# Dark current minimization in type-II superlattice photodetector

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**Type-II Superlattice (T2SL) photodetectors are at the forefront of optoelectronic detector technology, primarily attributed to their excellent band gap tunability and outstanding optoelectronic characteristics. However, the presence of dark current necessitates the use of an extra cryogenic setup and limits the detector's performance. Therefore, it is essential to understand and minimize the dark current. In this work, we study the dark current characteristics of 10monolayer (ML)/10ML InAs/GaSb T2SL p-i-n photodetector, using TCAD Sentaurus in a reverse bias voltage range at a temperature of 77K. We analyze the variation in the generation-recombination (GR) current, trap assisted tunneling (TAT) current and band to band tunneling (BTBT) current with respect to the thickness of the absorber layer. With an increase in the thickness of the absorber layer, there is a slight increase in the depletion width. Consequently, the GR current increases slightly. As thickness of the absorber layer increases, we observe a decrease in the electric field. Consequently, we achieve a remarkable reduction in the band to band and trap assisted tunneling current.**

***Keywords—Dark current, TCAD, Type-II Superlattice***

## I. INTRODUCTION

Infrared image detection is extensively used in key areas such as national defense, biomedical imaging, industrial process monitoring, and cancer detection, etc[1]. The increasing popularity of mid-wavelength infrared region (MWIR) photodetectors based on the InAs/GaSb type-II superlattice (T2SL) is due to their excellent bandgap tunability, lower Auger recombination rates and higher effective masses as compared to the HgCdTe [1]. However, the presence of dark current in these photodetectors complicates the detector's design by requiring an additional cryogenic system. Therefore, it is crucial to minimize the dark current. TCAD Sentaurus is being used to simulate the dark current characteristics of 10ML/10ML InAs/GaSb T2SL p-i-n structure, in the reverse bias voltage range at a temperature of 77K. We vary the thickness of the absorber layer from 300nm to 400nm and investigate its effect on the generation-recombination (GR) current, trap assisted tunneling (TAT) current and band to band tunneling (BTBT) current.

## II. PHYSICS MODELS USED FOR SIMULATION

In the depletion region, there will be a generation of electron-hole pair due to the presence of the traps. As a result, we get the GR current. It is described by the Shockley-Read-Hall (SRH) recombination rate [1]:

$$R_{SRH} = \frac{pn - {n_i}^2}{\tau_p \left[n + n_i exp\left(\frac{E_{trap}}{K_B T_L}\right)\right] + \tau_n \left[p + n_i exp\left(\frac{-E_{trap}}{K_B T_L}\right)\right]} \quad (1)$$

where n, p, and $n_i$ are the electron, the hole, and the intrinsic carrier concentrations, respectively, $E_{trap}$ is the difference between the trap energy level and intrinsic fermi energy level. $\tau_n$ and $\tau_p$ are the electron and hole minority carrier lifetime and $K_B$ is the Boltzmann constant.

The presence of electric field and the traps in the depletion region give rise to the generation of TAT current. Hurkx model [1] gives the sum of GR and TAT current and it is presented as:

$$R = \frac{pn - {n_i}^2}{\frac{\tau_p}{1+\Gamma_n} \left[n + n_i exp\left(\frac{E_{trap}}{K_B T_L}\right)\right] + \frac{\tau_n}{1+\Gamma_p} \left[p + n_i exp\left(\frac{-E_{trap}}{K_B T_L}\right)\right]} \quad (2)$$

In the above equation, $\Gamma$ is the field enhancement factor and it is given as:

$$\Gamma_{n,p} = \frac{\Delta E_{n,p}}{K_B T_L} \int_0^1 exp\left(\frac{\Delta E_{n,p}}{K_B T_L} u - K_{n,p} u^{\frac{3}{2}}\right) du \quad (3)$$

Where, $\Delta E_{n,p}$ is the tunneling range for holes and electrons, u is the integration variation in terms of energy and $K_{n,p}$ is defined as:

$$K_{n,p} = \frac{4}{3} \frac{\sqrt{2 m_t \Delta E_{n,p}^3}}{q \frac{h}{2\pi} E} \quad (4)$$

In the above equation, E is the local electric field and $m_t$ is the tunneling mass, given as:

$$\frac{1}{m_t} = \frac{1}{m_e} + \frac{1}{m_h} \quad (5)$$

We have used the non local tunneling model [1], to get the BTBT current.

## III. RESULT AND DISCUSSION

Fig. 1. shows the device structure for SL p-i-n photodetector. 10ML/10ML T2SL is used as a bulk material for p-type contact, n-type contact and the absorber layer. The energy band gap and the effective mass of the 10ML/10ML T2SL are obtained by the k.p method [2]. The values of mobility and the electron affinity are obtained by the weighted average of the InAs and GaSb bulk values [2]. The absorber layer is doped as n-type with a doping concentration of $5.5X10^{15}cm^{-3}$. The carrier lifetime is selected as 40ns [2].

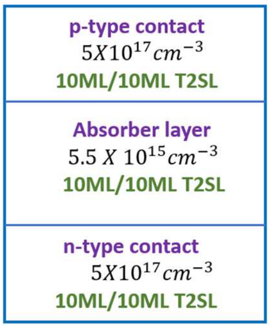


Fig. 1. 10ML/10ML SL p-i-n structure.

The thickness of the absorber layer is varied from 300nm to 400nm. Fig. 2. shows the variation of the GR current with respect to the thickness of the absorber layer. With an increase in the thickness of the absorber layer from 300nm to 400nm, there is a slight increase in the depletion width. As a result the GR current increases slightly.

TABLE I. Parameter values used for Simulation

| Parameter | Value |
|---|---|
| Band gap (eV) | 0.251 |
| $m_e/m_0,\ m_h/m_0$ | 0.032, 0.49 |
| Electron affinity (eV) | 4.66 |
| Permittivity | 15.42 |
| $\mu_e, \mu_h \left(\frac{cm^2}{Vs}\right)$ | $1.85X10^4$ , 930 |
| Lifetime (T=77K) | 40ns |

As we increase the thickness of the absorber layer from 300nm to 400nm, there is a slight increase in the electric field. Since BTBT and TAT current are the exponential function of electric field, therefore we get a significant decrease in the BTBT and TAT current, as shown in Fig. 3. and Fig. 4.

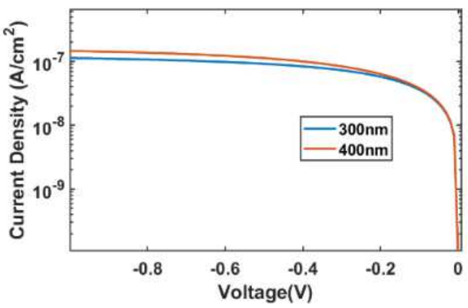


Fig. 2. Variation of the GR current with respect to the thickness of the absorber layer

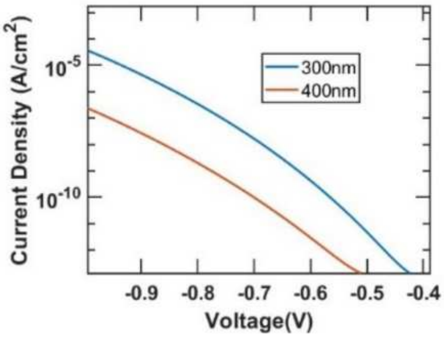


Fig. 3. Variation of the band to band tunneling current with respect to the thickness of the absorber layer

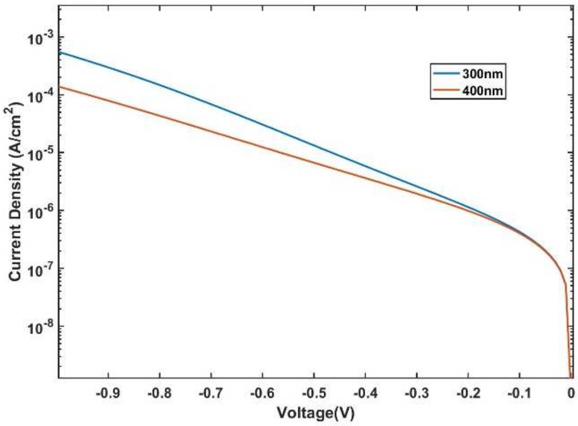


Fig. 4. Variation of trap assisted tunneling current with respect to the thickness of the absorber layer

## IV. CONCLUSION

We simulate the dark current characteristics of a 10 monolayer (ML)/10ML InAs/GaSb T2SL p-i-n photodetector using TCAD Sentaurus in a reverse bias voltage range at a temperature of 77K. We examine how generation-recombination (GR), trap-assisted tunneling (TAT), and band-to-band tunneling (BTBT) current varies with respect to the thickness of the absorber layer. As the thickness of the absorber layer increases from 300nm to 400nm, the depletion width increases slightly. This results in a slight increase in the GR current. The electric field decreases, with increase in the thickness of the absorber layer. This results in a significant reduction in TAT and BTBT tunneling current.

## V. ACKNOWLDGEMNET

The authors are thankful to the Indian Space Research Organization.

## VI. REFERENCES

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