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VARIATION OF QUANTUM WELL INFRARED PHOTODETECTORS PARAMETER WITH AN APPLIED ELECTRIC FIELD

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A model is presented for the performance of quantum well infrared photodetectors (QWIPs) utilizing intersubband electron transitions and tunneling injection electrons. The dark current and the responsivity are derived as functions of the QWIP parameters, including the number of the QWs and electric field dependent capture probability in an analytical form.

Keywords: *QUANTUM WELL INFRARED PHOTODETECTORS, INTERSUBBAND ELECTRON TRANSITIONS, DARK CURRENT, RESPONSIVITY.*

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1. INTRODUCTION

Quantum wells [1] are formed in semiconductors by using very common well material like gallium arsenide sandwiched between two layers of a barrier material with a wider bandgap, i.e. aluminium gallium arsenide. In this paper an analytical model is developed for evaluating the performance of QWIPs in which the electron injection from the emitter into the QW structure is associated with the electron tunneling through the extreme barrier, the aim of the paper is to investigate theoretically the QWIP operation using the proposed analytical model [2, 3].We also study the effect of the variation of capture probability[4] with electric field on QWIP operation.

2. THEORY

2.1 Mathematical description

The QWIP under consideration comprises a QW structure, sandwiched between the emitter and collector barriers followed by contact layers heavily doped by donors. Under the assumptions the model of the QWIP [5] is described by Poisson equation and an equation governing the electron balance in the QW structure. These equations can be estimated as,

$$\frac{d^2\varphi}{dx^2} = \frac{4\pi e}{\alpha} \sum_{n=1}^{N} (\Sigma_n - \Sigma_d)\delta(x - nL) \tag{1}$$

$$g_d \varepsilon(\Sigma_n) + \sigma I \, \Sigma_n = \frac{P_c}{e} j \tag{2}$$

Here φ is the electrostatic potential, e is the charge of electron, ε is the dielectric constant, Σ_n and Σ_d are the electron sheet concentration in the n-th QW and the donor sheet concentration in each well, $L = L_B + d$, N is number of quantum well, L_B is the thickness of barrier and d is the width of well, P_c the electric field dependent capture probability of electron in QW, $\delta(x)$ is the Dirac d function, g_d is the rate of the electron thermo excitation from the QW, j is the density of electron.

Solving the equation (1) under the boundary condition $\varphi\,(x = 0) = 0$ and $\varphi\,(x = W) = V$ we have

$$j_{inj} = \frac{j_m}{\tau} \cdot \left[\frac{\exp(\eta_d z - 1)}{\exp(\eta_d - 1)} \right] + \frac{e\sigma I \sum_d}{P_c} z$$

where $\tau = j_m P_c / e g_d$, $\eta_d = \pi\hbar^2\, \Sigma_d / mkT$ and I is intensity of light.

2.2 Dark current density

Dark current is the term for the electrical output of a detector in the absence of input. Under dark condition ($I = 0$) the simple formula for the dark current density is

$$j_{dark} = j_m \left[\exp - \frac{(\varepsilon_i / kT - \eta_d)}{P_c} \exp\left\{ \frac{e a_B}{N E_d} \left(E - \frac{E_t}{\ln_\alpha} \right) \right\} \right] \tag{3}$$

where $a_B = \alpha\hbar^2 / me^2$ is the Bohr radius and $E_t = \pi m^{0.5} (\varepsilon_0 - \varepsilon_F)^{1.5} (2\sqrt{2} e\hbar)^{-1}$, ε_0 is the height of the barrier for the electron in the emitter and ε_F is their Fermi energy.

2.3 Responsivity

The ratio of the detector output and the detector input is defined as the responsivity. It is given in ampere/watt or volt/watt. At low intensities of the infrared radiation responsivity can be estimated as

$$R = R_d \left[1 + \frac{E - E_t / \ln\alpha}{N E_d} \right] \tag{4}$$

Where $R_d = e\sigma\Sigma_d / P_c \varepsilon_t$.

3. RESULT AND DISCUSSION

In Fig. 1 we have seen that the dark current increase rapidly with electric field for single well but slowly increases for multiquantum wells and saturate for higher applied electric field. It is clear from Fig. 2 that responsivity of a photodetector increases with electric field and saturate from higher electric field. The responsivity of different numbers of well is shown in figure. According to this theory we can say that responsivity is independent upon number of well but dependent upon donor concentration.

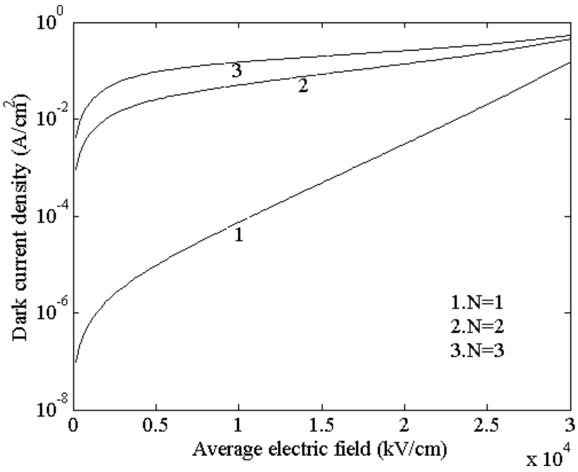

Fig. 1 – *Variation of dark current density with electric field*

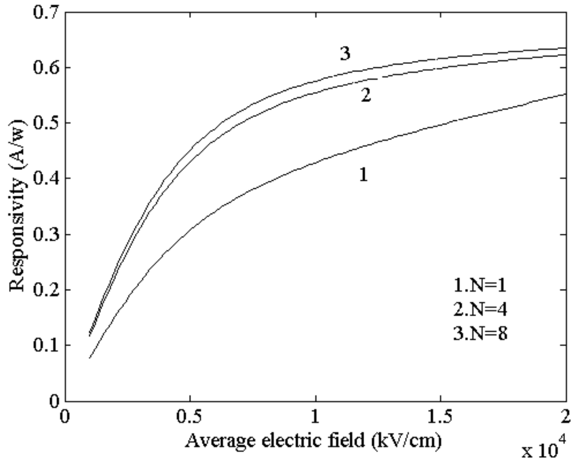

Fig. 2 – *Variation of dark current density with electric field*

4. CONCLUSION

From this study we conclude that the capture probability has significant effect at low electric field on QWIP parameter and the increasing the number of wells above $N = 8$ has no significant effect on responsivity and dark current.

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