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ChemTech

International Journal of ChemTech Research
CODEN (USA): IJCRGG ISSN: 0974-4290
Vol.7, No.3, pp 1526-1528, 2014-2015

ICONN 2015 [4th - 6th Feb 2015]
International Conference on Nanoscience and Nanotechnology-2015
SRM University, Chennai, India

Tunable Polariton BandGap in Quantum Wire Superlattice System

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Abstract : The phonon polariton modes in quantum wire superlattice system are studied. The interfacial modes in the polaritonic gap of the GaAs/$Ga_{1-x}Al_xAs$ quantum wire superlattice are reported as suggested by some recent literature. By varying aluminum concentration the optical parameters of the system are determined. The results are presented for different values of x. Our results shows that as the concentration increases, the polaritonic gap increases and the interfacial modes remains to be constant and it occur in the lower frequency region.
Keywords: Polariton,Band Gap,dispersion.

Introduction

Superlattice(SL) is a periodic structure of layers of two (or more) materials. A SL in the form of the periodic planar heterostructure is artificially fabricated crystals of alternate layers of different materials[1]. The recent development and advances in nano fabrication technology such as molecular beam epitaxy (MBE)[2] and metal organic chemical vapor deposition (MOCVD) or self-assembled method have made possible to manufacture different sizes and shapes of semiconductor SL were their applications extend over many areas. Quantum wire superlattice(QWSL) is a quasi-one dimensional systems in which particle are restricted to moves in one direction.

The polariton dispersion in a QWSL is investigated by several authors. J.S.Nkoma studied the phonon polariton modes in semiconductor superlattices illustrated with GaAs-GaP superlattice[3]. B.Jogai and D.CReynolds calculated Intersubband optical absorption in quantum wire Superlattices[4].The polartions in a quantum dot SL have been investigated by one of the authors[5]. J. Požela et.al calculated surface phonon and plasmon–phonon polariton characteristics of GaAs, $Al_xGa_{1-x}As$/GaAs, and GaN/Al_2O_3 layered structures are investigated by means of terahertz radiation reflection spectroscopy[6]. In the present work we have calculated the Phonon polariton band gap of the Quantum Wire Super lattice System (QWSL) consisting of quantum wires of cross-section with their axes along the z-direction. The theory is outlined in the next section. The result and discussion are presented in Section 3.

Theory and calculation

Inside any material, light waves propagates as polariton modes wherein the quantum of the electromagnetic field gets coupled to the various elementary excitations of the material. We concentrate on phonon polariton modes. The system consists of alternating layers of GaAs and $Ga_{1-x}Al_xAs$ of thickness d_1 and d_2 along the z-direction. Several authors have derived the dispersion relation for TM modes assuming the electromagnetic boundary conditions namely the electrostatic potential and the electric displacement field perpendicular to each other interface are continuous .The dispersion relation for polariton modes in QWSLs

$$1+\left(\frac{\varepsilon_B(\omega)\alpha_1}{\varepsilon_A(\omega)\alpha_2}\right)^2+2\left(\frac{\varepsilon_B(\omega)\alpha_1}{\varepsilon_A(\omega)\alpha_2}\right)\left(\frac{\cosh(\alpha_1 d_1)\cosh(\alpha_2 d_2)-\cos(qL)}{\sinh(\alpha_1 d_1)\sinh(\alpha_2 d_2)}\right)=0$$

The dielectric function is given by $\varepsilon_i(\omega)=\varepsilon_i(\infty)+\frac{S_i\omega_T^2}{\omega_T^2-\omega^2}$

Where i refer to A and B medium, ω_T refers to the TO phonon frequency and S_i measures the strength of resonance which is given by $\varepsilon_i(s)$- $\varepsilon_i(\infty)$.Here $L=d_1+d_2$ is the superlattice period and q is the component of the wave vector along the superlattice axis and $\alpha_i^2=k_x^2-\frac{\omega^2}{c^2}\varepsilon_i$ where k_x is the component of the wavevector in the x-direction for TM modes. GaAs is considered as A layer for which the physical parameter used for the calculation are the static dielectric constant $\varepsilon_i(s)=13.18$, the high frequency dielectric constant $\varepsilon_i(\infty)=10.89$, $S_i=1.97$ and $\omega_T=50.386$THz[5].

$Ga_{1-x}Al_xAs$ is considered as B layer for which the physical parameters vary with the aluminum concentration of x. The values of x is in between 0 to 1.The variation of x with static dielectric constant is $\varepsilon_i(\infty)=10.89-2.73x$ [5].The high frequency dielectric constant $\varepsilon_i(s)=13.18-3.12x$.The TO phonon frequency is $33.29-0.64x-1.16x^2$ [7]. By varying the value of x, the static dielectric constant, high frequency dielectric constant and the transverse optical phonon frequency of $Ga_{1-x}Al_xAs$ are determined and hence the phonon polariton behavior of the quantum wire superlattice system is studied. In the present work we have chosen x=0.05,0.1,0.15,0.2, etc and hence we have analyzed the dispersion for each cases.

Result and discussion

The polartion dispersion for QWSL is as shown in figure 1.The dispersion relation of equation is solved numerically and the results are plotted for x=0.05 in the figure 1 we have considered $d_1=d_2=50$Å.

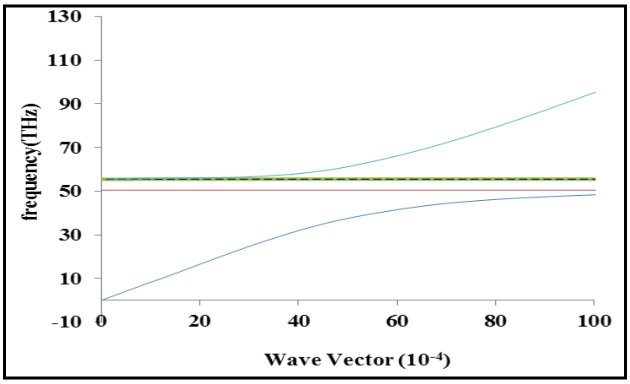

Figure 1. The polartion dispersion of GaAs/ $Ga_{1-x}Al_xAs$ quantum wire system for x=0.05

We get five modes. The top and the lowest modes exhibit the behavior of the well-known bulk modes while the other three modes approaches the surface mode frequency as q tends to zero[5]. These interfacial modes are found to be constant. There is a polaritonic gap in which propagation of electromagnetic waves is forbidden. Similar graphs are also can be obtained for various values of x. By varying the value of x, the other optical parameters of the system are calculated. It is found that the width of the polaritonic gap increases with the value of x as shown in Figure 2.Also the interfacial modes are found to be constant and occupy lower frequency values.

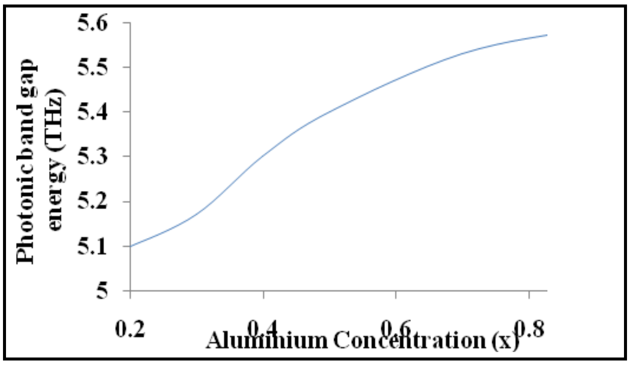

Figure 2.represent the variation of polartonic gap verses with aluminum concentration x

In figure 2 we have noted that the photonic band gap (the electromagnetic wave cannot propagate in the region) energy increases linearly as the aluminum concentration increases. When we compare the photonic band gap of quantum well wire superlattice with that of QWSL we found that the quantum well wire superlattice have higher energy. Thus the concentration of aluminum is also important while studying the phonon-polariton modes in quantum wire superlattice systems. The physical pictures of polartion modes in a QWSL given in this communication may be very useful for designing some important optical devices.

Acknowledgments

The authors would like to thank Prof.K.Navaneethakrishnan (Rtd), School of Physics, Madurai Kamaraj University, Madurai, India for his valuable and useful suggestions. One of the authors (ARJ) also thanks Prof.Sr.Gerardin Jayam, Principal, Holy Cross College, Nagercoil, India for encouragement and support during the part of these investigation.

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