AlGaN/InGaN/GaN/BGaN UV P-I-N Photodetector

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Abstract - We performed high performances of high electron mobility AlGaN/InGaN/GaN/BGaN P-I-N photodetector using DevEDIT and Atlas under SILVCAO-TCAD. Our device exhibited sensitivity ($I_{Illumination}/I_{dark}$) of 2.33 at Vanode 4 V with 70 mA illumination current, photocurrent of 1.4e-7 A, and a suitable value of efficiency η equal to 47% without using BGaN and 95% with using BGaN. In addition, this kind of photodetector can successfully be developed to sense radiation in UV spectral range from 100 nm to 600 nm, and can be used in Military and medical applications.

Keywords - AlGaN/InGaN/GaN/BGaN, UV, P-I-N photodetector, Pop, SILVCAO-TCAD.

I. INTRODUCTION

In Recent researches on high-quality devices using nitride III-V materials led to the realization of high-performance photodetectors in the UV spectral range. They have been recognized as a key technology for high-density and low-cost manufacturing optical devices [1], and have received more attention to their important applications in the military and civilian domains. They are used in defense warning systems, UV communication, space science, environmental monitoring, industrial production, medicine, and healthcare [2-6]. That allows building visible blind sensors and solar collectors [7]. They have many applications such as chemical detection, flame detection, ozone hole detection, short-range communication, missile detection and guiding, monitoring vegetation growth, UV astronomy, and gas detection [8-11]. Several types of GaN-based photodetectors such as HEMT, MSM, PIN, and Schottky photodetectors are now studied [11]. The structure based on AlGaN/GaN materials gives many interesting properties related to internal electric fields caused by spontaneous and piezoelectric polarizations [12]. The field can be used to attract electrons, which leads to the formation of two-dimensional (2D) electron gas in the channel layer [13]. AlxGa1-xN-based photodetectors potentially offer a significant detector technology in terms of cost, robustness, stability, power demands, and bandwidth [14].The p-i-n photodetectors manufactured in SiC or GaN provide low-noise, high-speed, high-sensitivity, low-reverse-polarization response due to a low-capacitance terminal, and high shunt resistance.

They can work imperceptibly towards visible backgrounds / IR without visible-blind filters interference [15].This paper reports the successful development of large-format UV with Al-GaN/InGaN/GaN/BGaN P-I-N photodetector by SILVACO-TCAD simulation; we obtain principal characteristics.

II. DEVICE DESCRIPTION

AlGaN/InGaN/GaN/BGaN PIN Photodetector is performed in three dimensions with 3D-DevEDIT, and advanced luminous 3D optical device simulator (Fig. 1).

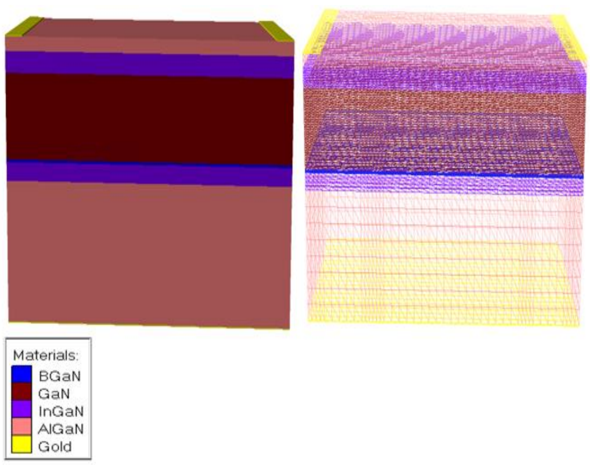

Fig. 1. 3D structure of AlGaN/InGaN/GaN/BGaN PIN Photodetector.

For the device meshing, it is necessary to choose a refined mesh for obtaining good results. We present a 2D cross section of our device in figure 2 with different regions, ma-terial concentration of different layers and the dimension of layers of high doped P+, N+ and intrinsic regions of GaN and BGaN with a light illumination for creation of 2DEG. Because the photo-detection in a semiconductor is based or working with the general rule that is the creation of electron-hole pairs under the action of light, when photons have energy at less equal to the gap (Eg) of the semiconductor.

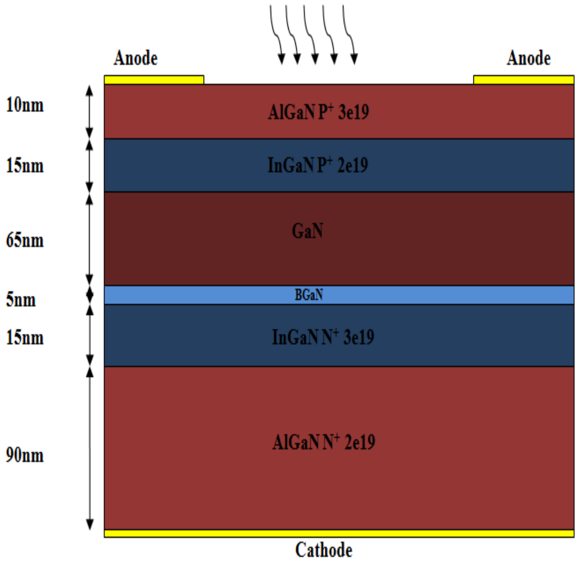

Fig. 2. 2D cross section of AlGaN/InGaN/GaN/BGaN PIN Photodetector.

III. RESULTS AND DISCUSSION

Numerical simulation is an extremely helpful tool for investigation of physical phenomena of devices, which determine electrical characteristics. Simulation results presented in this study were obtained using Atlas Silvaco Software, with the Shockley-Read-Hall (SRH) model, at room temperature (300 K).The Energy spectrum of absorption in different layers is mainly defined by band gap- energy difference between the top of the valence band and the bottom of the conduction band; therefore, we present in figure 3 the band diagram of P-I-N Photodetector, without and with BGaN in darkness and under light.Figure 4 represents the electrical field for P-I-N Photodetector with and without BGaN, in darkness and in illumination. The electrical field increases in the interface of layer that receives the illumination (AlGaN) from 2.58e5 V/cm at darkness to 2.60e5 V/cm in light without BGaN layer; and we obtained by using BGaN layer, 2.62e5 V/cm at darkness and 2.9e5 V/cm in light.

We used AlGaN alloy as a layer that received illumination, because it is direct band gap semiconductor, and it has high chemical resistance and high radiation resistance.

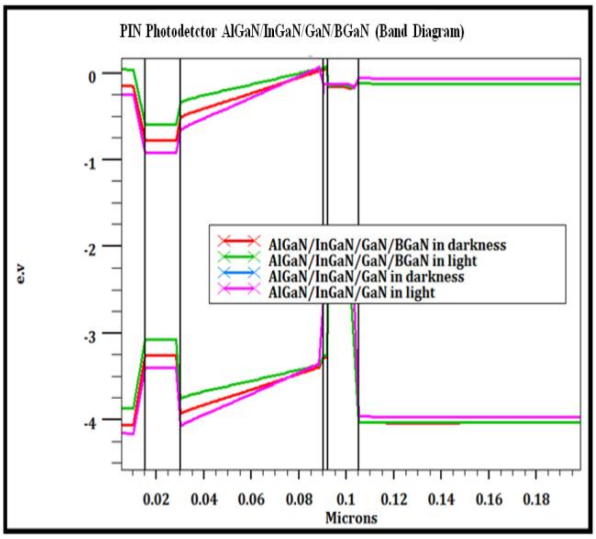

Fig. 3. Band diagram of AlGaN/InGaN/GaN/BGaN PIN Photodetector.

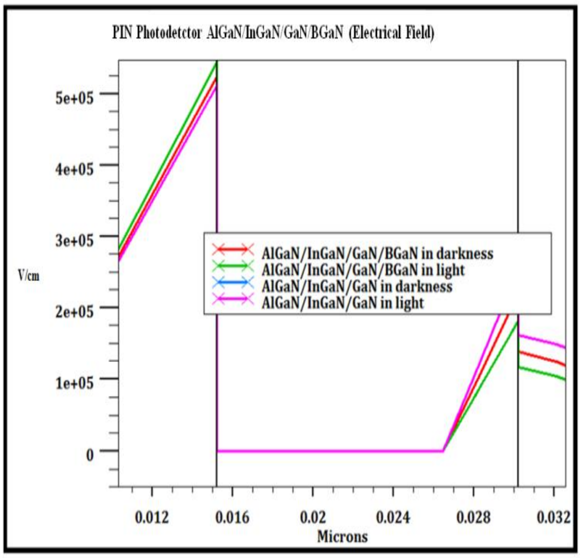

Fig. 4. Electrical Field of AlGaN/InGaN/GaN/BGaN PIN Photodetector

We illustrate in Figure 5, I-V characteristic of P-I-N Photodetector in darkness and in illumination. At Vanode = 4 V, we obtain respectively, 70 mA and 30 mA; the sensitivity (Illumination / Idark) is 2.33. It is clearly shown that this device is a better candidate for photosensitivity applications, as it has less dark current and improved photo sensitivity due to its efficiency control of two-dimensional gas in the channel of GaN and due to BGaN materials. In figure

6 we can see the comparison between I-V characteristics of AlGaN/InGaN/GaN and AlGaN/InGaN/GaN/BGaN P-I-N Photodetectors.

We obtain an anode current of 28 mA at an anode voltage of 4 V, without BGaN. With BGaN, the current increases from 30 mA for 1% of boron content to 70 mA for 4% of boron content. An improvement of 150% is obtained.

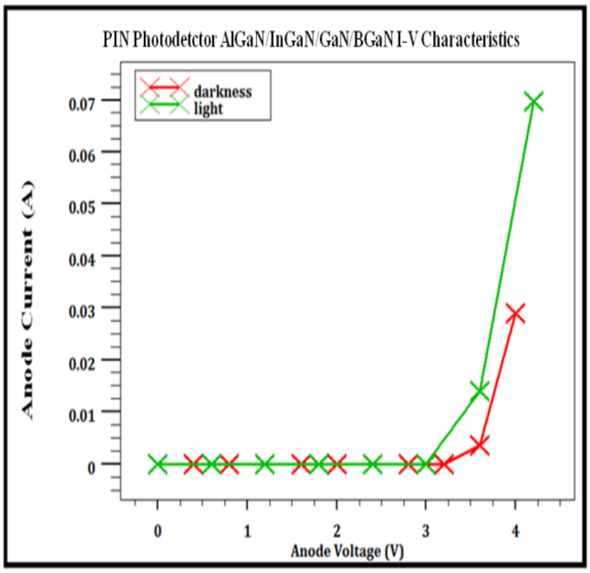

Fig. 5. I-V characteristics of AlGaN/InGaN/GaN/BGaN PIN Photodetector

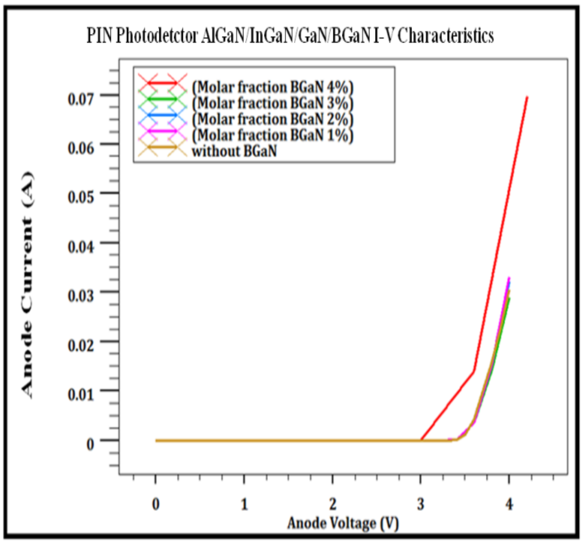

Fig. 6. I-V characteristics of AlGaN/InGaN/GaN/BGaN PIN Photodetector with different molar fraction of boron in BGaN

The available photocurrent is the generated current by the light, without an applied polarization; we fix then anode voltage only at 0.5 V (just to start the photodetector running), and represent by figure 7 the available photocurrent as a function of the wavelength. The maximum photocurrent is obtained at around 0.3 µm wavelength of the incident light because at this wavelength the maximum quantity of light is absorbed by the semiconductor; it is ~1e-7 A without BGaN, and ~1.4e-7 A with BGaN in PIN Photodetector. We obtain the same photocurrent for all contents of boron in BGaN.

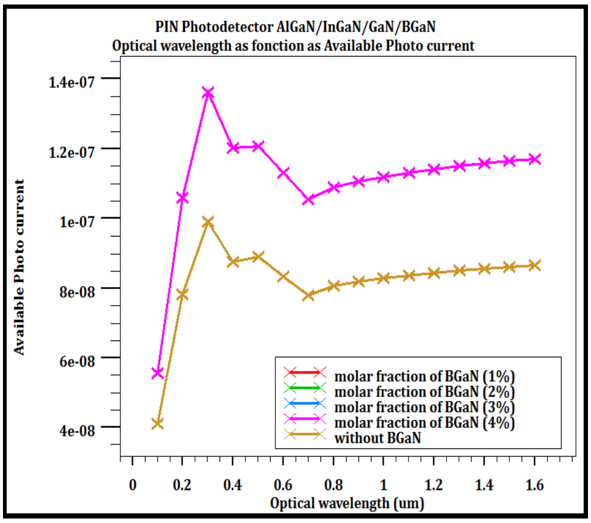

Fig.7. Spectral response of AlGaN/InGaN/GaN/BGaN PIN Photodetector

Figure 8 shows the optical response of P-I-N photodetector device over a range from 0.1 µm to 1.6 µm without and with BGaN layer. Maximum responsitivity is obtained at lower wavelengths in the range of 0.1 µm to 0.6 µm with maximum sensitivity at $\lambda = 0.4$ µm.

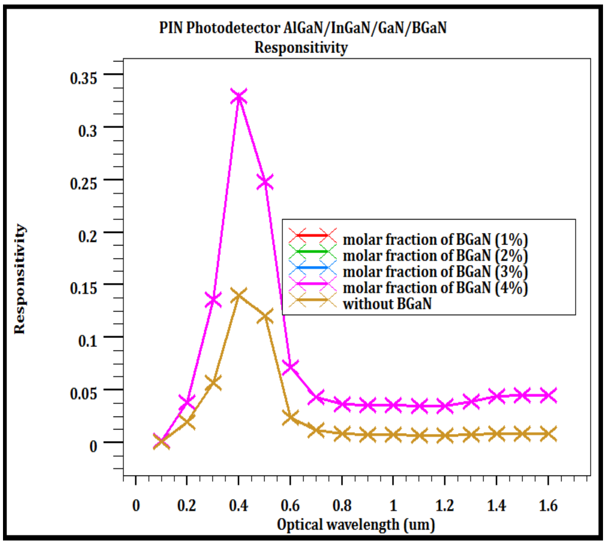

Fig. 8. Responsitivity of AlGaN/InGaN/GaN/BGaN PIN Photodetector

The device is able to detect mainly in the UV, and in the visible range; it could have a great important in diverse applications including environmental and biological research, sensing, detection, missile launch and imaging. The same responsivity is obtained for all contents of boron in BGaN, 0.32 A/W; it is of 0.15 A/W without BGaN. By using a BGaN layer, the reponsitivity increases. The efficiency (η) calculated by equation 1, is then 47%, and 95%, respectively without and with BGaN.

$$R = \eta \frac{e}{\hbar\omega} = R_{\max} = \eta \frac{\lambda[\mu m]}{1.24} \quad (1)$$

From the value of responsitivity found in Figure 8; in the table 1 we made a comparison between our device and others of the same type but only different materials and geometry. We can say that we obtained a high value of responsitivity compared to others that's have a direct impact in efficiency, this means that our component follows the requirements of the International Technology Roadmap for Semiconductors (IRTS).

TABLE 1. Devices Comparison in Responsitivity

Devices	Responsitivity (mA/W)	Ref
P-i-N GaN	150	[16]
P-i-N GaN	140	[17]
P-i-N AlGaN/GaN	65	[18]
P-i-N 4H-SiC	120	[19]
P-i-N SiCN	140	[20]
P-i-N AGaN/InGaN/GaN/BGaN	320	This work

Using (Al, In, Ga, B) N alloys, the absorption can be extended; the detection edge can be tuned to capture the maximum of photons and reduced the transmission of the photon. Absorption and transmission of the UV P-I-N Photodetector are represented in figure 9 versus the wavelength of the incident light. The absorption and transmission are identical for all contents of boron in BGaN, and they are greater than that of photodetector without BGaN; this has a direct impact on efficiency η.

IV. CONCLUSION

We have designed and characterized a high sensitivity illuminated AlGaN/InGaN/GaN/BGaN P-I-N ultraviolet Photodetector. A maximum efficiency η of 95% is obtained by using BGaN layer, the rate of recombination of excess carriers decreases due to increasing electric field, and due to high currents by adding the BGaN. This device can be used in different application in UV range.

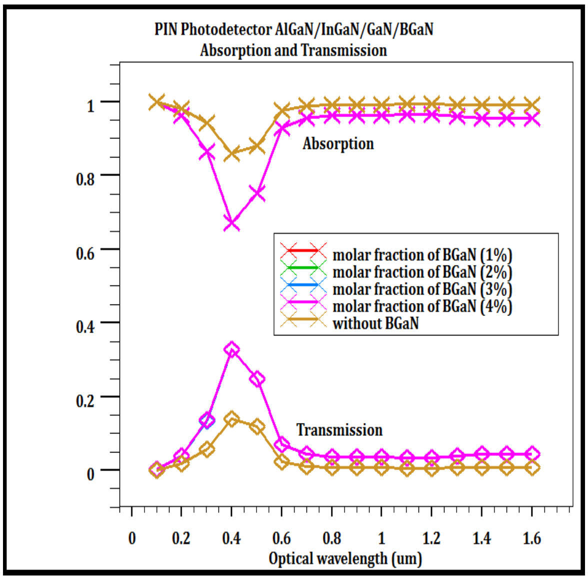

Fig. 9. Absorption and Transmission of AlGaN/InGaN/GaN/BGaN PIN Photodetector

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