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Effect of Various Radiations on the Working of P-N Junction Diode

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ABSTRACT: This paper presents the behaviour of various radiations (i.e., solar, x-ray, gamma, and neutron) on the working of p-n junction diode. A number of p-n junction diodes have been exposed to various radiations. In the experiment I-V characteristics (current dependence on voltage) of these p-n junction diodes have been measured after irradiation. The electrical characteristics of p-n junction diode can be analysed by current-voltage (I-V) measurement. This paper investigates various irradiations by its electrical characteristic of different radiations exposure time. A brief review of surface physics is given as background for the subsequent discussion on the role of surfaces in the behaviour of semiconductor devices. The amount of work done on non-passivized diodes which may be discussed in terms of the surface effects of radiation is rather limited. Nevertheless, some interesting effects have been observed on diodes and deserve a discussion at this point.

KEYWORDS:P-N junction diode, solar radiations, X-rays, Gamma radiations, Neutron radiations, I-V characteristics.

I.INTRODUCTION

The main purpose of this research is to help in making of the instruments and devices that contain the p-n junction diode as its component and are capable of working in the environmental conditions effected by the various kind of radiations that are discussed here. From the provided discussion it will be clear that how the p-n junction diode used in the various applications will get affected by various radiations and how they can be solved accordingly to use that device or instrument in the harsh conditions where these radiations may affect their working. As known from the previous knowledge we can make use the solar radiations to use it in various applications as required. Likewise various other radiations can be used that are unknown till now due to their side effect on semiconductors. Hence to resolve it the study of effect of various radiations on semiconductor is necessary.

Semiconductor devices are widely used as radiation detection in a large variety of fields such as nuclear physics, elementary particle physics, optical, x-ray astronomy, medicine, material testing and so on.Ifthe semiconductor exposed to radiation is part of a device, the device characteristics will change; the changes depend on such factors as the nature and energy of the radiation, the materials and geometry of the device, and even the processes used in manufacturing the device. The changes in characteristics which occur when these effects take place in the bulk of a device have been investigated for some time and are quite well understood in terms of the usual physics of solids. However, effects can also occur at the surface of a device, giving rise to the so-called surface effects which have only more recently received attention and which are governed by the less well understood physics of surfaces. The aim of this paper is to investigate a detailed characterization of radiation defects in P-N junction diode by the irradiation. X-rays are induced defect at 5 and 15 second, while defects reduced after irradiation at 125 second. The result shows that the time of X-ray exposure at 75 and 125 second can reduced defect in P-N junction diode.X-ray and γ-radiation are formed by electromagnetic radiation; they can interactwith matter in three types. 1. Photo Effect; 2. Compton Effect and 3. Pair production. The x-ray and γ-radiation are extremely short wave length, the x-ray is from 10E-9m to 10E-12 and γ-radiation is from 10E-12 to 10E-14 which finds many important applications in since and medicine. Increases in temperature reduce the band gap of a semiconductor, thereby effecting most of the semiconductor material parameters. The decrease in the band gap of a semiconductor with increasing temperature can be viewed as increasing the energy of the electrons in the material. Lower energy is therefore needed to break the bond. In the bond model of a semiconductor band gap, reduction in the

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bond energy also reduces the band gap. Therefore increasing the temperature reduces the band gap. The open-circuit voltage decreases with temperature because of the temperature dependence of I_0.It is well known that nuclear radiation can destroy or substantially degrade the performance of semiconducting electronic devices and systems. The permanent damage can be estimated from an analysis of their pre and post irradiated electrical characteristics. As a first step in understanding the radiation damage mechanisms in such devices, it was decided to study the electrical characteristics of different variety of diodes including p-n junction, p-i-n and Schottky diodes. Degradation of electrical parameters and eventual total failure of such devices can begin at as low as (10"l-1012) n/cm2 1 MeV equivalent fluence range. Such devices are amongst the simplest of all semiconducting device structures and the corresponding results are therefore more amenable to analysis. An in-depth investigation of nuclear radiation effects on these devices can also lead to a better understanding of radiation effects in more complex semiconducting devices consisting of 2 or more p-n junctions. Radiation damage in a semiconducting device occurs mainly due to Ionization and displacement damage in semiconducting materials and oxide barrier regions of the device. The results at the moment are somewhat confused, contradictory, and incomplete. It is hoped that this summary may help to illuminate the problem and suggest paths for future studies. A brief discussion of the present physical theory of surfaces, as required for an understanding of device degradation, will be given before starting a discussion of experimental results and specific models for radiation effects on surfaces since it is against this background that radiation effects must be explained.

II.EXPERIMENT

1. Solar radiations:-

P-N junction has optical generation of carriers that may be swept across the junction by the drift field. Optical generated carriers are swept from being minority carriers on one side to being majority carriers on the other. How is the IV equation affected by the optical generation? We can solve for the IV equation. This means the differential equation to be solved for the carrier concentration increase is given by:

$$\frac{d^2n(x)}{dx^2} = \frac{\Delta n}{\tau_n D_n} - \frac{G(x)}{D_n}$$

We simplify by assuming that the generation is constant (solving it otherwise is a nightmare) means we get the following simple solution to the differential equation:

$$\Delta n(x) = Ae^{-x/L_n} + Be^{x/L_n} + G\tau_n$$

We can proceed in an identical manner as for the un-illuminated case i.e. differentiate the carrier concentration increase to find the current and then equating the currents on the p and n sides of the junction, we then end up with:

$$J = \left[q\frac{D_n}{L_n} n_{p0} + q\frac{D_p}{L_p} p_{n0} \right] \left[e^{qV/kT} - 1 \right] - qG\left(L_n + L_p + W\right)$$

This means the light generated current is simply a superposition on top of what we get for the un-illumined case. We bundle this information up in the following expression:

$$J = J_0\left[e^{qV/kT} - 1\right] - J_L$$

$$J_L = qG\left(L_n + L_p + W\right) \qquad J_0 = q\left[\frac{D_n n_i^2}{L_n N_A} + \frac{D_p n_i^2}{L_p N_D}\right]$$

Meaning of I_0:

We want to extract the light generated current with a forward bias meaning the diode current determined by I_0 works against the light generated current. The first term is a recombination current found by considering the diode without illumination – often referred to as the dark current. We therefore want to reduce I_0 to as low a value as possible in order to be able to extract as much light generated current as possible.

$$J = J_0\left[e^{qV/kT} - 1\right] - J_L$$

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Short Circuit:
Means no load attached but current can flow. Recombination is essentially what we expect for thermal equilibrium and can be ignored.

$$J_{SC}= J_0\,(e^{q.0/kT}-1) - J_L= J_0(1-1) - J_L = -J_L$$

Open Circuit:
Infinite load attached – no current flow.

$$J=J0\,(e^{Qvoc/nkT}-1) - JL=0$$

Reverse Bias:
Deliberately reverse bias the diode that is under illumination – diffusion current is switched off. Current seen is essentially equal to the light generated current – slight increase seen but if I_0 is low we can neglect. Assuming that we get ~100% extraction of photons absorbed and absorption is good then the current is proportional to the number of photons with energy above the bandgap.

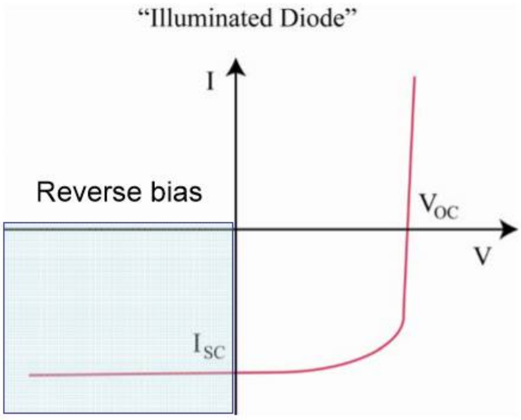

Figure 1: I-V characteristics of diode during illumination in reverse biasing

Forward Bias:
What if we deliberately make the recombination of carriers very unlikely and shine light on it?According to the IV characteristic we need a forward bias to raise the dark current to kill off the light generated current – this is V_{OC}. This implies power is being generated by the diode.

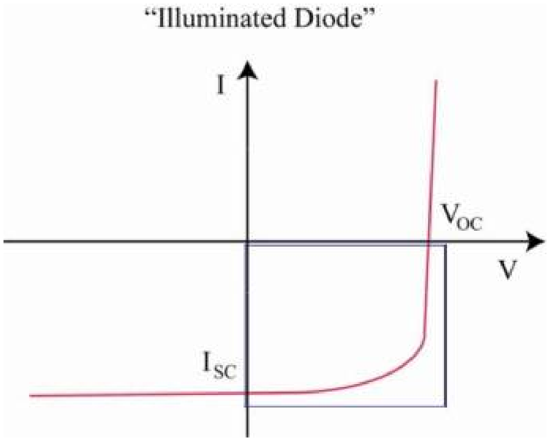

Figure 2: I-V characteristics of diode during illumination in forward biasing

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2. Neutron radiations:-

FORWARD I-V CHARACTERISTICS-

A wide range of neutron radiation effects on the I-V characteristics of diodes were observed. Figures show representative results for the I-V characteristics of some of these diodes before and after irradiation with neutrons.All of our results and the published results for the forward I-V characteristics of neutron irradiated diodes .We limit our discussion to the voltage region beyond the generation-recombination region in the diode forward characteristics. Thus, the present results and discussion are applicable to the diffusion and high current regimes in diode typical previous results for neutron radiation effects on p-n junction .These results show that the rate of changeof current with voltage decreases with irradiation. Thus, an increase in the diode forward voltage at constant current on neutron irradiation is reported in most previously published results for neutron radiation effects on p-n junctions. At the same time, the reverse leakage current increases and breakdown voltage becomes more negative with irradiation.

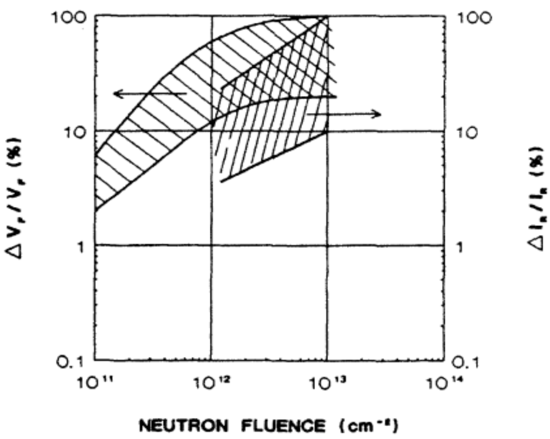

Figure 3: Percentage change in forward voltage

And reverse current of diode after and before neutron irradiation.

REVERSE I-V CHARACTERISTICS-

Reverse I-V characteristic measurements were limited to Zener diodes only. They have no use in p-n junction diode.

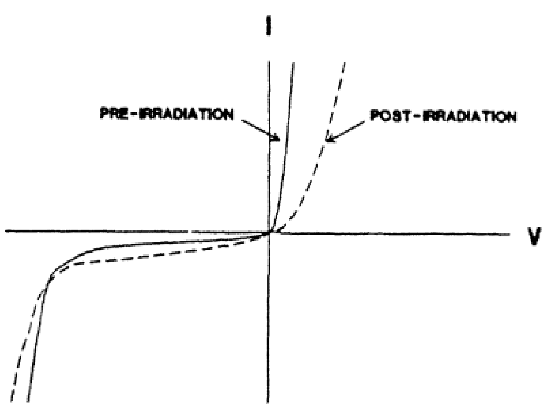

Figure 4: Typical I-V Characteristics of p-n junction diode

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3.X-rays and Gamma radiations:-

X-ray and gamma radiations are formed by electromagnetic radiations; they can interact with matter in three types.1.PhotoEffect; 2.CromptonEffect; 3.Pairproduction.The x-ray and γ-radiation are extremely short wave length, the x-ray is from 10E-9m To 10E-12 and γ-radiation is from 10E-12 to 10E-14 which finds many important applications in since and medicine. Irradiation has helped agriculture, engineering and industry, and has saved thousands of lives through its medical and biological effects. The p-n junction plays an important role, in both modern electronic applications and semiconductor devices .It is used extensively in rectification, switching and other operations in electronic circuits. It is the basic building block for the bipolar transistor, thyristors and JFETS.

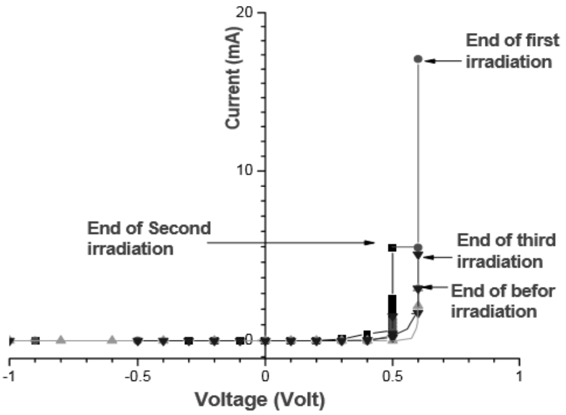

Figure 5 :Effect of x-ray irradiation on p-n junction diode

Experimental Method:

Current values at different bias voltage were measured for pn junction diode, before and after subjecting them to x-ray and γ-radiation were plotted as shown in figs.The table 1 shows these characteristics together with the radioactive sources used in work and the energy of the x-ray. In the statement of γ-radiation the sample was irradiated in three times as shown in figs. In the statement of x-ray the sample was irradiated in three times as shown in figs.

Sample	Type of the source	First time irradiation	Second time irradiation	Third time irradiation
Diode 1 N 1405	Co-60 Energy of γ-ray	7 day 5mci – 1.17,1.33MeV	7 day 5mci – 1.17,1.33MeV	7 day 5mci – 1.17,1.33MeV
	X- RAY Voltage and Energy Of X-ray	0.2 Sec	0.3 Sec	2.4 Sec
		55 KV 5.6 KeV	85 KV 8.52 KeV	85 KV 8.52 KeV

Table 1: Illustrate the energy of x-ray and γ-ray radiation and time irradiation. Time irradiation in (Sec.), Volt in (KV) and energy x-ray in (KeV) and γ-ray energy (MeV) and radioactivity of the source radiation in mci

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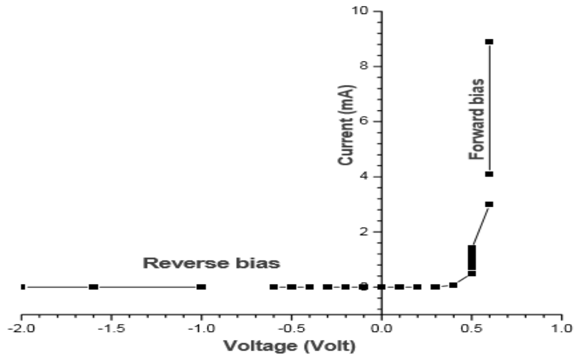

Figure 6: Effect of gamma ray(Co-60, Energy=1.17,1.33 MeV, Time irradiation after third time irradiation on p-n junction Diode

III. RESULT AND DISCUSSION

1. Solar radiation:-

Light generates excess minority carriers. Carriers swept across junction by electric field – electrons and holes are separated .Do we get a voltage? Depends on the load. We are sending carriers to opposite sides of the junction –if not extracted we have a build up of charge –get an electric field and potential difference between p and n regions –this corresponds to a forward bias across the p-njunction. So we can get both current and voltage extraction when illuminating the pnjunction –can get power out. We have a solar cell –i.e. it converts solar energy directly to electrical energy. Figure 1 and figure 2 are used as a reference showing the I-V characteristics of pn junction diode after illumination in reverse biasing and forward biasing respectively.

2. Neutron radiation:--

Neutron irradiation could lead to poor conductivity modulation and decrease in base conductivity which would result in an increase in V. On the other hand, the life time 70 of the carriers decreases with neutron irradiation which leads to a decrease in the junction voltage. In this section figure 3 showing percentage change in forward voltage and reverse current after and before the neutron irradiation and figure 4 showing typical I-V characteristics of pn junction diode for the neutron irradiation are used as reference.

3. X-rays and Gamma radiations:-

The γ-ray and x-ray radiation are electromagnetic form of radiation, they interact with matter in three types interaction, photo effect, Compton Effect, and pair production. In using x-ray and γ-ray irradiation we find that the response diode before and after irradiation are significantly different in fact in γ-ray and x-ray irradiation, the electrical properties were changed .For the first time γ-ray irradiation as shown in experiment the value of Potential barrier is 0.6 voltage, there is no change after gamma irradiation and the current start at 3 Am and increases in one line at voltage 0.6 volt to 14 mA. But in x-ray irradiation we see different results. In experiment the potential barrier was changed from 0.6 voltage before irradiation to 0.5 voltage after irradiation but in both case x-ray and gamma ray we see the current increasing that means electron-hole is produced in the forbidden gap after breaking the equivalent band. In this section figure 5 is showing the I-V characteristics of pn junction diode by the effect of x-ray radiation and figure 6 showing the effect of gamma ray after third time irradiation on pn junction diode. The table number 1 is illustrating effect of energy of x-ray and gamma radiation with respect to time irradiation.

IV.CONCLUSION

We can say especially which device can be used according to the type and energy of the detected radiation. We get different result between the effects of various radiations. This gives the information about the effects of ionising radiation on different types of electronic devices that are widely applicable as radiation detectors and we can also limit the place of using the semiconductor diode. We can also make sure that it will not be damage if the energy of various radiations used in the experiment is increased.

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VII. BIOGRAPHY

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