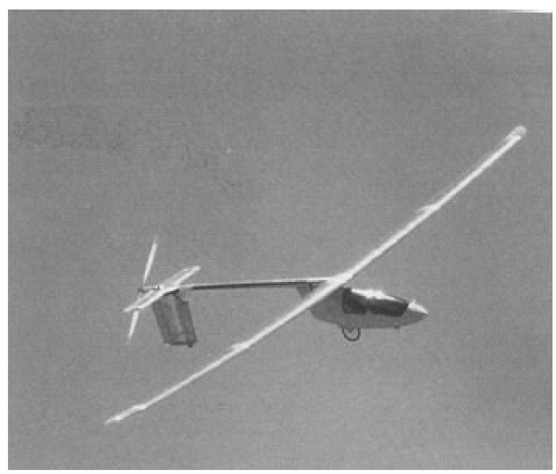
SOLAR CELLS

LECTURE 2

Prof. John David



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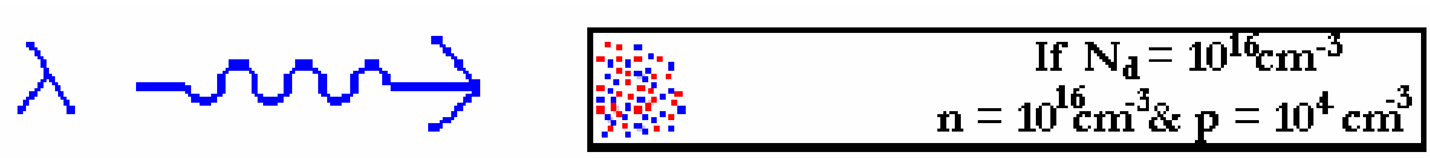
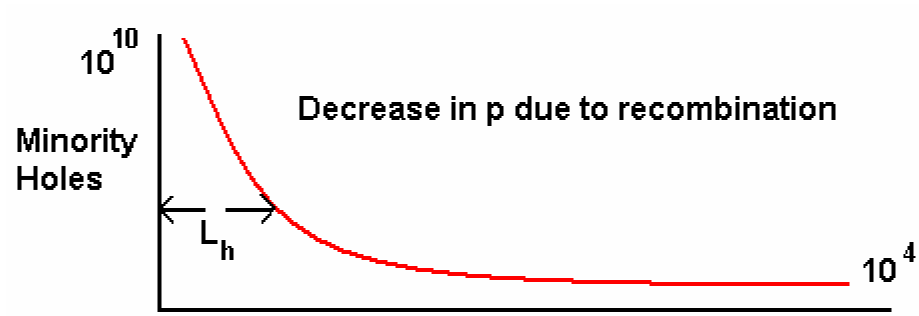
Lecture notes :
Either at http://www.shef.ac.uk/webct/ or http://hercules.shef.ac.uk/eee/teach/resources/MEC316/MEC316.html

Diffusion of Minority Carriers

Suppose extra electron-hole pairs are produced locally by shining light of suitable wavelength, λ, onto a semiconductor, as shown below



$n = p = 10^{10}\text{cm}^{-3}$

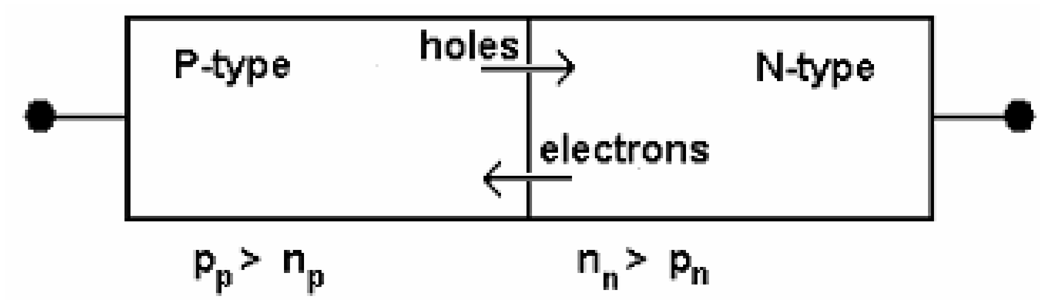


There is a rapid fall off of minority carriers due to recombination. The diffusion length for minority carriers, L_h, is typically a few µm. So a single crystal of silicon cannot produce an electric current because of the recombination within a short distance.

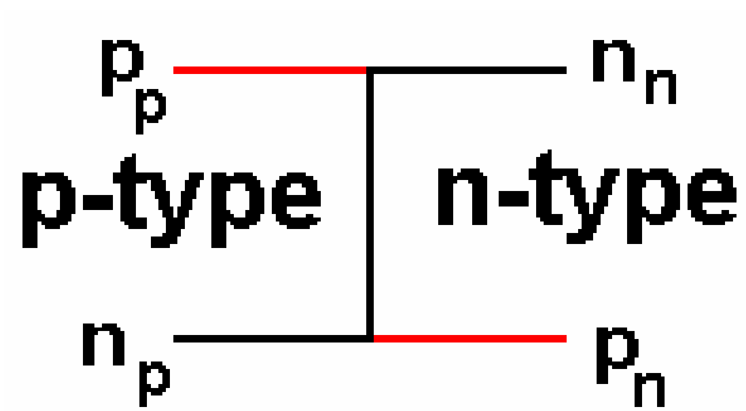
We therefore need to separate minority holes from majority electrons. This is done by the built-in electric field in a p-n junction.

The PN Junction Diode

The pn junction diode is made from a piece of single crystal silicon, one part of which is doped n-type, while the other part is doped p-type.



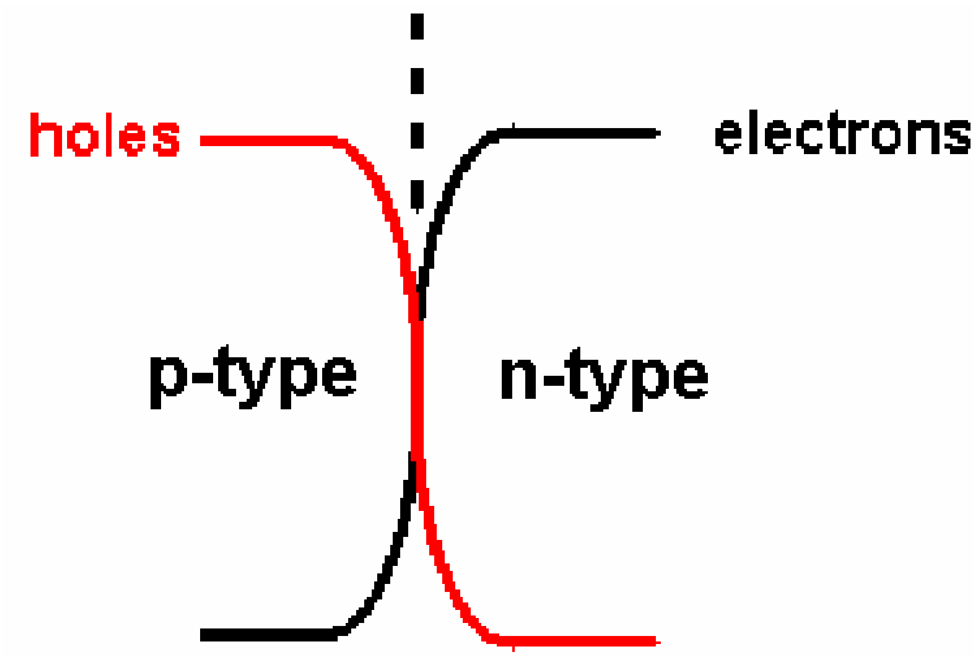
On the p side of the junction, p_p is very large, while on the n side of the junction n_n is very large as shown below -



This gives rise to a very large concentration gradient in the density of both electrons and holes at the junction.

The PN Junction Diode

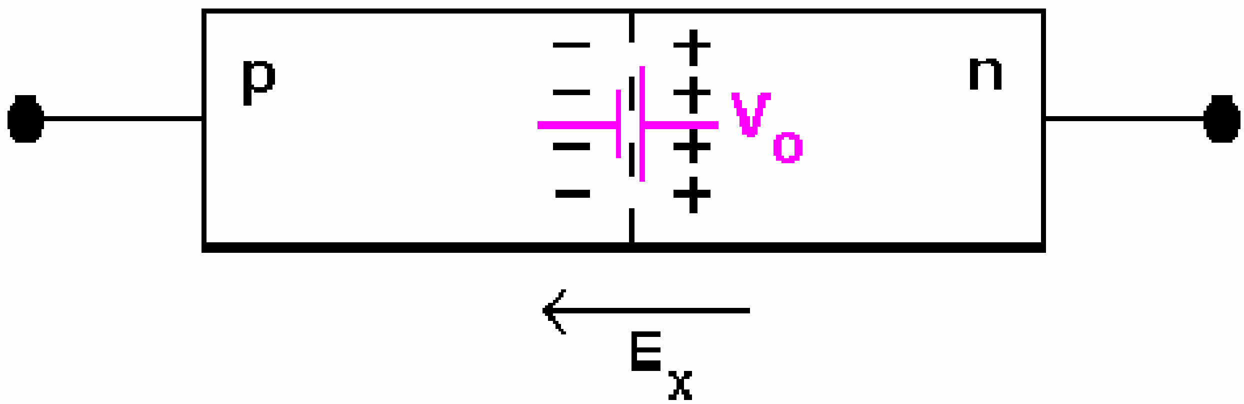
As a result of these large concentration gradients we would expect holes to diffuse to the right, (since $p_p >> p_n$)
& we would expect electrons to diffuse to the left (since $n_n >> n_p$)



Electrons would "fall down" the concentration gradient into the p-type region and holes would "fall down" the concentration gradient into the n-type region.

The PN Junction Diode

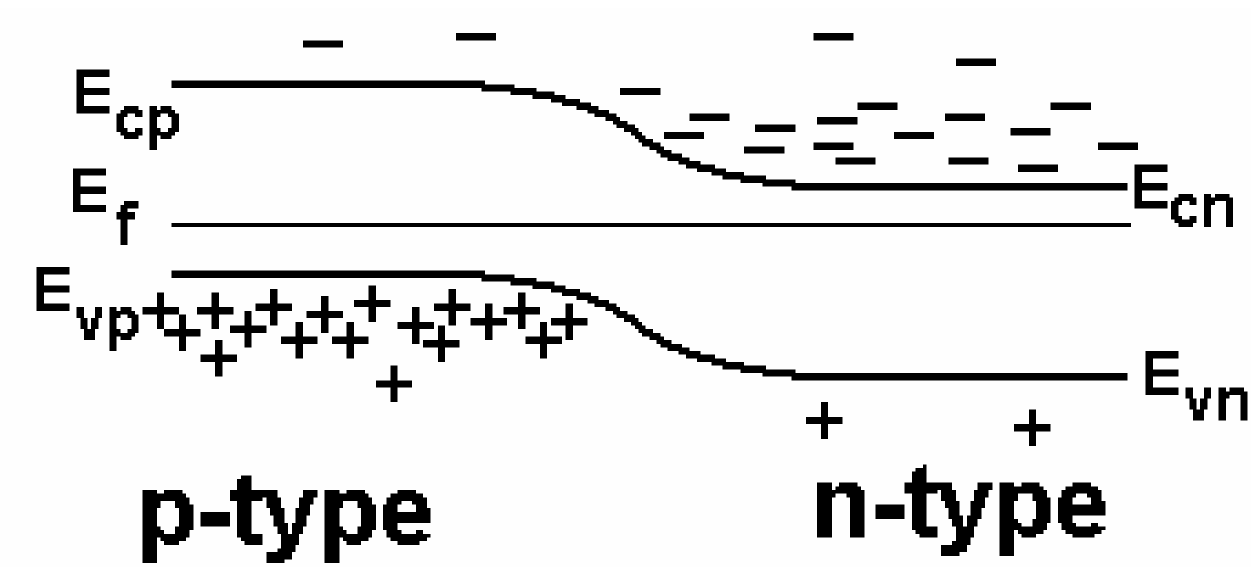
However, as holes diffuse out of the p-type region into the n-type region, they leave behind a fixed negative charge on the acceptor atoms.
Similarly, as electrons diffuse out of the n-type region into the p-type region, they leave behind a fixed positive charge on the donor atoms.



A double charge layer forms at the junction as shown above and this gives rise to an electric field, E_X, across the junction. The electric field direction is such that it tries to prevent further diffusion of carriers across the junction. Diffusion continues until the electric field is large enough to counter balance the force on electrons and holes produced by their respective concentration gradients. The voltage, V_O, is called the built-in voltage of the junction.

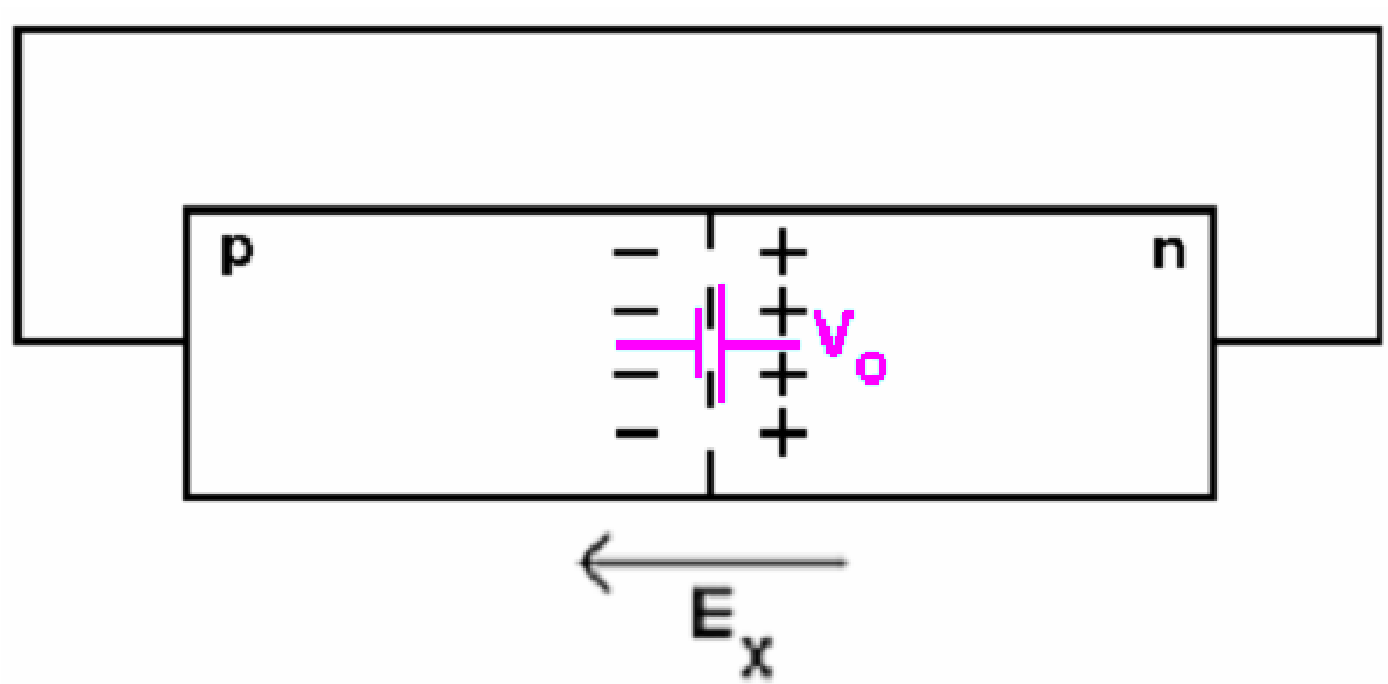
The PN Junction Diode

Another way of picturing this is by use of a band diagram showing the conduction and valence bands in the n- and p-type regions. As electrons diffuse into the p-type region and leave behind fixed positively charged acceptor atoms, a gradient appears in the conduction and valence bands which inhibits further diffusion of electrons to the left and holes to the right.



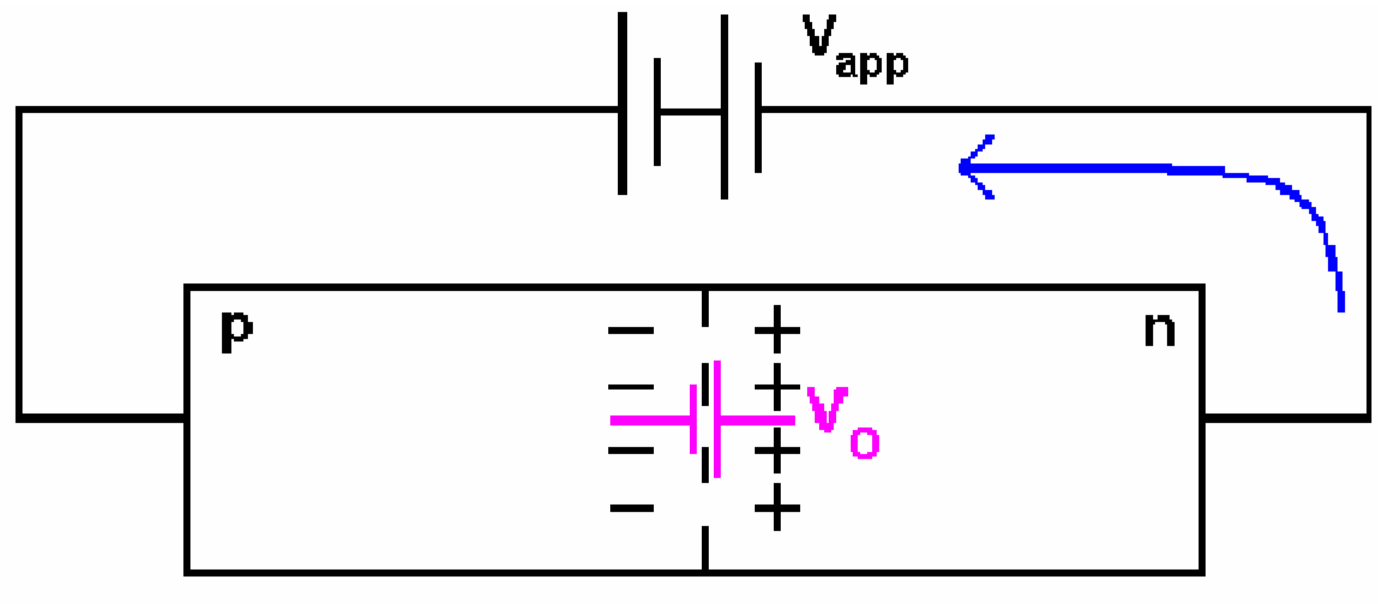
The PN Junction Diode

If a wire is connected across the pn junction, it might be expected that an external current would flow around the circuit. However, additional built-in voltages appear at the metal-semiconductor junctions which cancel out the diodes built-in voltage.



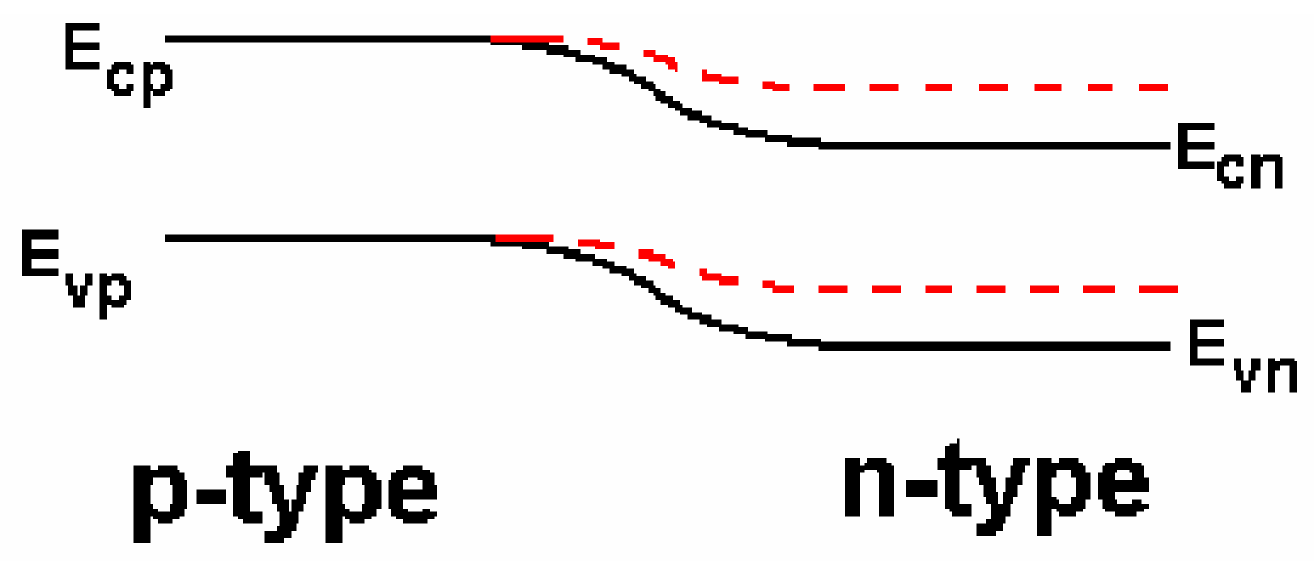
The PN Junction Diode

If an external voltage is applied as in the diagram, then the applied voltage counteracts the built in voltage of the diode and current flows through the diode. Conventional current flows in the direction shown.



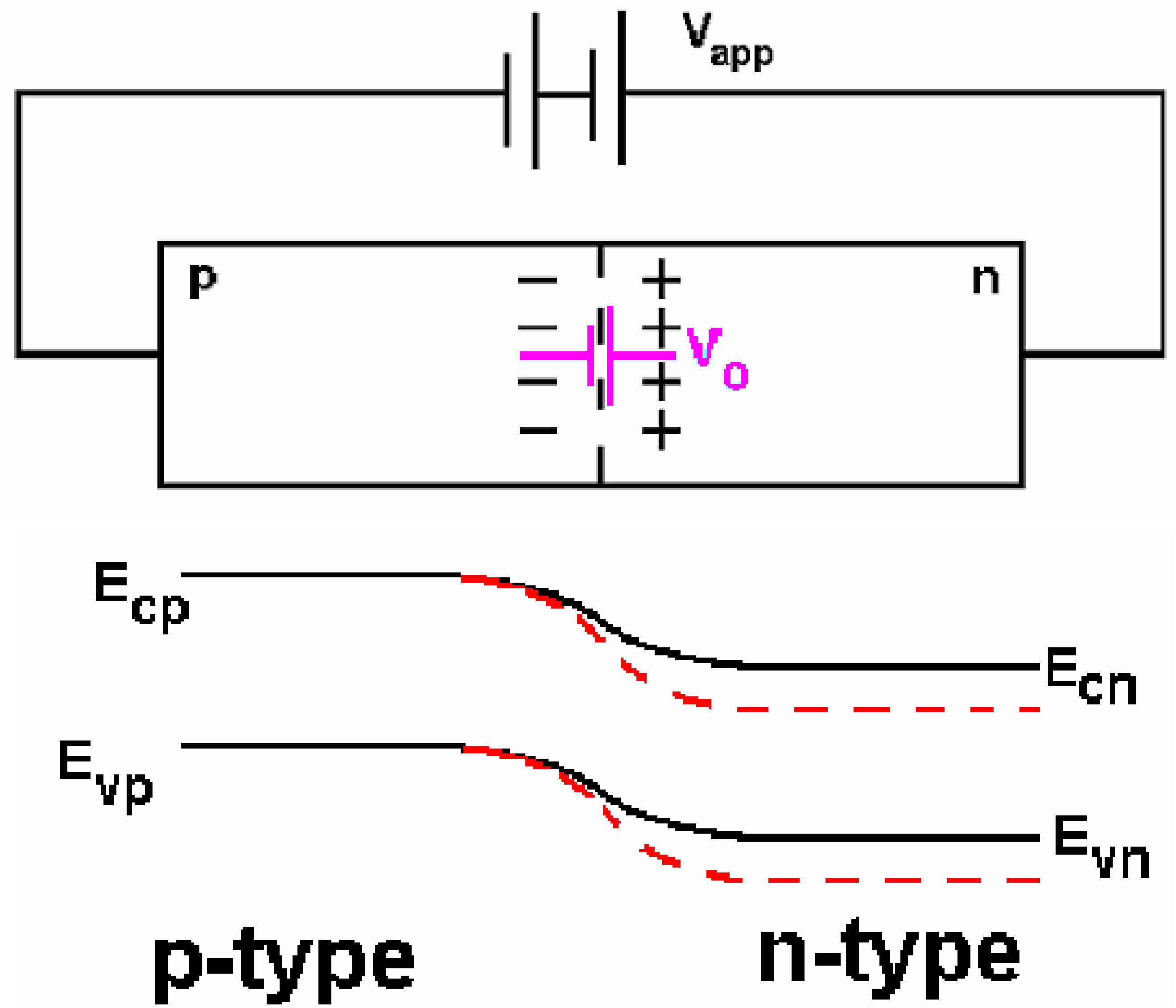
The PN Junction Diode

Again, we can view this from the perspective of the band diagram. When the external voltage is applied as shown in the last diagram, the slope in the conduction and valence bands is reduced, making it possible for electrons to surmount the barrier when moving from the n-type region to the p-type region.
A similar argument applies to holes moving to the right (remember that for holes, increasing energy is downwards rather than upwards).



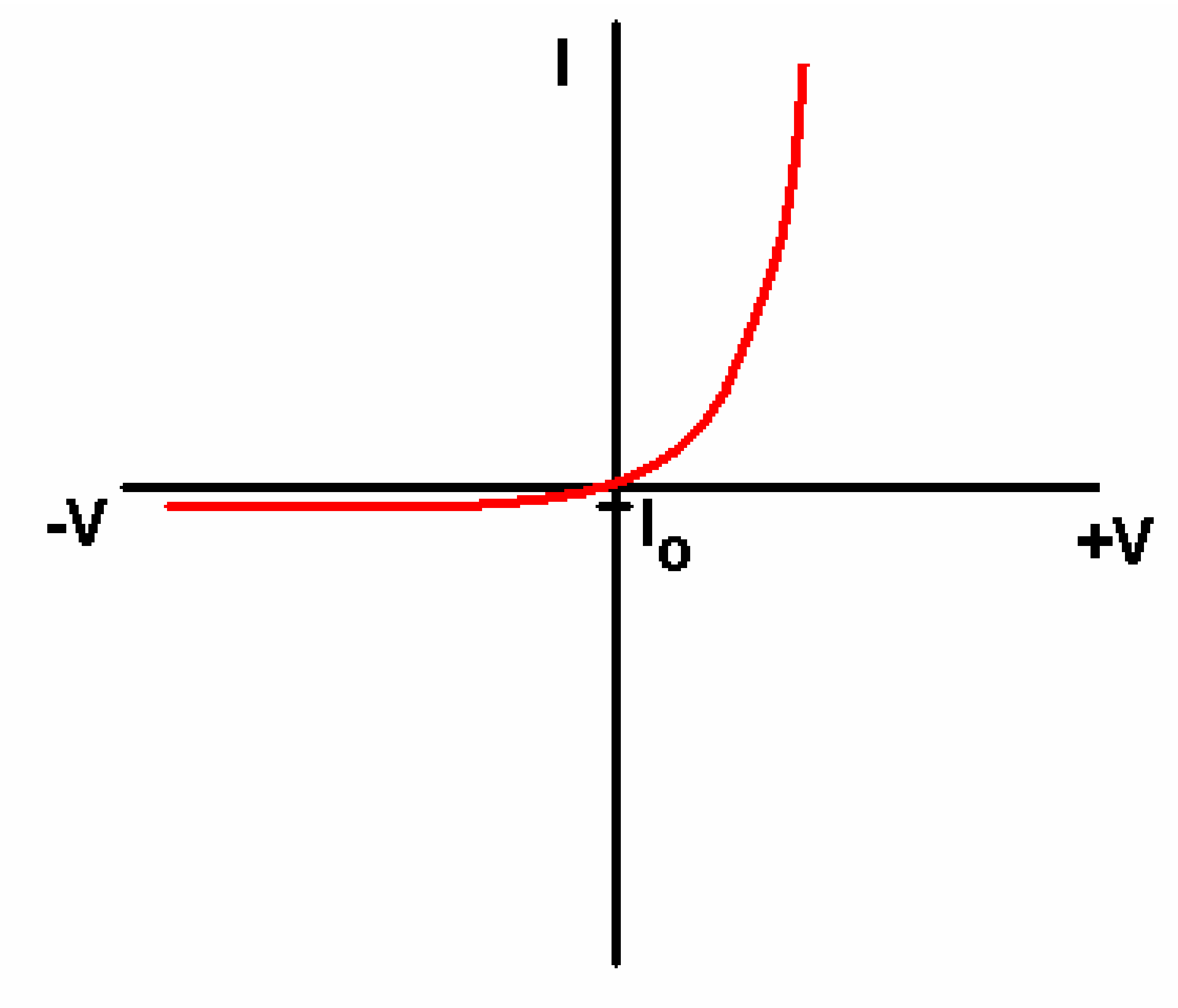
The PN Junction Diode

If the external voltage is applied as in the diagram below, then the applied voltage increases the built in voltage of the diode and very little current flows through the diode. This is called the reverse bias direction.



The I-V Characteristic of the PN Diode

If we plot the current passing through the diode as a function of the external applied bias, then we obtain a curve similar to that shown below, with the reverse current being virtually constant with voltage and the forward current increasing exponentially with voltage.



The I-V Characteristic of the PN Diode

The current, I, flowing through the diode at a voltage, V, is given by the equation -

$$I = I_o\,[\exp(eV_{app}/kT) - 1]$$

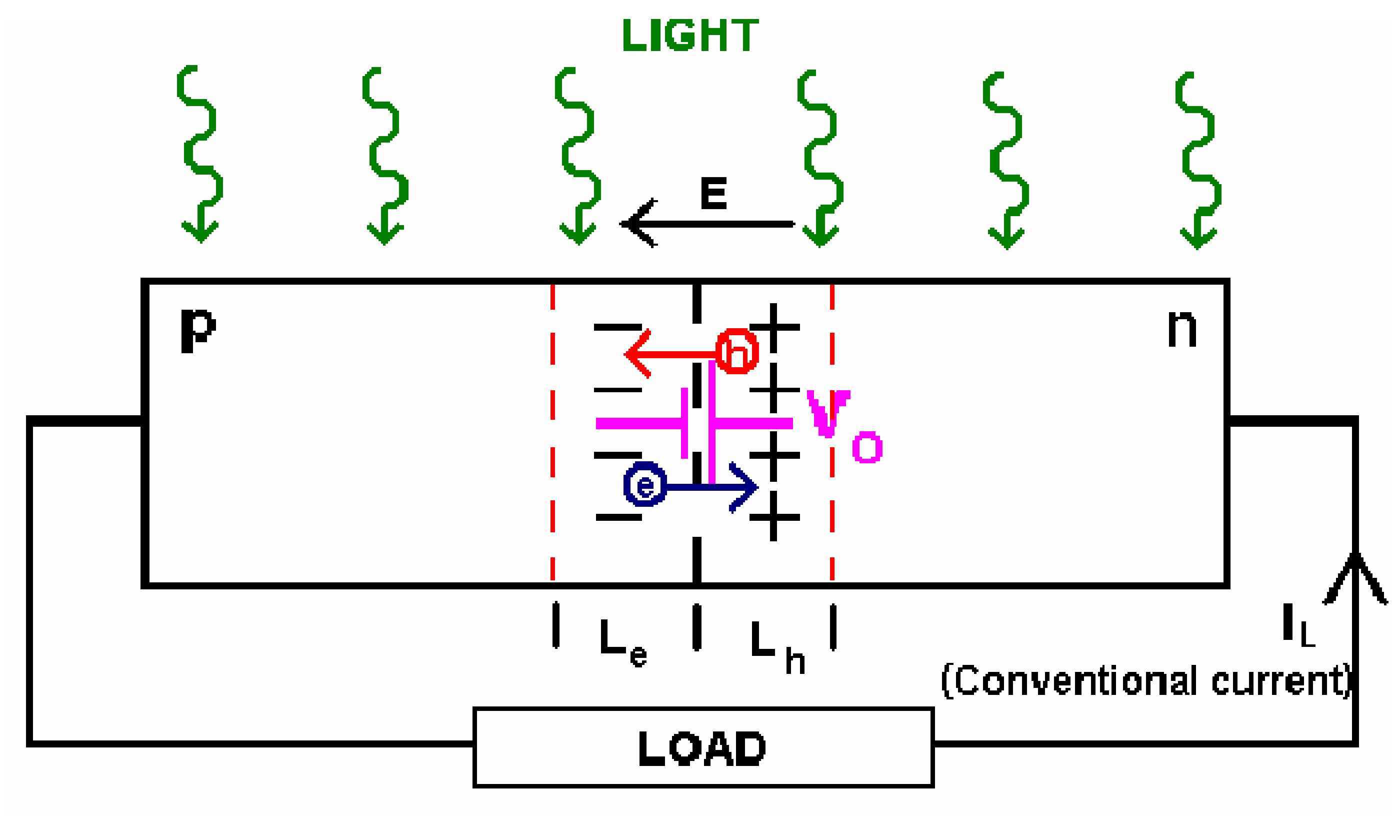
where

I_o = the saturation current
e = the electron charge
k = Boltzmann's constant
T = absolute temperature

When V is +ve $I = I_o\,[\exp(eV_{app}/kT)$
When V is -ve $I = -I_o$

Diode under Illumination

If $\lambda \leq \lambda_{max}$ falls on the diode, electron hole pairs are generated throughout the diode. Most of these are lost by recombination, since there is no electric field to separate them. Only those minority holes generated within L_h and minority electrons generated within L_e of the junction will give rise to an electric current. These charge carriers will be swept across the junction by the built-in electric field to produce a photocurrent.



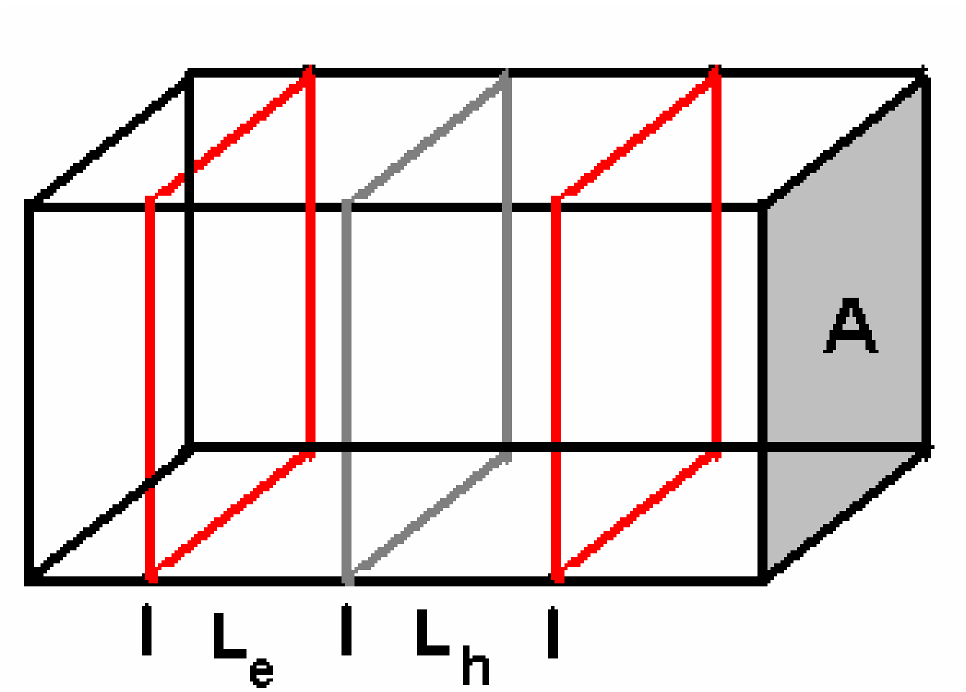
Diode under Illumination

Suppose that due to illumination the generation rate of minority electron-hole pairs is G_L.
The photocurrent due to holes, I_{Lh}, is given by -

I_{Lh} = (useful number of holes/sec) x e

= G_L x (useful volume) x e

= G_L (AL_h) e



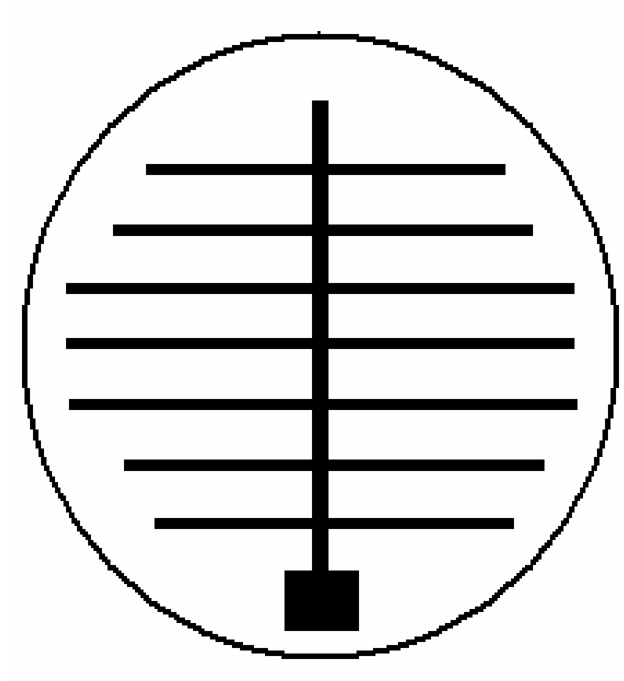
The photocurrent due to electrons gives an equivalent expression, so that -

$$I_L = G_L (AL_h) e + G_L (AL_e) e$$

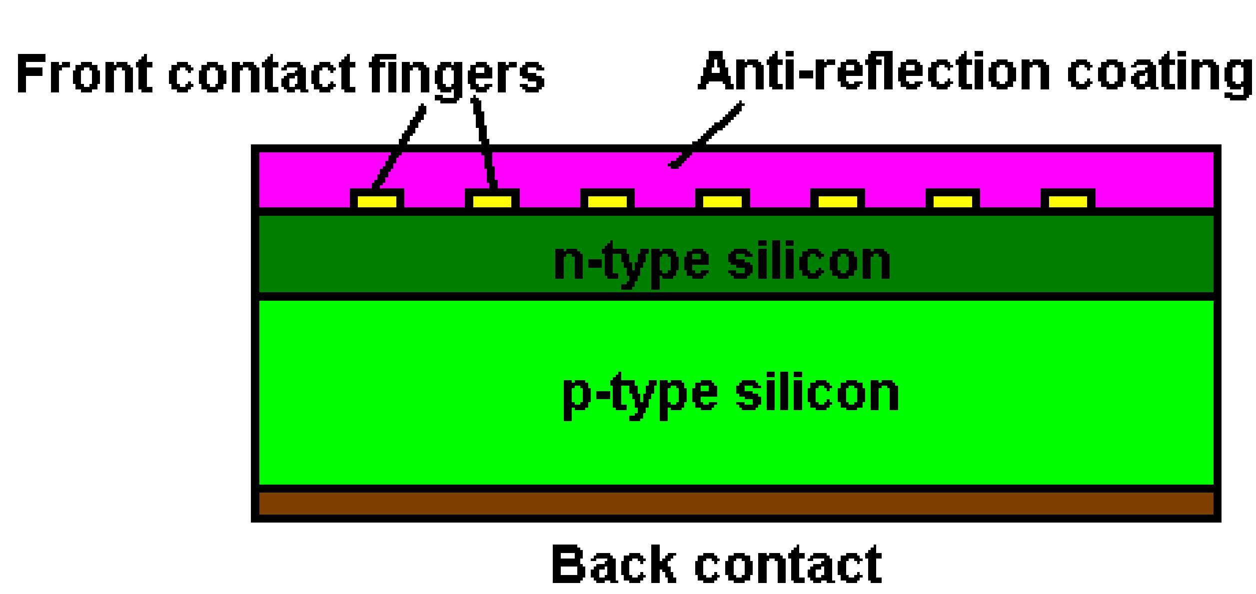
$$I_L = G_L A\, e(L_h + L_e)$$

For a large current, A and L should be large

Schematic of a typical silicon solar cell

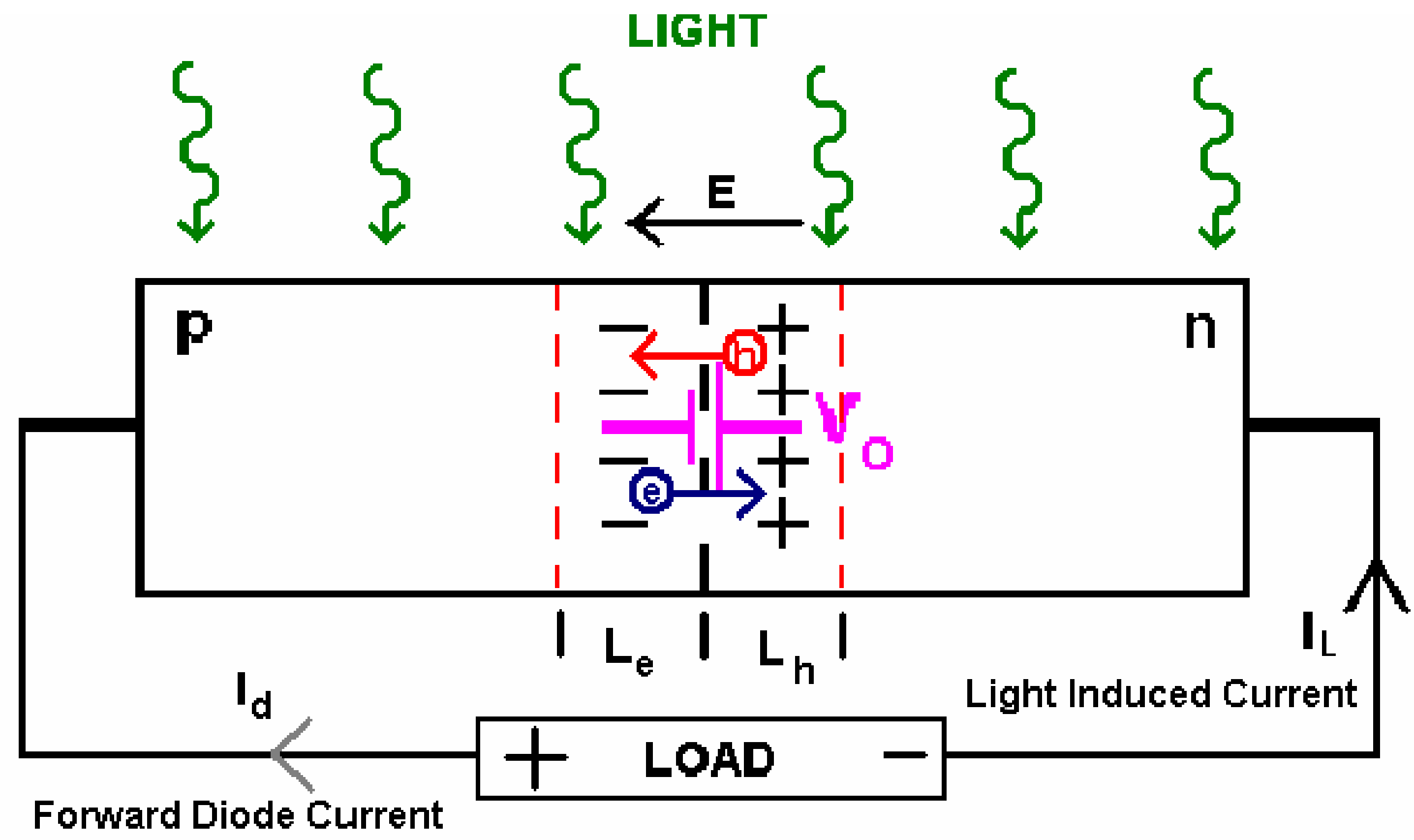


Plan View



Cross Section

Diode under Illumination



We need to think carefully about the currents flowing in the solar cell. When the solar cell is illuminated, a current flows in the circuit which generates a voltage across the load. This voltage then forward biases the diode and a forward diode current begins to flow in the opposite direction to the light-induced current.

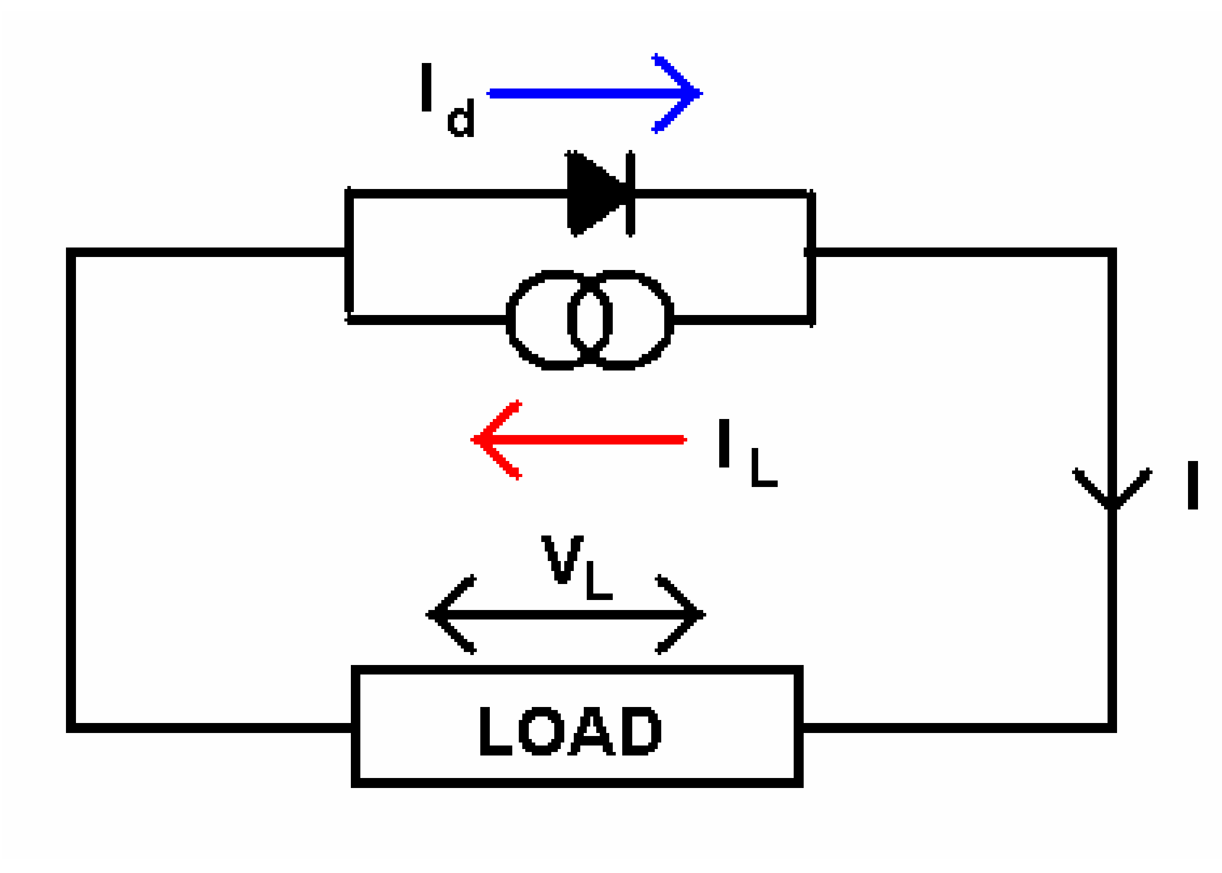
Equivalent Circuit of a Solar Cell

The photocurrent, I_L, generates a voltage across the load, which gives rise to a forward current flow through the diode, I_d, which is in the opposite direction.

Therefore, the total current $I = I_d - I_L$

so $$I = I_o\,[\exp(eV_{app}/kT) - 1] - I_L$$

We can therefore draw an equivalent circuit for the solar cell as shown below



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END OF LECTURE 2

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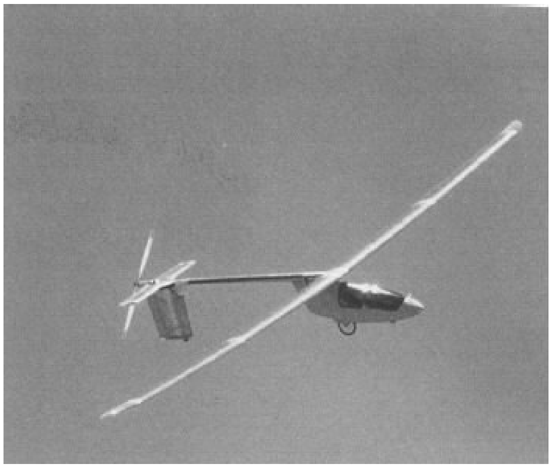

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Lecture notes :
Either at http://www.shef.ac.uk/webct/ or
http://hercules.shef.ac.uk/eee/teach/resources/MEC316/MEC316.html