Boundary conditions in characterizing $In_xGa_{1-x}As$ /GaAs quantum well infrared photodetector

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Abstract- **We study the optical transition between bound-to-continuum states in InGaAs/GaAs quantum well infrared photodetector (QWIP) by analyzing two possible boundary conditions for the continuum states. InGaAs/GaAs QWIP differs from the GaAs/AlGaAs QWIP in many aspects. Comparing running wave function and Bloch wave function with experimental results, we find that Bloch wave function is the much more suitable boundary condition for multiple InGaAs/GaAs quantum well (QW) structure. The blueshift of the responding peak is smaller when the Bloch wave boundary conditions apply.**

I. INTRODUCTION

Infrared photodetectors are widely used for infrared detection, guidance, night vision, resources satellite and earth observation satellite and so on [1-9]. AlGaAs/GaAs quantum well infrared photodetector (QWIP) have several advantages such as very long wavelength infrared detection, lower threshold current density, and higher gain [2-8], compared to typical HgCdTe based thin-film infrared photodetectors [4,5]. In addition, quantum well and quantum dot (QD) structures based on strained $In_xGa_{1-x}As$ layers grown on GaAs substrate have attracted great attention because of their interesting physical properties and potential for high-speed and optoelectronic device applications. Compare with the $Al_xGa_{1-x}As$/GaAs QWIPs, it is much more interesting to consider InGaAs as the well while GaAs as the barrier material since the carrier transport in binary GaAs is expected superior to that of a ternary alloy, as was found to be in the $In_{0.53}Ga_{0.47}As$-InP binary barrier structures[7,9].

II. RESULTS AND DISCUSSIONS

In this paper, we mainly use two boundary conditions to study the InGaAs/GaAs QWIP. The InGaAs/GaAs QWIP consists of 50 periods of 5.0 nm $In_xGa_{1-x}As$ wells separated by 50 nm of GaAs barriers. There is only one bound state in the $In_xGa_{1-x}As$ QW. We consider the quantum well structure in the form of:

$$V(z)=\begin{cases} U_0 & 0\le z<L \\ 0 & L\le z<L+W \\ U_0 & z\ge L+W \end{cases}$$

Describing periodic boundary conditions of InGaAs/GaAs QWIPs:

$$V(z+n(L+W))=V(z)$$

Here L is the InGaAs quantum well width, W is the GaAs barrier width, and U_0 is the barrier height, where n is an integer.

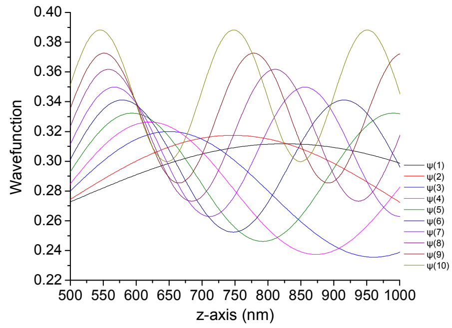

Fig. 1. Normalized wave functions of 10 excited states above the GaAs barrier, E_i, i = 1, 10. The wave functions are shifted up in the figure presentation in such a way that $\psi_i(z) + E_i$.

Due to the carrier transportation in the InGaAs/GaAs QWIP under normal device working conditions, we have to envisage the conduction of both the thermal-excited and photo-excited electrons from one $In_xGa_{1-x}As$ QW to the next one. Fig.1 present the normalized wave functions of these extended states with boundary conditions of $\psi(0)=\psi(2L+W)$. Here we show 10 states between z=0 and z=L. In small range of electron energy states which is higher than a GaAs barrier side, the relationship between the optical matrix element and extending state energy is very smooth，but the energy quickly reaches a peak, and above this energy, corresponding to the optical transition matrix element will basically disappear. According to the wave function, we can obtain the optical transition matrix element and the optical absorption spectra. By calculating the density of photo-generated carriers in the continuum above the GaAs barriers, we have demonstrated

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that the photo-carriers can be either in Bloch states in the multiple quantum wells (miniband states), or they transport from one quantum well to the next in the form of running waves. Fig. 2 presents the calculated photocurrent spectrum of InGaAs/GaAs QWIP.

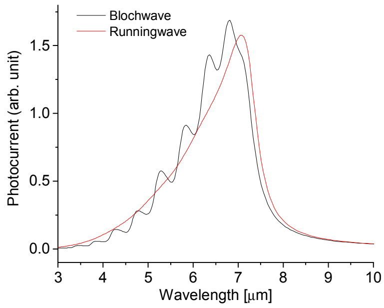

Fig. 2 Calculated photocurrent spectrum of InGaAs/GaAs QWIP

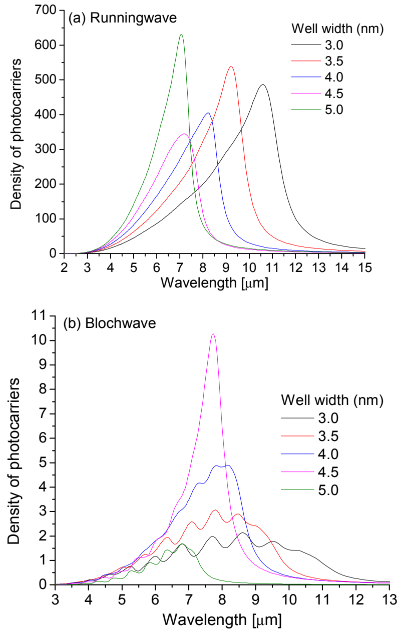

Fig. 3 Density of photo excited carriers as functions of the InGaAs QW width: (a) Running wave boundary conditions while changing of InGaAs QW width. (b) Bloch wave boundary conditions while changing of InGaAs QW width.

Fig.3(a) shows the density of photo excited carriers as a function of the InGaAs QW width. With the increase of QW width, the peak intensity of photo excited carriers becomes small. Fig.3 (b) shows the density of photo carriers as function of the photon energy with applying Bloch wave boundary condition. With the increase of the InGaAs QW width, the peak of photo excited carriers becomes shorter. It is noticed that the blueshift of the responding peak is smaller when the Bloch wave boundary conditions apply. Since the blueshift of the response wavelength is smaller for Bloch wave boundary conditions, a decrease in the variation of the InGaAs/GaAs QWIP's response wavelength as a function of the postgrowth activity can be induced due to the changes of the boundary conditions for photocarriers, which suggested that the boundary conditions of the photo-generated carriers depend on the device structure and device operation condition.

III. CONCLUSION

By calculating the density of photo-generated carriers in the continuum above the energy barriers using InGaAs/GaAs QWIP structures, we have demonstrated that the photo-carriers can be either in Bloch states in the multiple quantum wells, or they transport from one quantum well to the next in the form of running waves. The infrared optical absorption spectrum shows the expected blueshift of the response wavelength. The variation in the absorption peak intensity depends on the boundary conditions of the response wavelength. For InGaAs/GaAs QWIPs, the mean free path of photo-carriers is long so that the photo-carriers are largely coherent when they transport across InGaAs quantum wells. The Bloch wave boundary conditions are much more proper for continuum states in the InGaAs/GaAs QWIPs consisting multiple QWs.

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