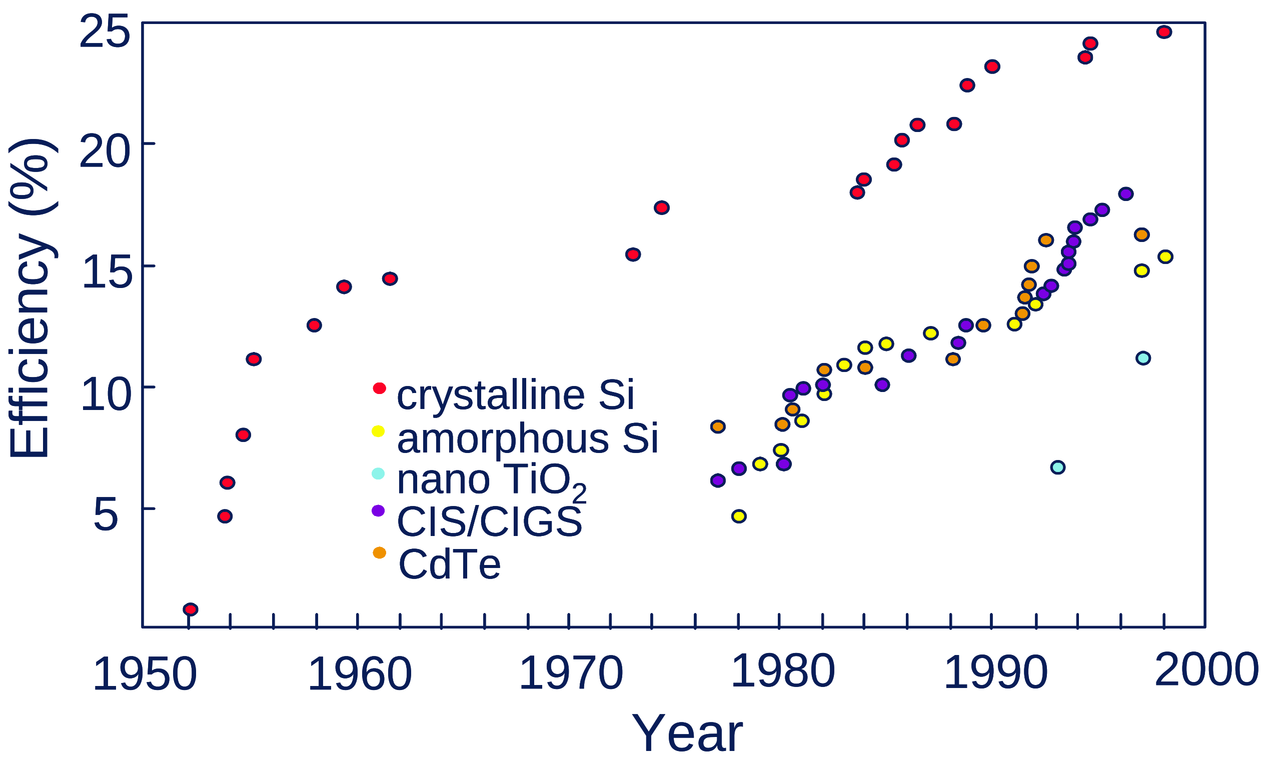
<u>Some common solar cell types</u>

High quality crystalline silicon and gallium arsenide solar cells can achieve efficiencies approaching 25%, but are relatively expensive because the cost of growing and processing large single-crystal wafers is high. The p-i-n structure is used for silicon cells in order to get an active light absorbing layer that is over 100 microns thick.

Thin-film solar cells can be much cheaper, but are not as efficient (10-15%). A very common material for thin-film cells is amorphous silicon. Silicon is a four-fold coordinated atom that is normally tetrahedrally bonded to four neighboring silicon atoms. In crystalline silicon this tetrahedral structure is continued over a large range, forming a well-ordered lattice (crystal). In amorphous silicon this long range order is not present and the atoms form a continuous random network. Not all the atoms within amorphous silicion are four-fold coordinated. Due to the disordered nature of the material some atoms have a dangling bond. These dangling bonds are defects in the continuous random network, which cause undesired (electrical) behaviour. The material can be passivated by hydrogen, which bonds to the dangling bonds and neutralises this defect. Hydrogen passivated amorphous silicon has a sufficiently low amount of defects to be used within devices. Amorphous silicon can be deposited over large areas using chemical vapor deposition methods.

Amorphous silicon (a-Si) becomes a direct-gap semiconductor with an band gap of about 1.75 eV. Absorption is higher in a-Si compared to crystal silicon (c-Si), but p-i-n structures are generally still used. The transport properties of a-Si are inferior to c-Si and so many carriers can recombine before they reach the contacts, reducing the efficiency of the cell.

Solar cell efficiency progress



<u>Brief discussion of global solar energy</u>

Total average global power consumption in 1990: 12 TW. Projected to grow to 28 TW by 2050.

$1.2x10^5$ TW of solar energy potential globally

Generating $2x10^1$ TW with 10% efficient solar farms requires $2x10^2/1.2x10^5$ = 0.16% of Globe = $8x10^{11}$ m^2 (i.e., 8.8 % of U.S.A)

Generating $1.2x10^1$ TW (1998 Global Primary Power) requires $1.2x10^2/1.2x10^5$= 0.10% of Globe = $5x10^{11}$ m^2 (i.e., 5.5% of U.S.A.)

U.S. Land Area: $9.1x10^{12}$ m^2 (incl. Alaska)

Average solar irradiance: 200 W/m^2

2000 U.S. Primary Power Consumption: =3.3 TW

1999 U.S. Electricity Consumption = 0.4 TW

Hence:

$3.3x10^{12}$ W/($2x10^2$ W/m^2 x 10% Efficiency) = $1.6x10^{11}$ m^2

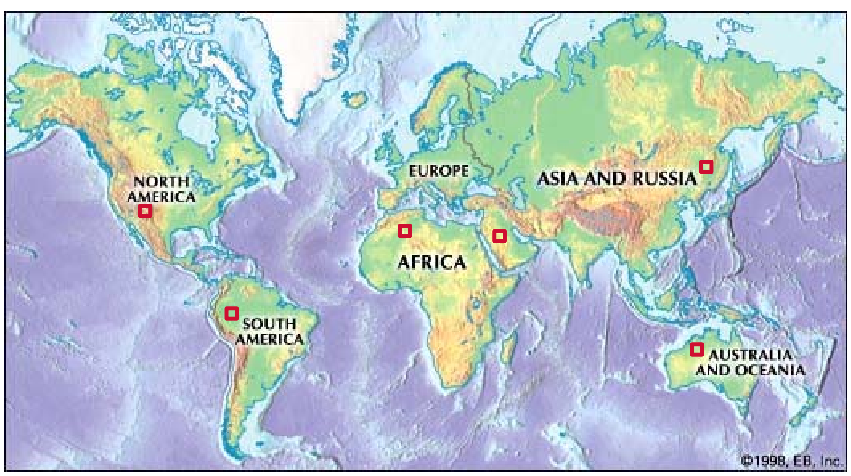
Requires $1.6\text{x}10^{11}$ m^2/ $9.1\text{x}10^{12}$ m^2 = 1.7% of Land

$7\text{x}10^7$ detached single family homes in U.S.

˜2000 sq ft/roof = 44ft x 44 ft = 13 m x 13 m = 180 m^2/home

= $1.2\text{x}10^{10}$ m^2 total roof area

Hence can (only) supply 0.25 TW, or ˜1/10th of 2000 U.S. Primary Energy Consumption



6 boxes at 3.3 TW each