PIN Infrared Detector Behavior Evaluation Via COMSOL Software

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Abstract

Infrared detectors can be used for a variety of applications such as: using in fiber-optic communications. Conventional technology for IR detectors is using p-i-n structure based on GaAs compound. This paper reports on the design and modeling of an IR detector using a p-i-n GaAs structure. Comsol software is used to simulate the model and the detector is discussed for terminal current, dopant profile, and energy band diagram. Finally, we have studied electric field according to layer depth under thickness, bias voltage, and field magnitude. We analyzed the electronic and optic behavior of IR detectors simultaneously, and detection spectrum was obtained in terms of wavelength

Keywords: fiber-optic, SIFT, IR detectors, Optical Comsol PIN Structure.

1. Introduction

Infrared ray is a part of electromagnetic spectrum whose essential part of energy is emitted to this form by materials. So to see things and physical actions without light reflection, IR rays are one of the important spectrums that must be studied. IR detector is an instrument that can detect rays of one source, which transmit in wavelength interval**,** 1000-0,7 μm of electromagnetic spectrum known as IR waves. More variety of these applications in different fields is shown discussing on the importance of these detectors. IR detectors applications are as follows:

- Military targeting and tracing
- Navigation and atmospheric control
- Fire stations and alarming systems
- Environmental, geological and herbal stability
- Vision cameras at night
- Medical diagnosis and thermic imaging
- Physic star and astronomy and industrial processes control

2. PIN Detector

First, we speak about PIN detector to describe performance of the detector. PN detector structure was shown at figure 1. By emitting light to these structures, photons are absorbed. When absorbing each photon, one electron is directed from valence band to conduction band. Therefore, electron-hole pairs are generated. Due to the fact that at PN vacancy bound area there isn’t free load, its resistance is high and almost whole voltage applied on two diode heads appears at its two heads. Carrier light generated at vacancy area that is affected by electric field moves to adverse poles; that is, electron moves to positive pole and also hole moves to negative pole. Therefore, photonic current is generated.

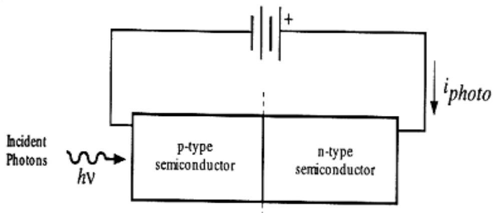

Fig.1. PN detector structure

At PN detector, low width of vacancy bound area leads to absorb low photons. So, diode current is low and receiver sensitivity isn't favorable. In order to solve problems above, PIN diode is suggested (6, 5, 4). At this structure, vacancy area is independent of biased voltage and it is at the form of area with low impure density. PIN detector is extensively used at optic telecommunication due to low noise and high speed. This diode lacks gains; that is, when absorbing each photon without second recombining, only one hole-electron pair is generated. According to figure 2, this detector consists of three areas including p, i, and n. (6).

Area i or inherent area has low impurity and it leads this area compared to areas n and p with high resistance. So, high percentage of voltage applied on two diode heads drops at inherent area. Strong electric field at inherent area is the main factor of separating optic carriers. (7).

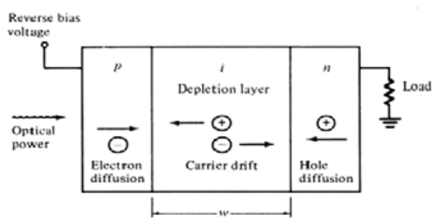

Fig.2. PIN detector structure

In order to detect spectrum area between 800 nm to 900 nm, several materials like InGaAs, GaAs, Ge, SI, InGaAsP are used. Silicon is extensively used. At wavelengths higher than 1 Micrometer, Si sensitivity is so low, because photons don't have sufficient energy for moving electron from valence band to conductance band. Therefore, other materials with high sensitivity are provided to 1 to 1.65 wavelengths that we can observe on some materials like GE, InP, InGaAsP. Germanium is ideal for detecting long wavelengths. Although germanium optic diodes are fast and sensitive, due to having ionization rate ratio of carrier following two additional coefficients, there is very big noise at intensity interest. Lower band gap of Ge is compared to Si and its very big dark current limit intensity interest (8).

Gallium Arsenide (GaAs) is material composed of periodic table elements of third and fifth groups. Success reason of Gallium Arsenide as a very fast semi-conductive is its high electron movement between 1.4×1.7 to 5×1.7 cm/s compared to Si with electron movement almost equal to 1.6×6 cm/s. Gallium Arsenide (GaAs) is resistant against radioactive and electromagnetic radiation, due to this reason. It is important material in space and military applications. Also, Gallium Arsenide has wide band spacing and it acts at very low or high temperature too. (from -200 to +200). (2).

3. Simulation of Gallium Arsenide Infrared Detector With Comsol Software

Comsol is a powerful software environment that can be used to model several scientific and engineering problems and it is based on differential equations with partial derivatives and it investigates models described of different problems by physical quantities related to them like parameters and material traits. Here, a P-I-N photo-diode device is modeled. (3).

3-1 Model definition

Simulated model is one GaAs-PIN structure shown at figure 3. Doping geometry and profile was shown at figure 4. PIN structure is so effective and efficient at photodiode pieces and applications and this is the result of gradient nature of conductance and valence levels that leads to the highest energy at P-contact and lowest energy at n-contact.

Although an absorbed photon generates one hole and one electron, electron moves to n-contact and a hole moves to p-contact. P-contact reaches 2 p-contacts and this kind of pieces places at reverse bias. For definite wavelength of shined light, current is linear and proportional to shininess. Also, reverse bias increase the gradient of energy levels (or layers) discharge layer width that leads to lower response time. This process is completed during increased dark current, because higher current moves at the absence of light due to direct bias. [7]

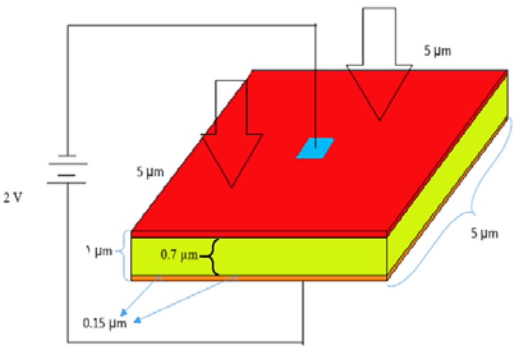

Fig.3.Biased PIN structure at reverse bias mode and applying light field (electro-magnetic)

Negative values are related to pure doping from P kind and also positive values are related to pure doping from n kind. PIN impurity profile is clearly and strongly dopped with layers from p and n kinds and it is visible near top and bottom planes. One wide area without dop spacing 0.15 , 0.85 micrometer. Bottom part and right hand: it shows diagram of obtained energy levels toward red arrow shown at genometric diagram and band edge and Quasi-Fermi levels. At natural area, Quasi-Fermi electron level is below conduction band and also Quasi-Fermi hole level is located at top of valence layer. This means that despite valence layer is full, conduction band is vacant and this area is suitable for photon absorbtion.

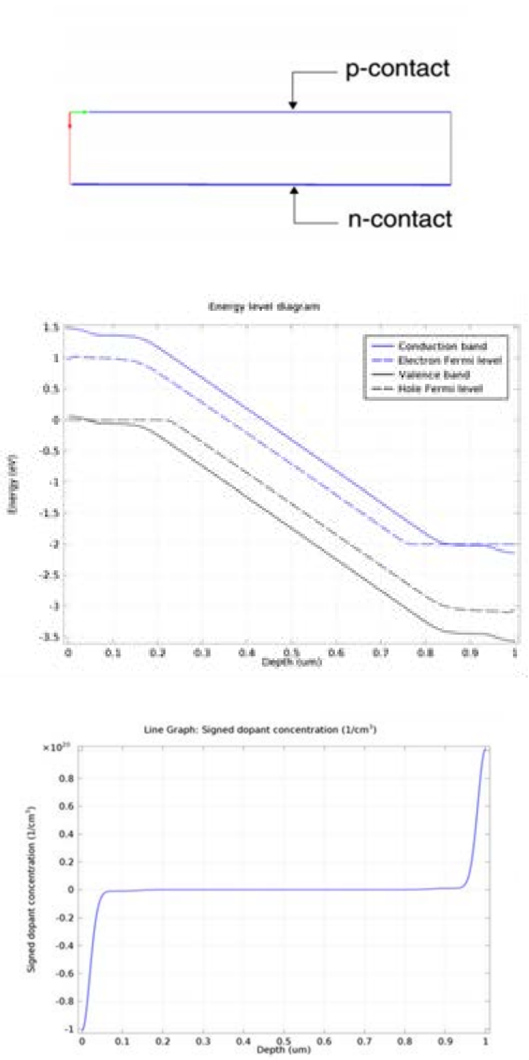

Fig.4. Device geometry. Doping and energy diagram. At higher part of paper: piece geometry of simple rectangle with p-contact on top surface of n-contact.

4. Results

In order to evaluate the suggested method according to obtained data and efficiency parameters of infrared detectors at Comsol of one optic spectrum was applied and also these results were obtained based on reverse bias of photodector. These results were obtained on the basis of 2 volt bias voltage, 5 W field magnitude and 1 micrometer thickness.

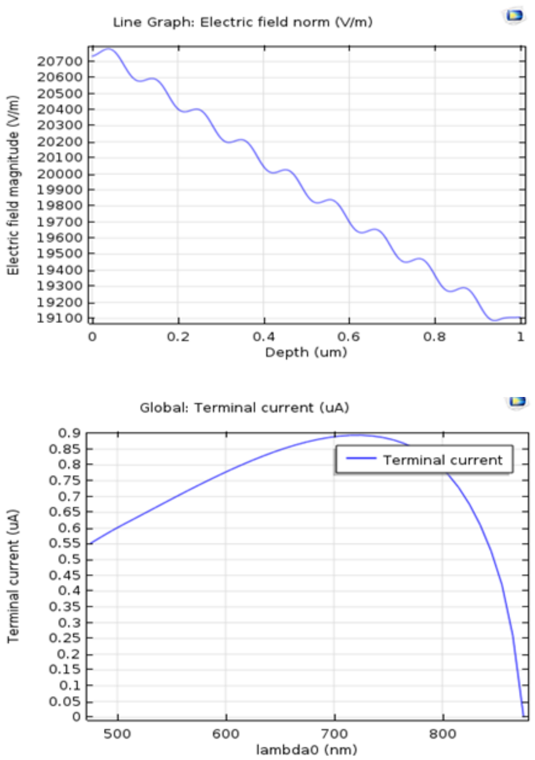

Fig.5.Normalized electric field and current moving from detector compared to applied frequency spectrum based on basis of 2 volt bias depth, 5 W radiation power and 1 micrometer thickness.

By changing radiation power to 0.1 W. the results below changed as follow:

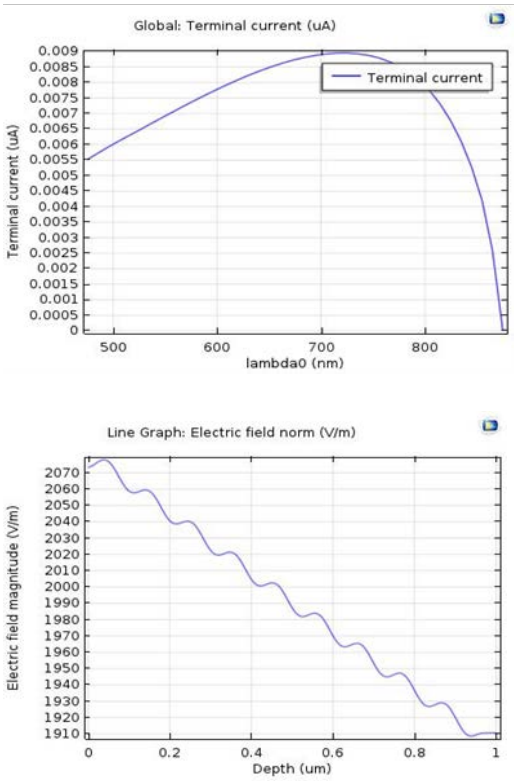

Fig.6. Normalized electric field and current moving from detector compared to applied frequency spectrum based on basis of 2 volt bias, 5 W radiation power and 1 micrometer thickness.

By investigating Figures 6 to 8, in was concluded that by increasing biased voltage, terminal current and electric field increase. Also, by decreasing radiation intensity, terminal current power and electric field intensity decrease. By increasing thickness, terminal current decreases and electric field increases. By increasing very big amounts of biased voltage from 4 volt to 8 volt, it was observed that terminal current didn't go farther than 0.45, because other terminals were saturated but electric field became stronger.

5. Conclusion

At the present article, solutions were provided for modeling infrared detector at Comsol. First, some PIN infrared detector performances with Gallium were investigated by Comsol software. One of new ideas was to use semi-conduction at Comsol due to its advantages investigated in this paper. Also, at this structure, applying optic wavelength spectrum from high and low infrared range, increasing terminal at middle infrared range was obtained.

By changing voltage from 2 V to 4V with 5 W radiation power, the following results were obtained:

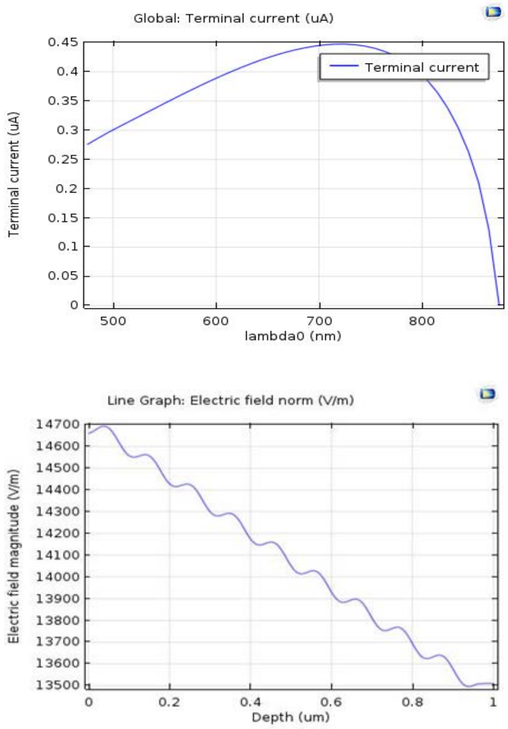

Fig.7. Normalized electric field and current moving from detector compared to frequency spectrum based on basis of 4 volt bias, 5 W radiation power and 1 micrometer thickness.

By changing thickness from 1 Micrometer to 2 micrometer with 5 W radiation power and biased voltage of 2 volts , the following results were obtained:

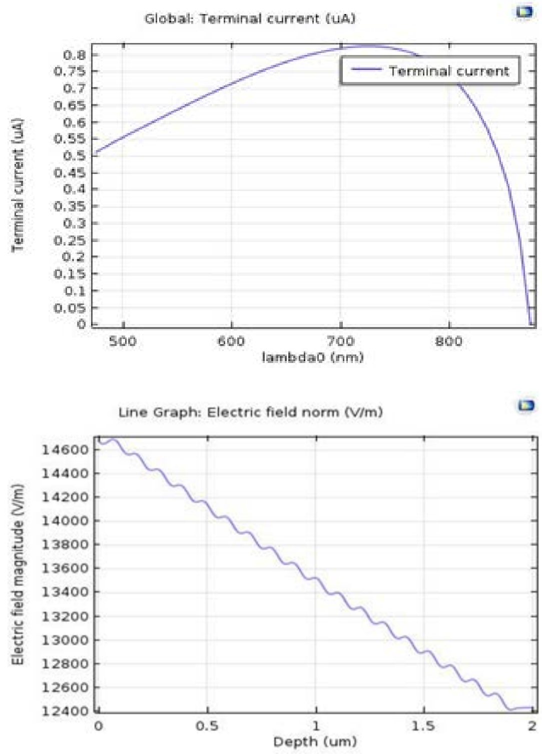

Fig.8. Normalized electric field and current moving from detector compared to frequency spectrum based on basis of 2 volt bias, 5 W radiation power and 2 micrometer thickness.

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