STUDY OF VOLTAGE TUNABLE ASYMMETRIC QUANTUM WELL STRUCTURE FOR INFRARED DETECTION

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ABSTRACT

The performance of GaAs/AlGaAs asymmetric quantum well infrared detectors exhibiting inter subband absorption has been studied. The asymmetric quantum well structure considered for the present study consists of two regions, a step quantum well with a 100_ $Al_{.18}Ga_{.82}As$ step and 80_ GaAs well, followed by a double barrier tunneling structure with 50_ $Al_{.44}Ga_{.56}As$ barriers and a 40_ $Al_{.2}Ga_{.8}As$ well. The quantum well structure has three bound to bound energy levels, one below the step (E_1) and the other two above the step (E_2 & E_3). Transitions from E_1_E_2 and E_1_E_3 are employed for dual band detection. The energy difference E_1_E_2 and E_1_E_3 changes with the applied voltage due to stark effect. The absorption coefficient calculated at zero bias reaches the peak at 11_m and 17_m corresponding to the transitions from E_1_E_3 and E_1_E_2 respectively. However with increasing applied bias the absorption coefficient peaks for smaller wavelengths. Fig.2 shows the variation of absorption coefficient with respect to wavelength at different bias voltage. Resonant tunneling occurs at 20mV and 80mV for E_1_E_3 and E_1_E_2 transitions corresponding to 10_m and 14_m respectively. Photo generated carriers then tunnel through the double barrier structure. Thus the photocurrent is generated by inter subband absorption followed by resonant tunneling phenomena. The responsivity reaches a maximum of 0.37A/W at 20mV corresponding to 10_m and 0.48A/W at 80mV corresponding to 14_m. The calculated detectivties are 1.066×10^6 (cm√Hz/W) at 20mV and 1.319×10^6 (cm√Hz/W) at 80mV.

1. INTRODUCTION

Recently, there is a great deal of interest in the fabrication of multicolor quantum well detectors. In order to get response in several wavelength ranges, one approach is to build several stacks of square quantum well with different peak response wavelengths[1-3]. The response due to different wavelengths can be achieved either by contacting each stacks separately or by controlling the bias across the stacks to sequentially activate different stacks[4, 5]. The other approach is to use an asymmetric or coupled quantum well structure where the transitions from the ground to several excited states are allowed[6-8]. The advantage of the later approach is that it requires only one set of quantum well, which makes the fabrication relatively simple.

In the present work, a voltage tunable two color asymmetric GaAs/AlGaAs quantum well infrared detector is studied. The structure used for this study consists of an 80Å GaAs well and a 100Å $Al_{.18}Ga_{.82}As$ step followed by a double barrier tunneling structure with a 50Å $Al_{.44}Ga_{.56}As$ barriers and 40Å $Al_{.18}Ga_{.82}As$ well is shown in Fig 1. Transitions from both E_1 to E_2 and E_1 to E_3 are employed for dual band detection. Photo generated carriers then tunnel across the barrier structure. Resonant tunneling occurs at 20mV and at 80mV corresponds to E_1 to E_3 and E_1 to E_2 transitions respectively.

2. THEORETICAL CALCULATION:

2.1. Electron Energy Level and Envelope Wave Function:

Fig. 1 shows energy levels in an asymmetric quantum well structure used for the present study. In the effective mass approximation, the one-electron Schrodinger wave equation for the electron in quantum well can be written as

$$\frac{\_^2}{2m^*(z)}\frac{d^2\varphi(z)}{dz^2} + U(z)\varphi(z) = E(z)\varphi(z) \quad \text{--(1)}$$

where

_ = reduced Planck's constant,

$m^*(z)$ = effective mass along the z direction.

$E(z)$ = z component of energy and $U(z)$ is the total potential energy.

The boundary condition for envelope wave functions is that $\varphi(z)$ and $(1/m^*)d\varphi/dz$ are continuous at the interfaces. Total potential energy $U(z)$ in eV in Schrodinger equation is written as

$$U(z)=U_{\text{built-in}}(z) - V_F(z). \quad \text{--(2)}$$

Where $U_{\text{built-in}}(z)$ is the built in potential energy in eV and $V_F(z)$ is the sum of electrical potential energy and the induced electric potential energy due to the screening effect. $V_F(z)$ is obtained by solving Poisson's equation with proper charge distribution inside the quantum well. Self-consistent calculations are used[9] to solve both Schrodinger and Poisson's equations.

2.2. Absorption Coefficient:

The absorption constant α in the well is defined as $h\omega$ times the number of transitions per unit volume per unit time divided by the incident power per unit area.

$$\alpha = \frac{1}{V}\sum_i\sum_f\sum_k\sum_{k'}\left\{\_\omega W_{fi} \Big/ \frac{n_r\omega^2A^2}{2c\mu}\right\} \quad \text{--(3)}$$

where the summations over i and f are for the quantized initial and final energies, respectively for the z components of the momenta and k, k' are the wave vectors of the electron in the x-y plane for the initial and final states respectively. If we calculate the total transition rate and take in to account the line broadening to get [10]

$$\alpha=\sum_i\sum_f\frac{\mu c m k_B T e^2}{\pi\_^2 m_0^2 L n_r\omega}(\cos^2\theta)\,|M_{fi}|^2 \times \ln\frac{\{1+\exp(E_F-E_i)/k_BT\}}{\{1+\exp(E_F-E_f)/k_BT\}}\;\frac{\Gamma/2}{(h\omega-E_{fi})^2+(\Gamma/2)^2} \quad \text{--(4)}$$

where $M_{fi} = \frac{m_0(E_i-E_f)}{i\_}\int_{-L/2}^{L/2}\varphi_f^*(z)\, z\, \varphi_i(z)dz$,

μ is permeability, c is the velocity of light in free space, θ is the angle between the polarization vector and the normal to quantum well.

2.3. Responsivity

The photocurrent I_p is expressed[11] as $I_p = n_p e v$, where n_p is the number of photo generated carriers/cm^3 and v is the transport velocity along the supper lattice. The generation rate of the photo carriers is $(P\cos\theta\alpha/\_\omega)$, where $P\cos\theta$ is the optical power incident on the active area of the detector at an angle of θ. Hence n_p can be expressed in terms of the hot carrier escape probability from the quantum well p_e and recapture lifetime τ_L as

$$n_p= (P\cos\theta\,\alpha/\_\omega)p_e\tau_L \quad \text{--(5)}$$

Thus defining peak responsivity as $R_p = I_p/(P\cos\theta)$, we get

$$R_p= (e/\_\omega)\eta_a p_e g \quad \text{--(6)}$$

Where g is the optical gain given by $g = v\tau_L/l = \tau_L/\tau_t = L/l$ and $\eta_a = (1-e^{-2\alpha l})/2$ is the unpolarised absorption quantum efficiency. L is the length of the high field domain. The photo excited tunneling escape probability p_e can be obtained from the branching ratio between τ_t and the photo excited state recombination time τ_r.

$$P_e = [1+\tau_t/\tau_r]^{-1}. \quad \text{--(7)}$$

Where $\tau_t = 2L_w/vT(\omega)$ is the tunneling life time.

2.4. **Dark Current**

In order to calculate the dark current I_d we first determine the effective number of electron n, which are thermally excited out of the well in to the continuum transport state as a function of bias voltage[12]

$$n = \frac{m^*}{\pi\_2L_w} \int_{E_0}^{\infty} f(E)T(E,V)\, dE \qquad \text{--(8)}$$

T(E,V) is the bias dependent tunneling current transmission factor for double barrier tunneling structure, which accounts for both thermionic emission above the energy barrier and thermionically assisted tunneling below the barrier. Then bias dependent dark current I_d is given by[12]

$$I_d = nev \qquad \text{--(9)}$$

Where, $v = \mu F[1+(\mu F/v_s)^2]^{-1/2}$ is the average transport velocity. μ is the mobility and F is the average electric field.

2.5. Detectivity

The most commonly used figure of merit for infrared detectors is its detectivity, which is a normalized signal to noise ratio. The spectral detectivity D_λ is given by[11]

$$D_\lambda = \frac{R_p\sqrt{(A\Delta f)}}{i_n} \qquad \text{--(10)}$$

Where R_p is the spectral responsivity, A is the detector area and in is dark current given as[13]

$$i_n^2{}_{dark} = 4e(1/p_e)I_{dark}\,\Delta f \qquad \text{--(11)}$$

Where $g_{noise}=1/p_e$, is the noise gain.

3. RESULTS AND DISCUSSIONS

The structure considered in the calculation is a modulation doped asymmetric quantum well as shown in Fig 1. The parameters used in the calculations are electron effective mass $m^* = (.0665+.0835x)m_0$, barrier height $U_0 = 0.6[1.247x-5.405\times10^{-4}(T+204)]$eV. $\varepsilon = (13.1-3.0x)\varepsilon_0$, where x is the Al- mole fraction and m_0 and ε_0 are the mass of free electron and the dielectric constant of free space respectively. Self-consistent calculations with the screening effect are used to obtain theoretical results. The calculated magnitudes of the three electronic eigen energies from the conduction band bottom are 33.3meV 104.7meV and 141.2meV corresponding to energy levels E_1, E_2, and E_3 respectively.

Absorption coefficients are calculated employing transitions from E_1 to E_2 and E_1 to E_3 for different voltages and plotted in Fig 2. Absorption peak shifts in wavelength for applied bias due to stark shift[10]. Fig. 3 illustrates the responsivity curve for different applied voltage. A maximum of 0.37 A/W is obtained at 20mV corresponding to 10μm and another maximum of 0.48 is obtained at 80mV corresponding to 14μm. Dark current is plotted for various temperatures for different applied bias as shown in Fig 4. Detectivity is found to be 1.066×10^6 (cm√Hz/W) at 20mV and 1.319×10^6 (cm√Hz/W) at 80mV.

4. CONCLUSION:

Asymmetric AlGaAS/GaAs multicolor quantum well structure has been studied. Absorption coefficient and responsivity are calculated. From responsivity curve it is found that it reaches a maximum at 10μm for 20mV and 14μm for 80mV. Thus by properly biasing the detector different wavelength can be detected.

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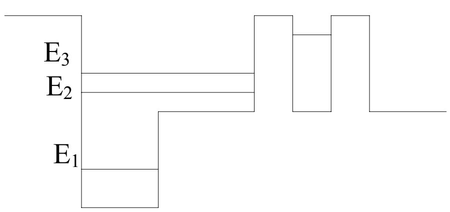

Fig 1. Potential energy profile for the asymmetric quantum well at zero bias.

Fig 2. Absorption coefficient vs Wavelength for different voltages

Fig 3. Responsivity vs wavelength

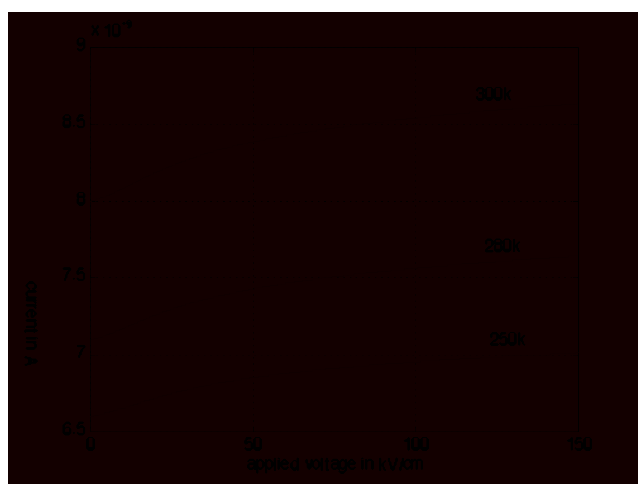

Fig 4. Dark current vs applied voltage for three different temperatures.