I-V Characteristic at Different Depletion Region for CMOS PN Photodiode for Optical Communication Applications

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Abstract - In this paper, CMOS PN photodiode will be design and analyze for the application at 5GHz optical communication. The paper will be divided in several section; the theory of CMOS PN photodiode and design with analysis of IV characteristics of PN photodiode. A better understanding of the operation will be investigated through this. The PN photodiode will be design using Silvaco TCAD and will be characterize and experimental in IV Characteristic. The effects of IV characteristic will be analyzed in term of changes the width and light. Further understanding of IV characteristic will be presents in this paper.

Keyword - PN photodiode, IV Characteristic, Silvaco TCAD

1. Introduction

1.1. PN Photodiode Structure

PN junction is one of the most simple of all semiconductor devices because it is much faster and very small in size and weight. It is the only most important device in the studies of modern semiconductors. It is the heart of the most photocells, rectifiers and transistors. It is also cheaper and has greater sensitivity [1].

PN junction forms a diode, and consequently a junction used as a photodetector is frequently called a photodiode [2]. It is formed by doping donor atoms on one side (N-side) and doping acceptor atoms on the other (P-side). Figure 1 shows the structure of PN photodiode. In this paper, the authors concentrate on the geometry of PN photodiode using different size of P+ region and its effects toward the I-V characteristics PN photodiode. The structure of PN photodiode is simulated with different size of P+ region and the analysis of I-V characteristic which is use Silvaco TCAD tools discussed in the next topic.

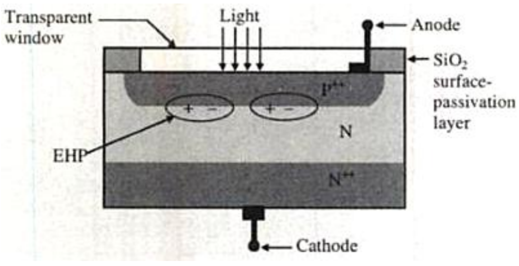

Figure 1: PN Junction Photodiode [3]

1.2. Reverse Biased

The PN junction operated in the reverse biased condition. The PN photodiode operation involving light and the light will be directed fall on the upper top of the portion of the photodiode. The depth where photons come into the depletion region depends on the wavelength of incident light. Electron-hole pairs will exist in the depletion region when the absorbed optical energy is sufficient. Electrons and holes are now attracted towards the opposite respective terminals of the battery. EHP that formed outside the depletion region will produce a photocurrent [4]. When a reverse bias voltage is applied to the PN junction, more electrons and holes are attracted to the contact. As a result, more donor and acceptor ions appear at the depletion region which in turn increases as well. [5].

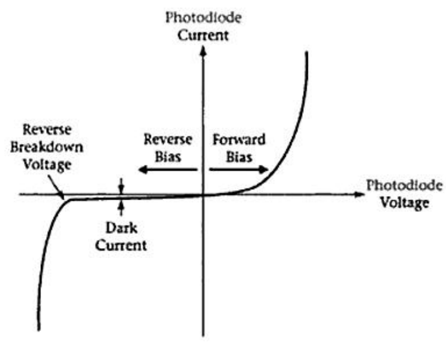

Figure 2: IV Characteristic of PN photodiode

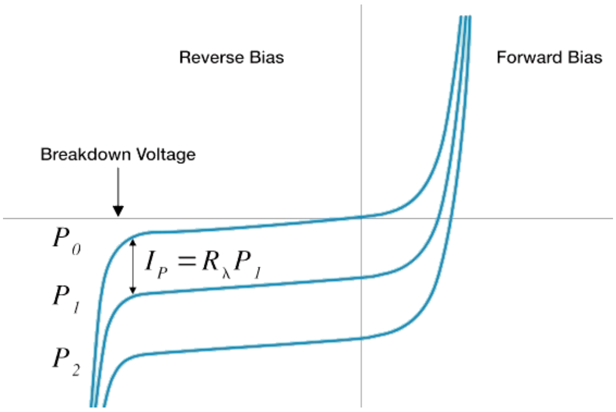

Figure 3: IV Characteristics with different light level

2. Methodology

In this project, SILVACO TCAD tool is used to design the PN photodiode and simulate the I-V characteristic. ATLAS is a physically based device simulator, providing general capabilities for 2D and 3D simulation of semiconductor devices [6]. In the Atlas project, it divided into 2 parts which is the structure and the I-V curve simulation. In the structure part, mesh is needed to generate meshes that are suitable for the design of PN photodiode. There are some methods and model that used in the second part of the coding. It will use for the simulation of I-V curve.

3. Result and Discussion

3.1. Different width depletion region, W

Figure 4 and Figure 5 show the structure of the PN photodiode using Atlas tools. Two heavily doped P region and N region with doping concentration 1e+20 is located beside each other. Two contacts for PN photodiode called anode and cathode is located at the top of P-type and N-type region. It may be noted that N-type and P-type region is formed within the n-well region. There is also a p-sub region which is located below n-well.

In the analysis, two different width of PN photodiode have been tested in the device structure which are 1 µm^2 and 3 µm^2. By comparing both structures, the different of width is change due to the different size of P+. Since the size of P+ reduced, the width will also change. The IV Curve is compiled together as it is easier to view the trend of voltage breakdown versus the width depletion region. Figure 8 illustrates the simulation for both structures. From the result, it is shown that both photodiode are start from V=0V and operated at the different reverse bias voltage.

The reduction of depletion region width with increased the electric field and reduced breakdown voltage. The breakdown voltage of the structure with width, W= 3 µm^2 is 4.9V while the breakdown voltage for the structure with width, W = 1 µm^2 is 4.7V.The applied electric field creates the depletion region on either side of the PN junction. Carriers – free electrons and holes – leave the junction area. The electric field and potential in the depletion region can affect the breakdown voltage. It can show from the equation below:

$$V_B = \frac{E_m W}{2} = \frac{\epsilon_s E_m^2}{2q}(N_B)^{-1} \quad (1)$$

From the equation (1), V_B is proportional to the W. As can be expected, reduce of depletion region can generate the small voltage breakdown. The structure which only uses less voltage supply will start the operation of reverse biased faster than the structure which uses more voltage supply.

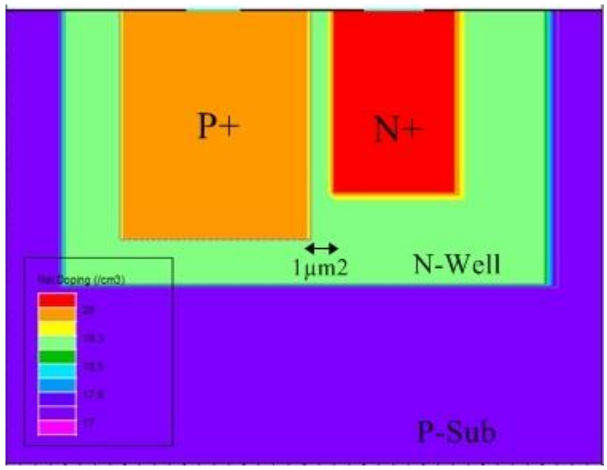

Figure 4: PN Photodiode with width, W= 1 µm^2.

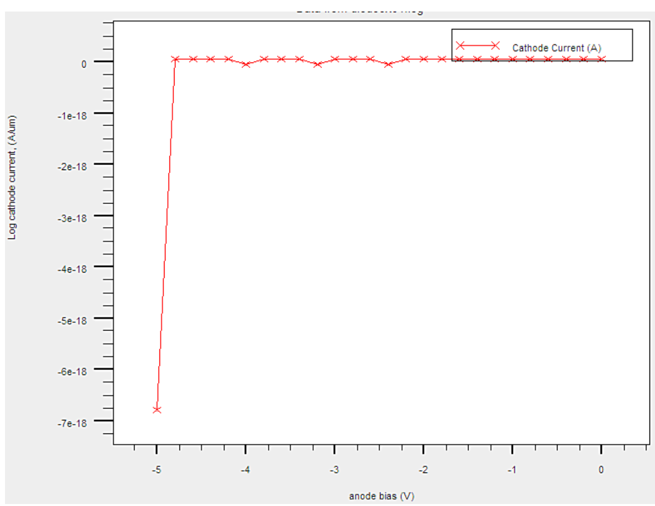

Figure 5: IV curve for PN Photodiode with width, W= 1 µm^2.

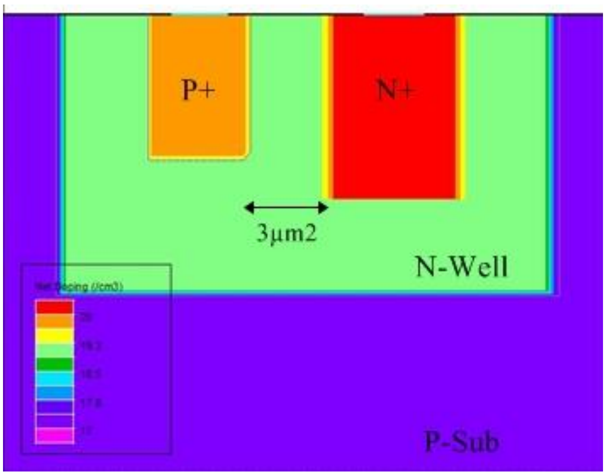

Figure 6: PN Photodiode with width, W= 3 µm^2.

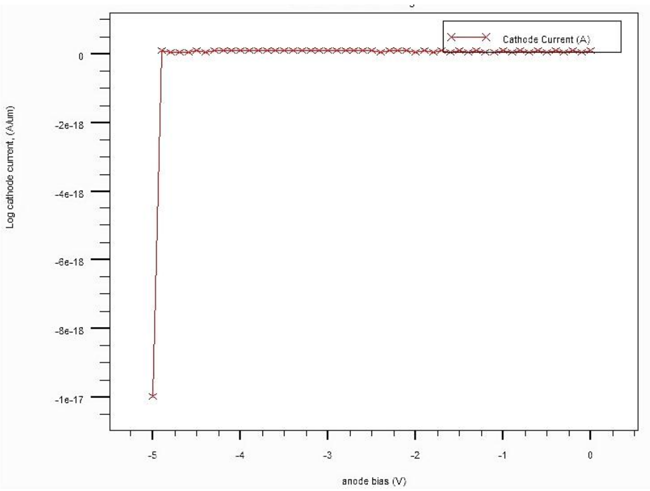

Figure 7: IV curve for PN Photodiode with width, W= 3 µm^2.

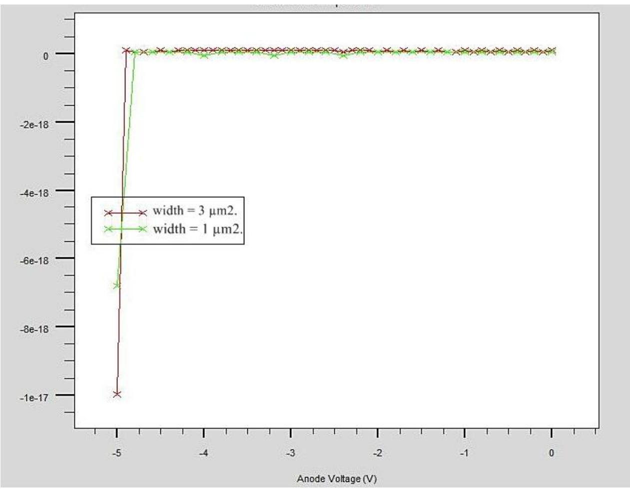

Figure 8: I-V curve of PN Photodiode with different width.

In reverse bias, the number of free carriers in the device depends primarily on the current in the device and the voltage is clamped at the knee voltage of the diode. Because of the IV curve for the photodiode in reverse bias is exponential, a small change in V has a much larger impact to the device.

3.2. Presence of light

For the analysis of presence of light, the second structure is chose, shown in Figure 6. From the analysis, some photon are incident on the surface of PN photodiode. Since the photon will pass through it and strike the junction. Light that is absorbed by the photodiode produces current flow through the entire external circuit.

The depth at which the photons reach into the depletion region depends on the incident of light. Figure 9 show the IV curve with no light falling on the PN photodiode. When no light is falling on the photodiode, a very small current passes through the photodiode. This current is basically due to the reverse bias applied to the PN photodiode.

Figure 10 show the IV curve with light falling on the PN photodiode. As the light is incident on the photodiode, photocurrent is developed. This photocurrent gets increased by increasing the light intensity.

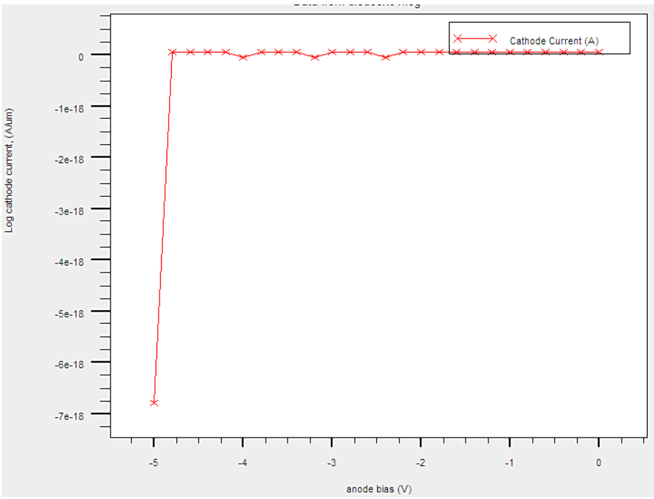

Figure 9: IV curve for PN Photodiode without light.

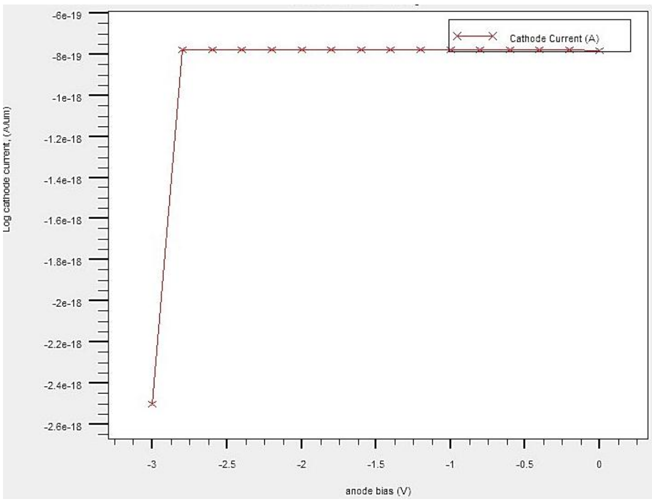

Figure 10: IV curve for PN Photodiode with light.

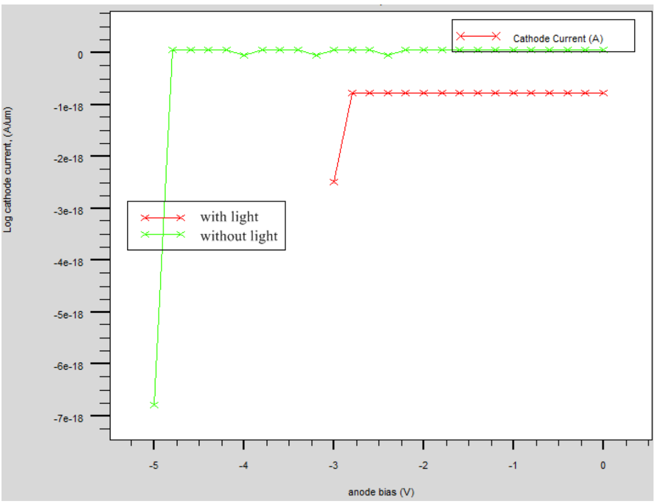

Figure 11: I-V Curve of PN Photodiode with presence of light.

4. Conclusion

In this paper, the different width of depletion region effects of the PN photodiode on its I-V characteristics has been successfully simulated and verified. The presence of light also affects the IV curve of the PN photodiode. In order to perform the I-V curve, the SILVACO TCAD is used. The result is compared between the different of structure. It is proved that the smaller width of depletion region, the better the device. From this paper also can conclude that the photocurrent gets increased by increasing the light intensity.

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