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Laser Co_2 Radiation Detection Using QWIP

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Abstract

Quantum well infrared photodetector (QWIP) become one of the important devices recently for their efficient, stability, uniformity, and high intrinsic speed. The photodetector was designed, and the validity, absorption coefficient, and band transitions are studied extensively. The quantum wells included in this research operate in mid infrared wavelength region (9-11 µm). Results showed that peak absorption coefficient at (10.6 µm) is (9000 cm^{-1}) for Bound – bound transition and is more narrow and intense from bound-continuum transition (1800 cm^{-1}) and the quantum well based devices can be used to detect such wavelength providing that the external electric field stays below a reasonable value. This makes such device a promising solution for MIR applications.

Keyword: Quantum wells, Photo detector, Infrared radiation.

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Introduction

The last years of the last century have seen progress in the field of infrared radiation detection. This is due to the enormous scientific development made in the quantum well photodetector industry that depend on the progress of semiconductor physics [1].

The novelty and success of properties of heterostructure semiconductor are obtained by building two semiconductor materials with different energy bandgaps brought in contact to form one heterostructure device. As a result, quantum well based devices are innovated. Different materials can be combined to form different bandgaps determining the potential structure of the heterostructure material. One of the main challenges of such structures is the crystalline lattice constant matching. Several growth techniques have been developed metal organic molecular beam epitaxy (MOMBE), molecular beam epitaxy (MBE) and chemical beam epitaxy (CBE) that can produce defect free crystalline interfaces. These fabrication methods provided the perfect environment for producing and studying quantum well structures [2,3].

In this paper, will look for quantum wells photodetectors and show its models, and data and graphics that illustrate it. Then the most important mathematical treatment of differential equations that govern the electromagnetic phenomena and quantum within this type of detectors, and to provide numerical solutions to approve it, and simulation of the most important data of its Photonics and electrical properties [4].

Theory

A quantum well infrared photo detector is semiconductor device that is able to sense long wavelength photons. The basic structure of the device is shown in Figure 1 [3].

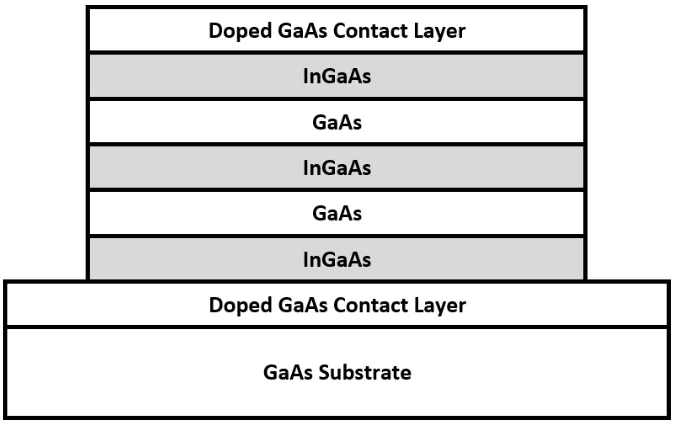

Figure 1: Basic layout of QWIP

The QWIP design is similar to most semiconductor devices in which a structure that is sandwiched and fabricated on a clean substrate. The energy profile of the device is shown in Figure 2 [5].

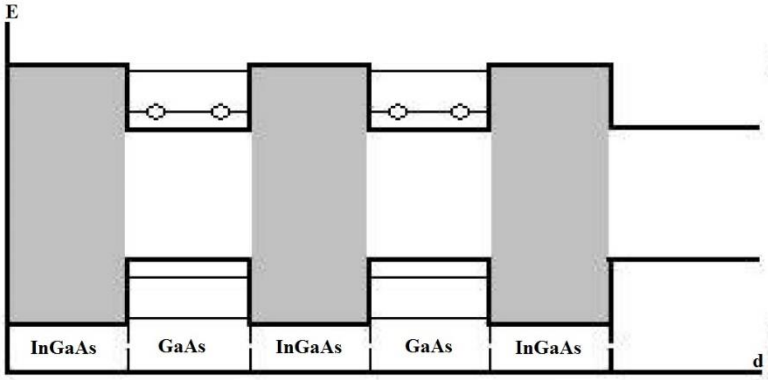

Figure 2: Electronic structure of QWIP

The quantum well devices consists of high and low energy bandgaps. The electrons are initiated and travelled through the material by potential difference created around the material. The travelling electrons are fallen and captured in low bandgap quantum wells. The captured electrons remain in the quantum well till they receive additional exciting energy. The source of the additional energy is either external photons or heat energy. If an electron gains enough energy to be excited to higher energy level near the top of the well, then it can leave the quantum well and contribute in the electron flow [6].

The electron usually coincide in the lower energy states of the quantum well. The electrons stays in its place till it is hit by a photon having energy enough to excite the electron to the upper energy level close to the top end of the well. Application of any additional energy results in escaping the electron from the quantum well in enters the moving electron flow outside the well. This type of electron generation is called photocurrent because the electrons are excited as a result of external photons. The flowing photocurrent electron can be altered either by external thermal excitation or tunneling as shown in Figure 3 [7,8].

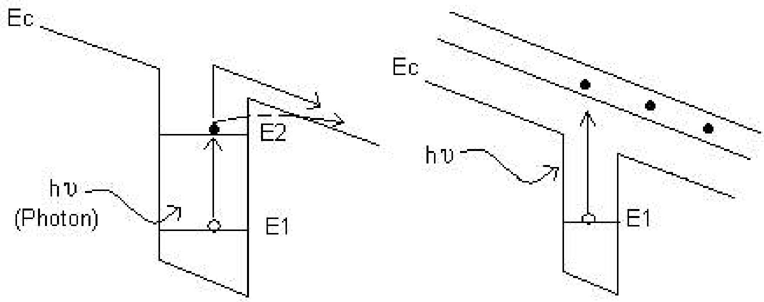

Figure 3: (a) wide well bound to bound state transition (b) narrow well bound to continuum transition

Free electrons are required to produce the whole process. The supply of these free electrons comes from doping the semiconductor materials for providing free electrons that can participate in the generation process. The mostly used material for such process is $Al_xGa_{x-1}As$ semiconductor material having bandgap near 6 µm [9].

One of the important parameters that determines the efficiency and property of QWIPs is the generation of dark current. It is defined as the current flows in the absence of photons hitting the well in a biased detector. To ensure high performance of a QWIP, the dark current must as low as possible [10].

Intersubband absorption occurs when an electron absorbs energy and excites into higher energy level in a quantum well. Only certain transitions are allowed inside a quantum according to the selection rules in quantum mechanics. The absorption process occurs only of the incident light has polarization parallel to the device's fabrication direction. So, this condition makes the fabrication process of such detectors harder and more complicated because the light that is perpendicularly polarized to the growth direction is not absorbed. Moreover, the electrons are excited out of a quantum well by external photons are captured again by another quantum well in short time. Furthermore, quantum well infrared Photodetectors have high dark current. In spite of the mentioned challenges of QWIPs, the device remain in research area because of the commercial availability and popularity. On the other hand, Quantum Dot Infrared Photodetectors are in development the overcomes most QWIPs

problems but they are still not commercially available [11,12].
The detector responsivity R is then defined as

$$R = \frac{e}{h\upsilon}\eta g \quad \dots\dots\dots\dots\dots\dots\dots\dots \quad (1)$$

Where e is electron charge, h is Planck constant, η absorption quantum efficiency and g is a photoconductive gain.

$$g = \frac{\tau}{\tau_{trans}} p_e \quad \dots\dots\dots\dots\dots\dots\dots\dots \quad (2)$$

$$\eta = \alpha\, \mathrm{L} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (3)$$

Where τ capture time, τ_{trans} transit time across one well, p_e escape probability, α is the absorption constant and L is the device length in the growth direction. Substituting Equation 2 and 3 into 1, one obtains:

$$R = \frac{e}{h\upsilon}\alpha p_e \tau\upsilon \quad \dots\dots\dots\dots\dots\dots\dots\dots \quad (4)$$

Where used the drift velocity $\upsilon = \mathrm{L}/\tau_{trans}$, and can be calculated peak detection wavelength from both the first excited state energy E_2 and the ground state energy E_1 [13].

$$\lambda_p = \frac{hc}{E_2 - E_1} \quad \dots\dots\dots\dots\dots\dots\dots\dots \quad (5)$$

Results

The results show detected wavelengths from the design structure by nextnano and TCAD silvaco The simulation code applied in nextnano to evaluate the energy bandgaps in conduction and valence bands for the semiconductor materials: $(In_{0.57}Ga_{0.43}As)_{0.25}$ $(GaAs)_{0.75}$ / $(In_{0.57}Ga_{0.43}As)$ / $(GaAs)_{0.35}$ $(In_{0.57}Ga_{0.43}As)_{0.65}$. On the other hand, the TCAD simulation software in Silvaco is used to estimate the absorption wavelength and absorption coefficient for band to band and continuum to band transitions.

Figure 4 shows the edge of the conduction band and valence band of the quantum well structure and wavefunctions represented at energy levels approved without an external field, Figure 5 shows detected wavelengths and energies available in the conduction band and valence band. Figure 6 shows the conduction band and valence band and wavefunctions and the energy levels with external field 1.7 V/μm.

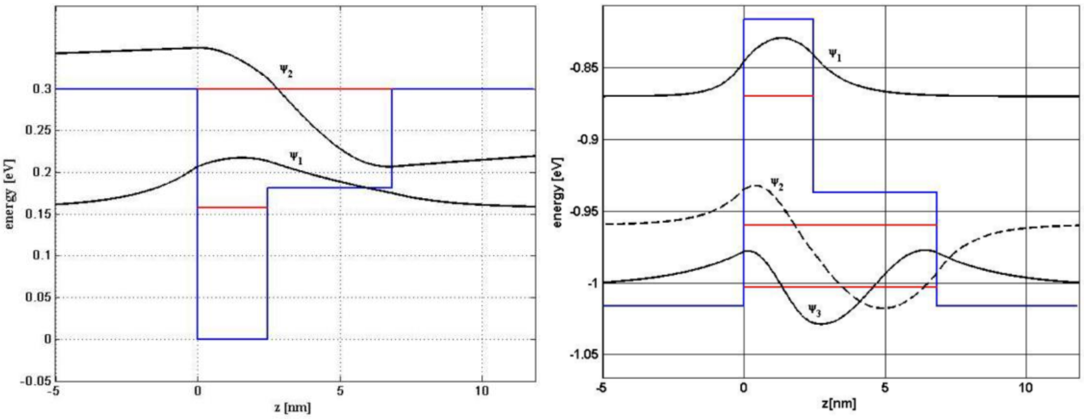

Figure 4: Quantum well structure and wavefunctions without external field

(a) conduction band (b) valence band

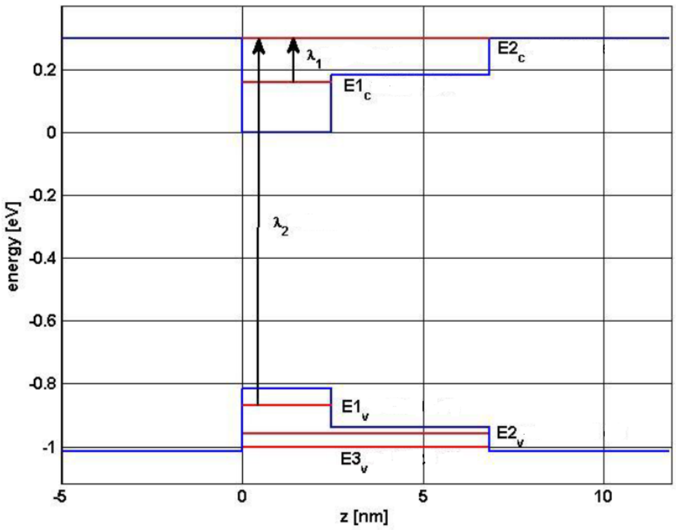

Figure 5: Energy levels in the conduction band and valence band without external field.

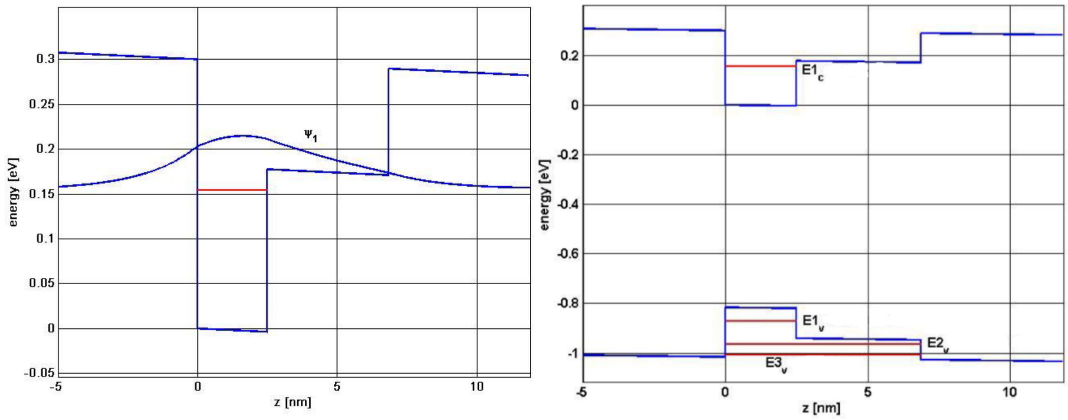

Figure 6: External field effect on (a) quantum well structure and wavefunctions in conduction band (b) Energy levels in the conduction band and valence band

The relation between absorption factor and wavelength at the bound – bound transition and at the bound – continuum transition without external field effect shown in Figure 7 and Figure 8 respectively, Figure 9 shows the comparison in absorption with and without external field effect 1.7 V/µm.

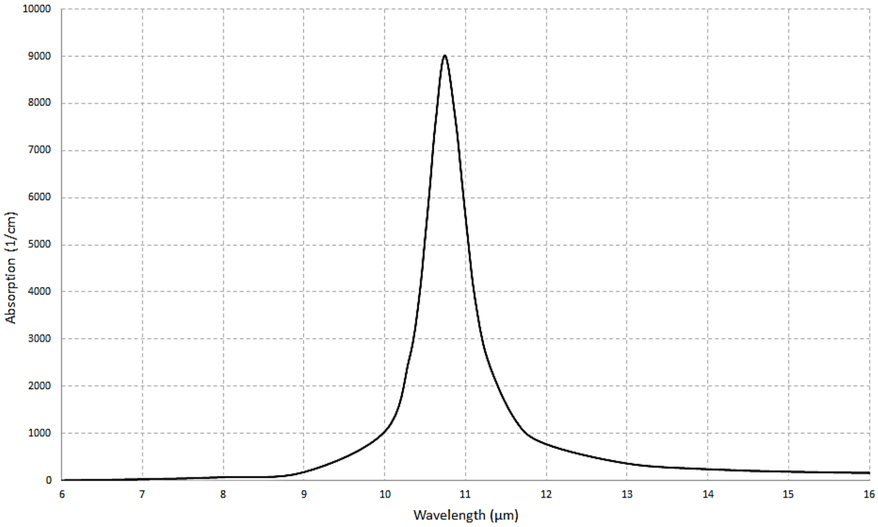

Figure 7: Bound – bound transition without external field effect

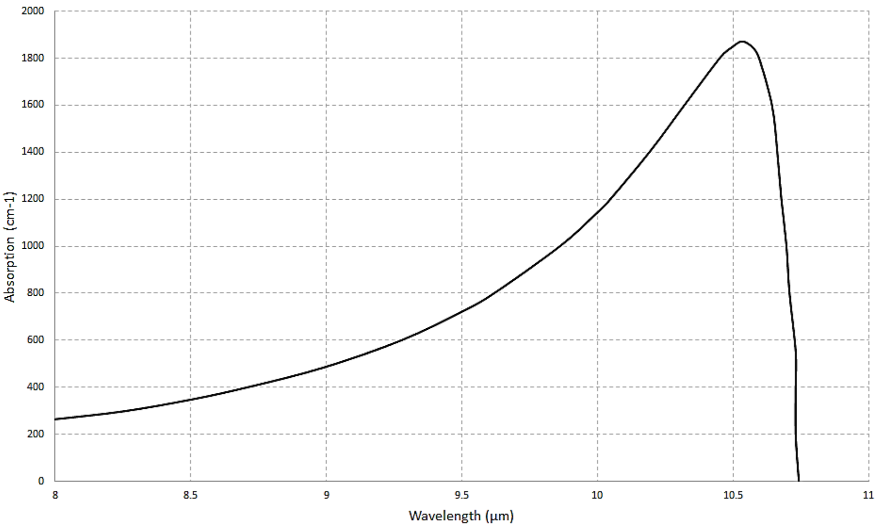

Figure 8: Bound – continuum transition without external field effect

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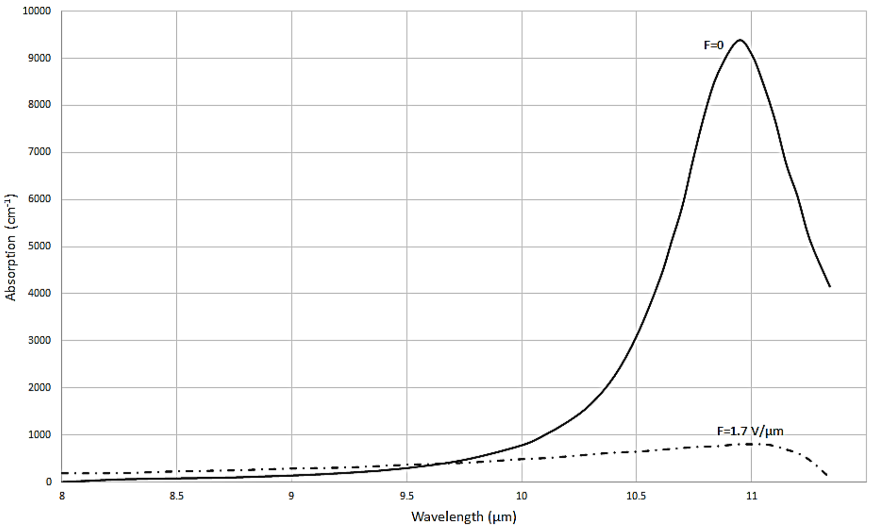

Figure 9: Absorption with and without external field effect

Conclusion

The results show that in the valance band produces three available energy levels E_{V1}= 0.87 eV, E_{V2}= 0.96 eV and E_{V3}= 1.003 eV, but only two available energy levels in conduction band E_{C1}= 0.3 eV and E_{C2}= 0.15 eV, the external field effect leads to high second energy level continuous field of energy level and then arise current. The absorption in bound-bound transition is more narrow and intense from bound- continuum transition peak absorption coefficient at 10.6 μm is 9000 cm^{-1} for Bound – bound transition and 1800 cm^{-1} for Bound – continuum transition. In other words, the absorption spectrum for the simulated quantum well detector is wide such that it ensures that structure of this design detects the infrared at the CO_2 laser applications range (9-11) μm as long as the external field stays below a reasonable value (900 cm^{-1}). The technical importance of these wavelengths is to using in many applications such as LADAR and air armaments guidance.

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