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Computation of Optical Response of GaAsSb/InGaAs based Photo Detector

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Abstract

In this paper, the calculations for determining the optical response of GaAsSb/InGaAs based photo detector have been performed and the results have been analysed successfully. The k.p model has been used to identify the behaviour of wave functions of the charge carriers and their discrete energy states. Finally, in optical response of the designed heterostructure, the optical absorption coefficient of the heterostructure has been computed. The computed results shows that the designed GaAsSb/InGaAs based heterostructure can be functional in designing the photodetectors operating in MIR (mid infrared) regions.

Keywords: *GaAs, InAs, Optical property, k.p theory, Photo detector*

1.0 Introduction

In the recent era, the heterostructure semiconductor devices are being used universally in high speed and elevated frequency for the digital and analog electronic systems[1-3]. It is noticeable that the heterostructures have a great impact on our routine life because of advance and revolution of semiconductor heterostructures. Heterostructure based electronic systems are widely used in the area of human civilization. It is quite impossible to imagine our modern life without making utilization of heterostructures. The obvious instances can be seen as the double heterostructure lasers and the telecommunication systems based on such laser systems[4,5], heterostructure-based light-emitting diode (LEDs) [6-8], heterostructure based photo detectors[9,10] bipolar junctions transistors (BJTs), or Low Noise High Electron Mobility Transistor (LN-HEMT) for high frequency applications.

However, among various heterostructures based devices the mid-infrared (MWIR) photo detectors are important for applications such as medical diagnostics, chemical sensing, gas monitoring, and free-space communications. Generally, for the operations in MWIR and LWIR wavelengths, the predominant material system is Mercury Cadmium Telluride (HgCdTe), but it has suffered from low capitulate and reduced material uniformity. Therefore, as an alternate, the III-V semiconducting materials based heterostructures have been searched for fabricating the heterostructures based devices as a mid-infrared (MWIR) photo detector. In fact, the III-V compound semiconducting materials offer the materials basis for a numerous well-established marketable technologies as well as for the novel cutting edge classes of electronic gadgets.

In the following sections of this article, a proper layer arrangement of III-V compound semiconducting materials (InGaAs and GaAsSb layers) for designing the type-II InGaAS/GaAsSb based simplified quantum well (QW) heterostructure has been shown. In addition, the calculated charge carrier's wavefunctions and corresponding quantized energy states have been shown. In addition, the conduction

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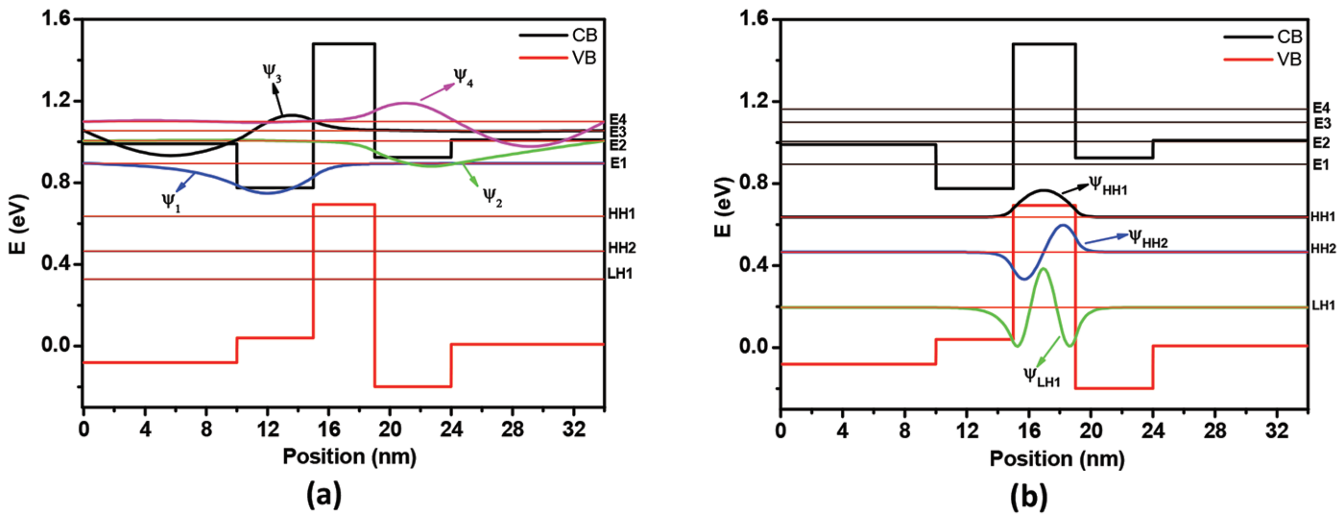

Figure 1: (a) Wavefunctions (a) in conduction (b) valence band of the heterostructure

and valence subbands of the designed heterostructure device have also been calculated. The key objective of the presented work is to determine the optical response of the designed type-II simplified QW heterostructure based on InGaAs-GaAsSb layer system.

2.0 Simulation Aspect and Results Analysis

In order to investigate the optical response of the planned layered heterostructure, the foremost task is to study the band diagram along with offset values of QW and barrier regions. Once the band diagram is planned, one can study the structure with the help of fundamental quantum mechanics. In the existing work, an attempt has been made to study the planned InGaAs-GaAsSb layered heterostructure quantum mechanically. In order to perform such study, the echo-friendly k.p model has been utilized in terms of 6×6 Luttinger-Kohn Hamiltonian to determine the carrier's wave functions and their discrete energies. The subbands of the designed heterostructure have also been calculated separately. Before the calculation of the optical response the matrix elements (for dipoles and momentum matrix) are computed and studied. Finally, as an optical response of the heterostructure, the optical absorption coefficient is calculated by the following expression:

$$\alpha(\omega) = \frac{4\pi^2 e^2}{n_r c m_o^2 V \omega} \sum_K |\hat{e}.p_{ba}|^2 \, \delta(E_b - E_a + h\omega)(f_a - f_b)$$

In the above expression, ê is symbolized for electric field polarization vector, f_a and f_b terms are used for Fermi functions, while the momentum matrix elements are generalized by the quantity p_{ba}.

In Figure 1 (a&b), the carrier's wave functions associated with the conduction (ψ1, ψ2, ψ3 and ψ4) and valence band (ψHH1, ψHH2, and ψLH1) of the heterostructure have been illustrated. The existence of behaviours of such wave functions confirms the nature of designed heterostructure i.e. it is of type II band alignment. The energy subbands have been calculated and shown in Figure 2 (a&b). In Figure 2 (a) the conduction subbands and in Figure 2 (b) the valence subbands have been illustrated. Finally, the partial optical absorption coefficient due to the single transition between the energy levels e1 and HH1 has been simulated and illustrated in Figure 3. The absorption is found in the MIR range. The calculated results suggest the applications of heterostructure in design of MIR photodetectors.

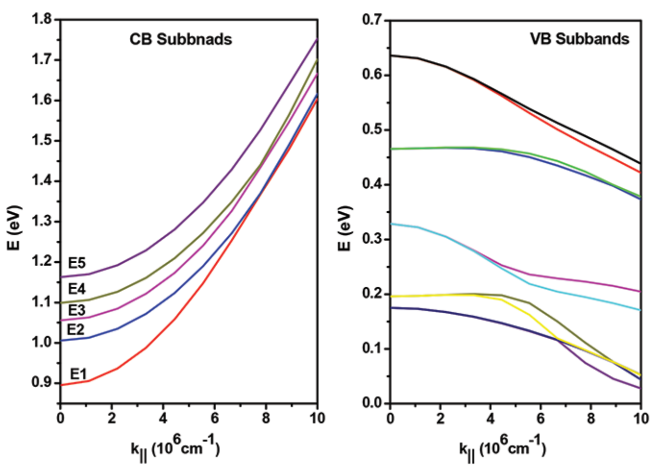

Figure 2: Energy subbands of (a) Conduction band (b) valence band

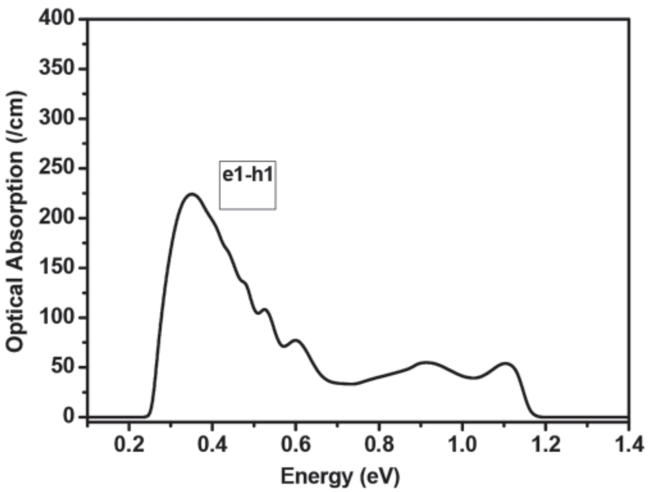

Figure 3: Illustration of optical absorption as a response of GaAsSb/InGaAs heterostructure based photo detector

3.0 Conclusion

The calculations for determining the optical response of GaAsSb/InGaAs based photo detector have been performed and the results have been analysed successfully. The k.p model has been used to identify the behaviour of wave functions of the charge carriers and their discrete energy states. Finally, in optical response of the designed heterostructure, the optical absorption coefficient of the heterostructure has been computed. The computed results shows that the designed GaAsSb/InGaAs based heterostructure can be functional in designing the photodetectors operating in MIR (mid infrared) regions.

4.0 Acknowledgements

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