Chapter 3.4 PN junction under light

- Solar Cell
- CIS Image sensor

Objective To understand the PN junction behavior under light and application to 'energy harvest from solar energy' and to the CMOS image sensor.

1. Semiconductor bar under light

Semiconductor behavior under the light can be easily understood by solving the continuity equation of minority carriers with G_L (generation rate due to illumination at the point).

dn/dt = -½ Å Fn + G_L -U. (1)

Under the low level injection, U = (n_p -n_{p0}) /¯$_n$ where ¯$_n$ is the monority carrier life time.

In the steady state with G_L is constant with Fn=0,

n_p= n_{p0} + ¯$_n$ G_L.

Now at t=0, the light is off, then the solution of (1) with the initial condition given by (2) is

n_p(t) =(n_p(0)- n_{p0}) exp(-t/¯$_n$) + n_{p0}.

A. G_L under solar light

The light shed on the surface of semiconductor is observed as it propagate into the semiconductor. The intensity of light I(x) in /cm^2 sec can be written as,

$I(x) = I_c \exp(-x/_L\ )$

where $_L$ is the obsorption coefficient.

$_L$ is a strong function of the wave length of light and 0 if

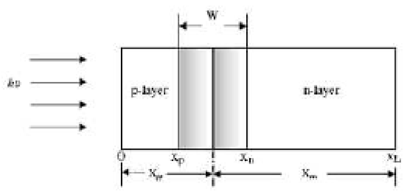
h© < Eg

where © is the frequency of the light.

The generation rate G(x) of charge carriers in the semiconductor layer at the depth x is given by;

$$G(x) = \int_0^{\lambda_{max}} [1 - R(\lambda)]\alpha(\lambda)N_{ph}(\lambda)e^{-\alpha(\lambda)x}d\lambda$$

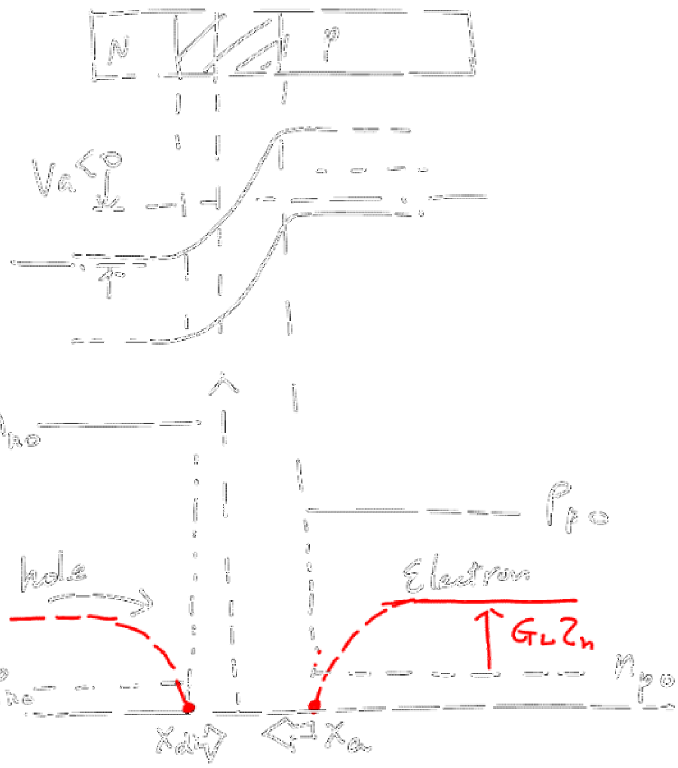
where is the absorption coefficient, Nph(§) is the incident photon flux, R(§) is the reflection coefficient at front surface. §max is the maximum wavelength determined by the condition that, each photon with energy h§ e Egap could generate electron-hole pairs.



<data> $_{L}$, vs wavelength

2. PN junction under the light

For a given $G_L(x)$ under the bias condition (Va + forward, - reverse bias), PN junction behavior under the light can be easily understood by solving the continuity equation of minority carriers with G_L (generation rate due to illumination at the point).



Electron Flux @ x_a:

$$0 = \frac{dn_p}{dt} = + D_n \frac{d^2 n_p}{dx^2} + G_L(x) - \frac{n_p - n_{p0}}{\tau_n}$$

- If $G_L(x)$ is constant,

$$n_p(x) = (\tau_n G_L + n_{p0})(1 - e^{-x/L_n}),$$

so $F_n(x = x_a = 0)$ is

$$F_n = -D_n \frac{(\tau_n G_L + n_{p0})}{L_n}$$

$$= F_{n,th} + F_{n,L}$$

- If $G_L(x)$ is not constant,

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$$F_n \simeq \int_{L_n} G_L(x)\, dx$$

Ex $\frac{D_n}{L_n} \tau_n G_L = \frac{D_n L_n}{L_n^2} \tau_n G_L = G_L L_n$

The total current in the PN junction with given $G_L(x)$ is sum of the normal component (thermal generation component in the reverse bias condition and the recombination component in the forward bias condition) and the light generation component.

The light generation component may be safely obtained by,

$$I_L = AJ_L = \int_{Lp} G_L(x)dx + \int_{Ln} G_L(x)dx + \int_{Wd} G_L(x)dx.$$

Here, it should be noticed that electrons generated in the P region are all collected by the N+ contact region, which means that electrons are not recombined with holes or traps during their excursion through the depletion region and the neutral n region.
In the case of organic solar cell, the recombination of electrons cannot be neglected since there are many reduction centers(traps) in the organic material.

A. Power delivered from Solar cell

The total 'Power conversion efficiency' of the solar cell is
£ = Maximum power delivered from the solar cell/ Pin.
Maximun power delivered from the solar cell can be obtained from the IV characteristics of the diode under the light.

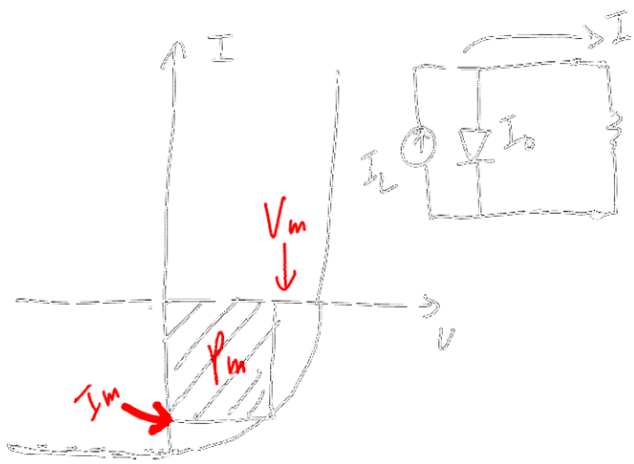


Fig. IV charicteristics of PN junction under illumination and its equivalent circuit

Power P can be written as,

$$P = IV = V(I_L + I_L)$$

$$= V(Is(exp(V/kT)-1) + I_L)$$

The condition for maximum power is obtained when dP/dV=0, or

$$Vm = Vt \ln\{ [1+ (IL/Is)]/[1+ Vm/Vt]\}$$

$$E \; Voc - Vt\ln(1+ Vm/Vt)$$

and $Im = Is(Vm/Vt)exp(Vm/Vt) \; E \; I_L (1- 1/(Vm/Vt))$

2. CIS Image sensor

As seen from an advertisement recently issued in the following and the feature of the chip, CMOS image sensor has been the major driving force for the image pick up device due to its compatibility with the CMOS technology, which is a strong advantage over CCD device. The operational principle of the CCD device will be treated when we study MOSFET device in chapter 5.

Sony Develops 35mm CMOS **Image Sensor** with 24.81 Effective

[Megapixel Resolution](http://www.cdrinfo.com/Sections/News/Details.aspx?NewsId=22386) from http://www.cdrinfo.com/Sections/News/Details.aspx?NewsId=22386

Major features

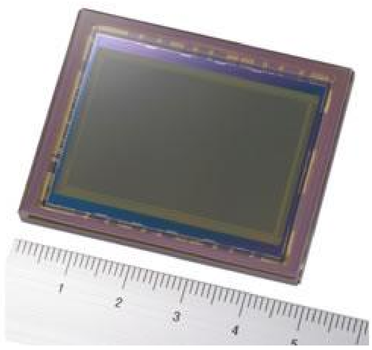
1. High picture quality in 35mm full size image sensor with 24.81M effective pixels

2. "Column-Parallel A/D Conversion method" achieves high S/N and high-speed imaging
- CDS/PGA(24dB)Circuit (PGA: Programmable Gain Amplifier)
- 12bit-AD Converter on chip
- Diversified readout mode
- All-pixel scan mode 6.3 frame/s (12bit)
- Window readout

3. High-speed digital output (12 channel parallel LVDS output)

Device Structure

Image size Diagonal: width 43.3mm (Type 2.7)
Total number of pixels: 6236(H) x 4124(V) approx. 25.72M pixels
Number of effective pixels: 6104(H) x 4064(V) approx.24.81M pixels
Number of active pixels: 6096(H) x 4056(V) approx.24.73M pixels
Chip size: 41.0mm (H) x 31.9 mm (V)
Unit cell size: 5.94?m (H) x 5.94?m (V)



- Operational principle

The CMOS image sensor has a simple structure composed of a

MOSFET switch and PN diode. The PN diode collects electrons from the light and the MOSFET transfers the electrons from the PN junction to drain to be able to process the signals from electrons.

The energy band diagram along x direction is drawn in fig. 4- , which means the doping concentrations in the NP region are adjusted in such a way that the N region is fully depleted in the 'no light' condition.

In the fig. below, the reverse bias is applied between the VPD and ground. As the depletion regions are extended from both P regions, N region becomes fully depleted.

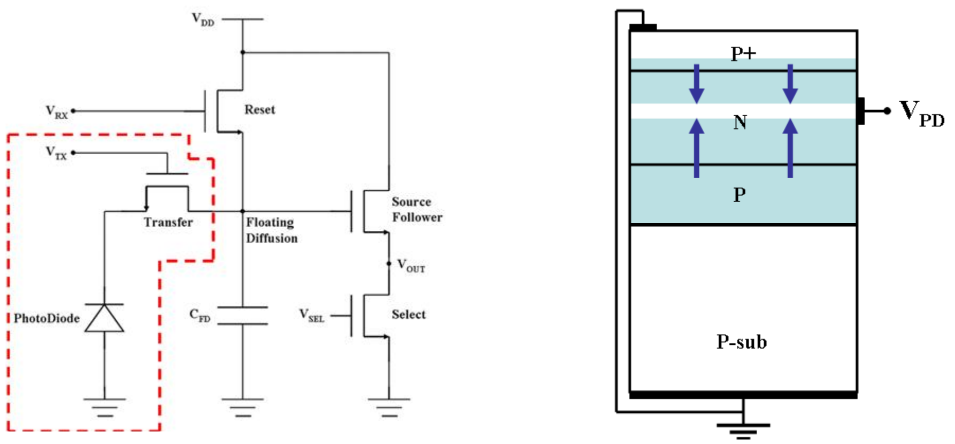


Fig. 4.

When light is on and electrons and holes are generated in the PN junction, holes are swept to the substrate and electrons are stored. The maximum electrons which can be stored in the PN junction is determined by the potential energy increased due to the charges in the potential well and the charge lost due to the 'lowering of the potential barrier' balanced each other.