Chapter 1 PN Junction

Introduction

1. Review: The main conclusions used for analyzing the PN junction

(1) Electron and hole concentrations in thermal equilibrium: n_0 and p_0:

For N-type semiconductor: majority carrier is electron and $n_{n0}=N_d$

minority carrier is hole and $p_{n0}=(n_i)^2/ n_{n0}$

For P-type semiconductor: majority carrier is hole and $p_{p0}=N_a$

minority carrier is electron and $n_{n0}=(n_i)^2/ p_{p0}$

(2) The nonequilibrium condition in which excess electrons △n and holes △p are present in semiconductor;

(3) There could be two kinds of currents in the semiconductor:

Drift current

Diffusion current

(4) The continuity equation, which is also called semiconductor equation and is used to determine the behavior of the semiconductor.

2. Main Points introduced for the PN junction

(1) The properties of the PN junction in thermal equilibrium.

(2) The DC current-voltage characteristics of the PN junction diode, including the breakdown phenomenon.

(3) The AC characteristics of the PN junction diode,

Including the diffusion capacitance and junction capacitance effects.

(4) The Switching transients.

3. Why we should discuss the PN junction?

(1) The PN junction itself is a device called diode, that coulde be used as rectifier、switch etc.

(2) The PN junction is the basic structure of most semiconductor devices, including BJT、MOSFET、JFET we will discussed later.

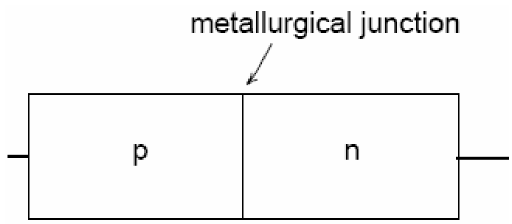
(3) The fundamental analysis techniques used for the PN junction will also be applied to other devices.

1.1 Basic Structure of The PN Junction

1. The formation of PN junction and its doping profile

(1) Metallurgical junction and PN junction

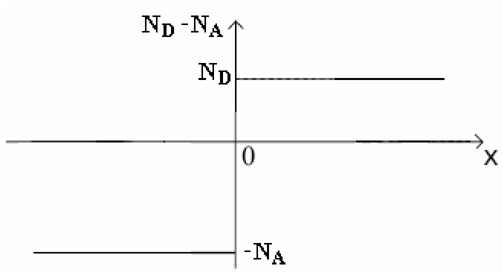
Metallurgical junction: The interface seperating the n type region ang p type region.



PN junction: A narrow region around the metallurgical junction, where the behavior is different from the single N type region or the single P type region as we will discussed in this chapter.

(2) The 1st typical structure of the PN junction－Alloyed junction

Step junction：The impurity on both side of PN junction are uniformly doped, that is the doping concentration is uniform in each region and there is an abrupt change in doping at the Metallurgical junction.



One sided step junction: A step junction where the doping concentration in one region is much larger than the doping concentration in the other region, that is $N_A >> N_D$ or $N_D >> N_A$

(3) The 2nd typical structure of the PN junction－diffused junction

Graded junction：The impurity are doped into a uniformed doped substrate semiconductor by diffusing process, so that the doping concentration is not uniform in the PN junction region and the change in doping at the netallurgical junction is graded.

Linearly Graded junction: as a first approximation, the net doping concentration near the metallurgical junction may be considered as a linear function of distance.

2. The electrostatics of PN junction: taking the step junction as an example for analyzing.

(1) Basic structure of the step PN junction for discussing:

P type region: let $N_A=10^{16}/cm^3$, so that

$p_{p0}=10^{16}/cm^3$, and $n_{p0}=(10^{10})^2/10^{16}=10^4/cm^3$.

N type region: let $N_D=10^{16}/cm^3$, so that

$n_{n0}=10^{16}/cm^3$, and $p_{n0}=(10^{10})^2/10^{16}=10^4/cm^3$.

(2) What happens after the formation of the PN junction

① there is a very large density gradient in both the n and p concentration

→② the majority carrier holes in the p region will begin diffusing into the n region

→③ the negatively charged acceptor atoms $(N_A)^-$ are left behand, and similarly as electrons diffuse from the N region into P region, they uncover the positively charged donor atoms $(N_D)^+$

→④ the net positive and negative charges in the N region and P region $(N_D)^+$ and $(N_A)^-$ induse an electric field in the region near the metallurgical junction, in the direction from the N to the P region

→⑤ the electric field produces a force on the electrons and holes, producing a drift in the opposite direction to the diffusion

→⑥ in thermal equilibrium, the diffusion and the drift exactly balance each other.

conclusion: in thermal equilibrium, there exists a space charge region near the metallurgical junction, but there is not any current flowing through the PN junction.

(3) The 1st important point of the PN junction—depletion layer

The space charge region is composed of the fixed $(N_D)^+$ and $(N_A)^-$, and depleted of any mobile charge carriers n and p, so that this region is also referred to as the depletion layer.

depletion layer approximation: as a first approximation, we can make the following approximation

within the depletion layer, both the n and p are all zero, i.e $n=p=0$

outside the depletion layer, both the n and p are all equal to their equilibrium concentration.

That is to say, at the boundaries of the depletion layer the n and p changes abrutly from equilibrium concentration to zero.

We use $-x_p$ and x_n to denote the position of the boundaries of the depletion layer.

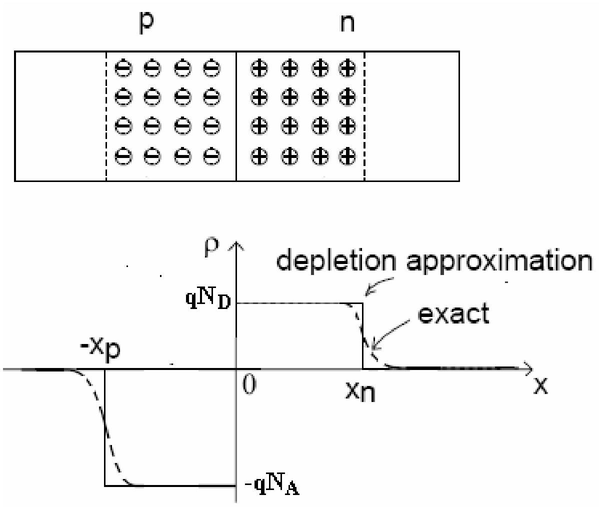
(4) The 2nd important point of the PN junction—space charge region

For step junction we can get the following relations of the density of space charge based on the depletion layer approximation:

the density of space charge per unit junction area:

$$\rho(x) = +qN_D \quad \text{for } 0 < x < x_n$$

$$\rho(x) = -qN_A \quad \text{for } -x_p < x < 0$$



the width of space charge W is: $W = x_n + x_p$

From the electric neutrality condition, there should exist the relation:

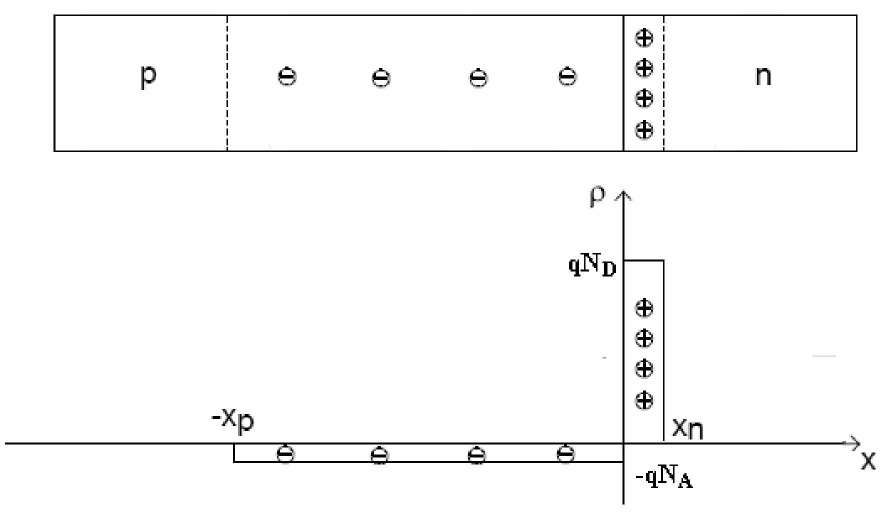
$$N_a\, x_p = x_n N_d$$

For one sided step junction, for example P^+N junction,

$$N_d >> N_a, \quad \text{then} \quad x_p >> x_n$$

so that $W \approx x_p$

that is to say, the entire space charge region nearlly all extends into the low-doped region of the junction.



(5) The 3rd important point of the PN junction—potential barrier

Because there exists a electric field in the space charge region pointing from n region to p region, there must be a electric potential difference between the n region and p region according to the electrostatics.

The potential difference is also called potential barrier, denoted as V_{bi}, where bi stands for built-in.

Conclusion:

① In thermal equilibrium, the PN junction region is a space charge region, also referred to as depletion region, or potential barrier region.

② The width of the space charge region is: $W= x_n+ x_p$

③ For one sided step junction, the entire space charge region nearlly all extends into the low-doped region of the junction.