Determination of the density distribution of holes injected into an N-Type material

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ABSTRACT

The density distribution of holes injected into an n-type material was studied using continuity equation which was applied to diffusion equation with some boundary conditions such as; N_h (x=0), for an injected hole density and N_h (x →∞), for equilibrium of hole density in the n-type material. The meaning of semiconductor and its basic characteristic properties were))For equilibrium hole density in the n-type material. The meaning of semiconductor and its basic concepts and characteristics properties were extensively and exclusively discussed. The meaning ofbasic concept and chwere extensively and exclusively discussed. The meaning of hole and its basic concepts were also explained. Our ability to develop the mathematical concept to calculate the density of holes injected into an n-type material will help in providing the best way to understanding the basic operations existing semi-conductor devices which is the backbone of electronic industries.

Key words: Semiconductor, effective mass of electron, carrier lifetime, drift, holes and continuity equation.
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INTRODUCTION

N-type material is a the doped semiconductor materials. Doping is the process of introducing a small number of suitable replacement atoms (called impurities) into the semiconductor lattice (3). The idea of doping is to make the semiconductor materials useful and well improved. Semiconductor itself is materials which can conduct electricity to an extent.

It is a material that has intermediate conductivity between a conductor and an insulator. It means that semi-conductor have unique properties somewhere in between a conductor like aluminum and insulator by doping a giving pure semiconductor, the conductivity of a material changes abruptly (4).

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In n-type semiconductor, the majority carrier is the electron while the minority carrier is the hole. Our objective is therefore to determine the density distribution of holes injected into an n-type material using continuity equation. This will help in controlling the percentage impurity in a doped p-type and n-type semiconductor depending on what the manufacturer wants, thereby making electronic circuitry much cheaper and more compact leading to subsequent improvement in the performance in the technology of semiconductors.

MATERIALS AND METHODS

The method involved solution of continuity equation with specified boundary conditions. The charge density $\rho(x,t)$ is related to the current density $J(x,t)$ by the continuity equation

$$\frac{\partial \rho}{\partial t} + \nabla.J_h = 0 \quad \text{-------------------------- (1)}$$

For the holes, current density is given as

$$J_h = -q \, D_h \frac{\partial \rho}{\partial x} \quad \text{----------------------------------- ------- (2)}$$

So that equation (1) becomes

$$\frac{\partial \rho}{\partial t} = -\nabla. \, q \, D_h \frac{\partial \rho}{\partial x} \quad \text{-------------------- (3)}$$

Where D_h is diffusion constant, q is charge and ρ is the hole density.

In order for us to calculate the density distribution of the hole, equation (3) is to be solved using continuity equation by subjecting equation (1) to the following boundary conditions;

    i) $\frac{\partial \rho}{\partial t} = 0$; $N_{h\,(x=0),}$ for injected hole density

    ii) $\frac{\partial \rho}{\partial x} = 0$; $N_h\,(x\to\infty)$, for equilibrium hole density in the n-type material.

Sequel to the diffusion and calculation of the density distribution of holes in n-type material, using continuous equation, some basic properties of semiconductor and its measurement has to be considered.

MOBILITY

Mobility is defined as the carrier drift velocity for unit field and is given as
$$\mu = \frac{v}{\epsilon} \quad \text{------------------------------ (4)}$$

Carrier mobility is measured by measuring the drift velocity caused by a known direct current (d.c) in electric field, provided an electric current remains constant in conductors and in doped

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semiconductor, mobility of carrier can be effectively deduced by measuring the distance, voltage and the drift velocity by taking the time required to move from one point to another (7,8,).

THE EFFECTIVE MASS
The mass on an electron in a crystal appears generally different from the free electron mass, and is usually referred to as effective mass. The standard method of measuring effective mass is to use the phenomenon of cyclotron resonance absorption which involve this is an interaction of electromagnetic wave with charge carriers, which leads to an absorption of the wave when the magnetic field causes the electron to vibrate at the same frequency as that of the applied electric field (6 and 8)

DISCUSSION

CARRIER LIFETIME
In the study of semiconductor, we are particularly interested in the minor carrier lifetime which is as a result of injection or optical generation; the minor carrier density may be considered above the thermal equilibrium value, where as the change in density of majority carriers is generally insignificant. For instance, silicon with 10^{22} fully ionized impurities per cubic meter. But silicon is about $10^{10}m^{-3}$ at room temperature, suppose that in addition of 10^5 electron-hole pairs per cubic meter are created by input light, the hole density in the silicon will then increase by a huge factor of 10^5, but the change in electron density will be on imperceptible 10^{-5}%. Thus using a circuit of which the current flowing in it consists mainly of holes created by the input light. If the light is switched off at $t=t_0$, the current (and also the voltage) across the resistance in the circuit declines and from the curve the lifetime of the holes can be determined (8).

DRIFT
Considering the drift phenomenon, when no electric field is applied to the semiconductor which is above 0^oK, the conduction electrons (as well as holes) repeatedly collide with each other and the fixed ions. Due to randomness of their motion, the net average velocity of these charge carriers in any given direction is zero. Hence, no current exist in the crystal under condition of no field. But when an electric field is applied to the crystal, carriers attain a directed motion which is superimposed on their random thermal motion. These results in a net average velocity called drift velocity in the direction of the applied electric field. The electrons and holes move in opposite directions, with opposite charges, as a result, they both produce current in the carrier flow in the extrinsic semiconductors. The drift velocity is proportional to the field strength ϵ, the constant of proportionality is called the mobility, μ. hence the exact relationship between field strength of electricity and drift velocity is given by

$v=\mu\epsilon$ (2 and 6) ------- ------------(5)

HOLES
A hole in semiconductor physics is an electric charge of a positive charge equal in magnitude but opposite in polarity to the charge on electron. A hole is the absence of an electron in a particular place in atom. In n-type material, hole is a minority carrier responsible for current in semiconductor material. Although, a hole is not a physical particle, but it can pass from atom to atom in a semiconductor material. A hole forms an atom when an electron moves from the bands

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or shells into the conduction band from which electrons must easily escape from, or are accepted by the atom (3 and 4).

From the foregoing,

The current density of a hole

$J_h = -qD_h\frac{\partial\rho}{\partial x}$ ------------------------- (6)

In other to derive the density of hole,

We recall from equation (3) that

$\frac{\partial\rho}{\partial x} + \nabla. J_h = 0$ ----------------- (7)

Using equation (6) in equation (7), the value of $J_h(x,t)$ will be determined. Our aforementioned boundary conditions are to be considered

$\frac{\partial\rho}{\partial t}$ =0; N_h (x=0), for injected hole density

$\frac{\partial\rho}{\partial t}$ =0;N_h (x→ ∞), for equilibrium hole density in the n-type material.

Equation (7) can also be formally written as in 3-dimention

$\frac{\partial\rho}{\partial t} + (\frac{\partial}{\partial x} + \frac{\partial}{\partial Y} + \frac{\partial}{\partial Z})$ $J_{h\,=\,0}$ -------------------- (8)

In one dimension
$\frac{\partial\rho}{\partial t} = \frac{\partial}{\partial x}$ (J_h) =0 ---------------------- (9)

Substituting equation (6) into equation (9), we have
$\frac{\partial\rho}{\partial t} + \frac{\partial}{\partial x}$(-qD$_h\frac{\partial\rho}{\partial x}$) =0 -----------------(10)

This implies that
$\frac{\partial\rho}{\partial t}$ –qDh $\frac{\partial^2\rho}{\partial x^2}$ =0 --------------------- (11)

This is one-dimensional diffusion equation

Applying the method of separation of variables by assuming ρ (x,t) = X(x)T(t)

Where X and T being respectively functions of x and t.

Such that

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$\frac{\partial \rho}{\partial t} = X\frac{dT}{dt}$ ------------------- (12a)

And

$\frac{\partial^2 \rho}{\partial x^2} = T\frac{d^2 X}{dx^2}$ ------------------- (12b)

Substituting equation (11) into (12), we have

$\frac{1}{X}\frac{d^2 x}{dx^2} = \frac{1}{qDh} \, T \, \frac{dT}{dt}$ -------------- (13)

Let $K^2 = qD_h$, than equation (13) becomes

$\frac{1}{X}\frac{d^2 x}{dx^2} = \frac{1}{K^2}\frac{dT}{dt}$ --------------- (14)

Equation (14) is separating variables and can be written as

$\frac{1}{X}\frac{d^2 x}{dx^2} = \frac{1}{k^2 T}\frac{dT}{dt} = -\lambda^2$ ---------------- (15)

Where X is a Constant of the separation

Hence $\frac{1}{X}\frac{d^2 x}{dx^2} = -\lambda^2$ ------------------- (16)

This implies that

$\frac{d^2 x}{dx^2} + \lambda^2 X = 0$

$\therefore \; X(x) = A\cos \lambda x + B\sin \lambda x$--------- (17)

And $\frac{1}{K^2 T}\frac{dT}{dt} = -\lambda^2$

Implies that

$\frac{dT}{dt} + k^2\lambda^2 T = 0$

$T(t) = Ce^{-\lambda^2 k^2 t}$

The solution of equation (11) is then
$\rho(x,t) = X(x)T(t)$

$= (A\cos\lambda x + B\sin \lambda x)e^{-\lambda^2 k^2 t}$ ------ (20)

C is a constant and can be absorbed.

Applying the boundary conditions;

$\frac{\partial y}{\partial x} = -\lambda^2 k^2(A\cos\lambda x + B\sin\lambda x)e^{-\lambda^2 k^2 t}$ -----(21)

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Hence $\frac{\partial \rho}{\partial t}|_{x=0} = \lambda^2 k^2(A)e^{-\lambda^2 k^2 t} = 0$ ---------(22)

when A $=0$

$\therefore \rho(x,t) = B \sin\boldsymbol{\lambda}x\, e^{-\lambda^2 K^2 t}$ -------------------- (23)

Equation (23) gives the density distribution of hole injected into the n-type material

CONCLUSION

In this work, we have successfully applied theoretical concepts using equation of continuity to determine the density of holes in n-type material. Hence, it is now possible to experimentally verify the theoretical equations applicable to the movement, diffusion and lifetime of holes as a minority carrier in order to determine the density of holes.

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