Phononic Properties for Enhanced Signal-to-Noise Photodetector

Yi Lan, Chenjie Tang, Junxia (Lucy) Shi, Mitra Dutta, Michael Stroscio
Department of Electrical and Computer Engineering
University of Illinois at Chicago
Chicago 60607, United State
ylan3@uic.edu

ABSTRACT

A reduced signal-to-noise reduced photodetector has been designed using single-and double-quantum well structures as well as phonon assisted transitions. To increase electron carriers, delta-doping is used in the first single well. In this contribution, the energy levels of the single-well—double-well structure are prescribed by determining the energy spectrum for the interface phonon potentials and their dispersion curves.

INTRODUCTION

According to "Enhanced Signal-to-Noise in Photodetectors Interface Phonon-assisted Transitions"[1], photodetector is designed into three quantum wells, one single well at the left and one double well at the right side. The photodetector absorbs one photon, emits a phonon, and absorbs another photon with the same energy the same as the first one. Accordingly, signal-to-noise as predicted by the Richardson formula is enhanced since the electron is approximately twice as deep in its initial state as in the corresponding single-well photodetector.

This series of processes - absorbing a photon, emitting a phonon, then absorbing a photon - works efficiently only if excess electrons are kept in the first single well. That's because electrons are needed for absorbing photons. Delta doping enhances the electron concentration that can absorb photons in the first process, and can be accomplished in a way that has little impacts on the energy states and offsets of the full structure.[2,3]

In this contribution, the phononic properties in this structure will be described, including the phonon dispersion curve and phonon potential in the structure in the single-well—double-well structure.

MODEL

Setting up regions for this structure, the dielectric function should be considered first. As known, in system such as AlAs and GaAs,

$$\epsilon(\omega) = \epsilon^{\infty} \frac{(\omega_{LO}^2 - \omega^2)}{(\omega_{TO}^2 - \omega^2)} \tag{1}$$

Since ϵ^{∞}, ω_{TO}, and ω_{LO} depend primarily on the x-value of $\mathrm{Ga}_x Al_{1-x} As$, n-type doping causes only small changes in the phononic properties. Accordingly, only the boundaries defined by the six interfaces in the active part of the single-well—double-well device, see Figure 1, need to be used to determine the phonon modes and their dispersion curves.

The single-double quantum well structure is depicted as Fig. 1, and by a Schrödinger equation calculation of energy levels, it is seen that the phonon-assisted transition from the single-well to the double-well can be driven by emission of a phonon with an energy of 32.19 meV.

The phonon potentials, φ, in the seven regions, satisfy the boundary conditions [4],

$$\varphi_n(z) = \varphi_{n+1}(z) \tag{2}$$

$$\varepsilon_n \frac{\partial \varepsilon_n}{\partial z} = \varepsilon_{n+1} \frac{\partial \varepsilon_{n+1}}{\partial z} \tag{3}$$

Using the phonon normalization condition [4] and performing all the calculations for different wave vectors, q, from 0 to $\frac{\pi}{a}$, where lattice constant of GaAs is 5.65325Å, we find the results of Figures 2-6.

CONCLUSION

Herein, the phononic properties for an enhanced signal-to-noise photodetector have been determined. Device design characteristics will be discussed in the presentation.

REFERENCES

[1] Yi Lan, Nanzhu Zhang, J. L. Shi, M. Dutta, M. A. Stroscio, Design of a Novel Heterostructure Photodetectors with Dramatically Enhance Signal-to-Noise based on Resonant Interface-Phonon-Assisted Transitions and Engineering of Energy States to Enhance Transition Rates, 2nd Int'l Conf. and Exhibition on Lasers, Optics & Photonics, Sept. 2014 Philadelphia.

[2] Paul Harrison, Quantum Wells, Wires and Dot: Theoretical and Computational Physics, 3rd edition, (Wiley, New York, 2010).

[3] Michael A. Stroscio, Interface-Phonon--Assisted Transitions in Quantum Well Lasers, Journal of Applied Physics, 80, 6864 (1996). [2]

[4] M. Stroscio and M. Dutta, Phonons in Nanostructures (Cambridge University Press. 2001).

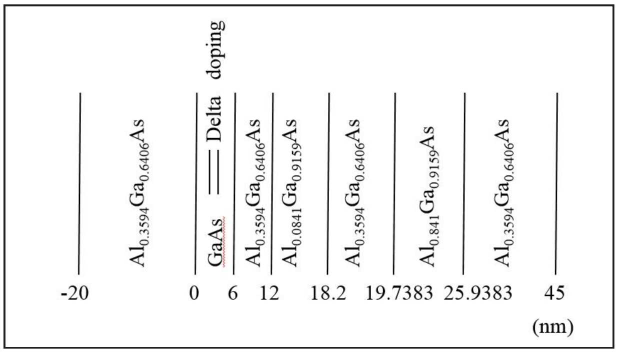

Fig. **1**. Structure of single-double well photodetector along z direction

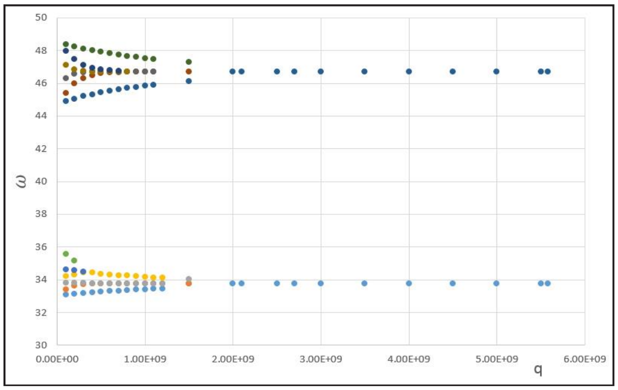

Fig. 2. Phonon dispersion curve. Phonon dispersion curves – as shown as Fig. 2 – form groups near 33.768 meV and 46.692 meV.

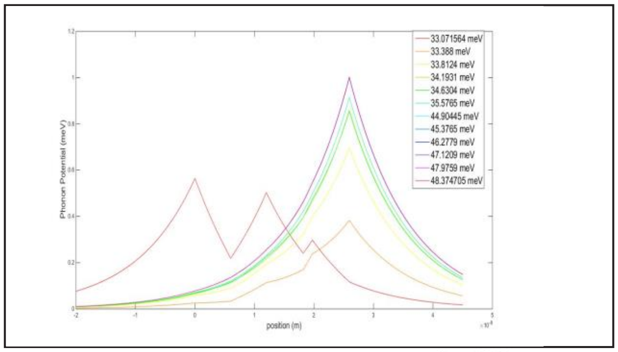

Fig. 3. Phonon potential along z-axis with q=1×10^8

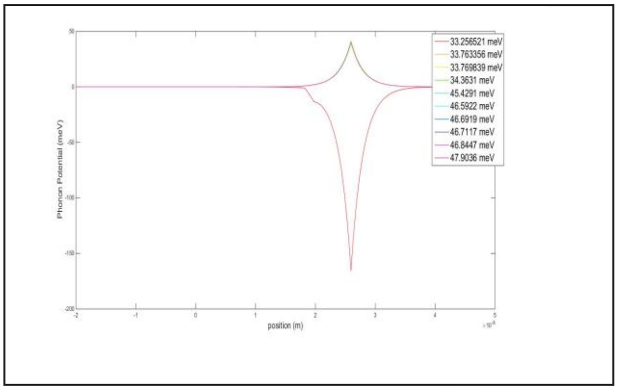

Fig. 4. Phonon potential along z-axis with q=5×10^8

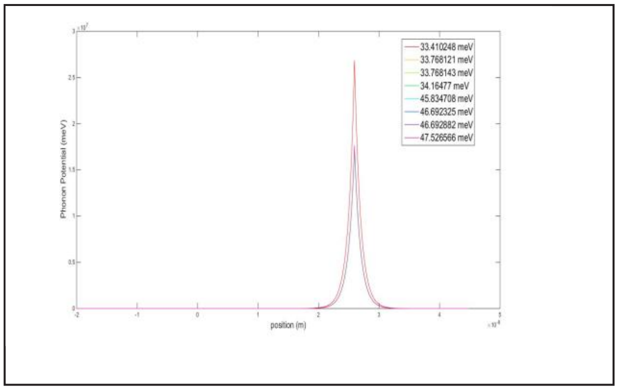

Fig. 5. Phonon potential along z-axis with q=10×10^8

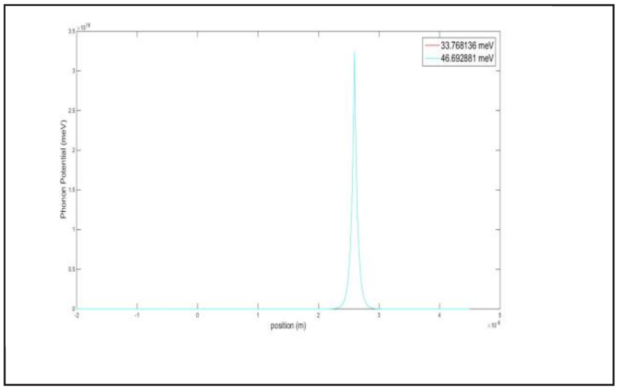

Fig. 6. Phonon potential along z-axis with q=20×10^8