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CAPTURE RATE AND MOBILITY IN GaAlAs/GaAs SUPERLATTICE DUE TO LONGITUDINAL PHONON EMISSION

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ABSTRACT
The variation of capture rate with well width in GaAlAs/GaAs super lattice has been studied taking into account both bulk and super lattice phonon emission. The capture rate decreases with increasing well width up to 4 nm for both bulk and super lattice phonons. Then it increases with increase in well width. The variation of mobility with well width has been studied and it has been found that the mobility curve has a peak around 4 nm for super lattice phonons. The peak is slightly lower than observed in case of bulk phonons.

I. INTRODUCTION:

The study of electron transport phenomena and its various aspects like capture rate and mobility in superlattice and semiconductor quantum wells has been a motivating and interesting field of research for many years [2-8]. The rate of emission of polar longitudinal optic (LO) phonons controls the rate of electron transitions in semiconductor quantum wells [1]. In this context, the authors have studied the variation of capture rate and mobility with well width in GaAlAs/GaAs superlattice taking into account interactions of electrons with both bulk and superlattice phonons. The important feature of electron-phonon interaction in GaAlAs/GaAs superlattice lies in the rates of the lowest order processes involving LO phonons and electrons in the superlattice. The electron energy relaxation rates via LO phonons in layered polar semiconductor heterostructures is controlled mainly by two factors. Firstly, the electronic energy levels and eigenfunctions are modified due to the presence of layers in a superlattice. Secondly the lattice vibrations are altered in both mode frequencies and their waveforms giving rise to phonon band structure. The solution of the Schrödinger equation is matched at the interfaces of superlattice and the electrons are treated in the effective mass approximation. The LO phonon field is quantized at layer interfaces and Bloch's theory is incorporated to take into account the superlattice periodicity along growth axis.

The knowledge of the variations in intersubband and capture rates of electrons with well widths from reference [3] has been utilised for calculation of capture rate and of mobility in GaAs/GaAlAs superlattice which has been presented in this communication and comparison has been made with the bulk phonon model.

II.THEORETICAL MODEL

Due to the periodic structure of GaAlAs and GaAs, the superlattice has a periodic potential.The binary alloy superlattice such as GaAlAs/GaAs is formed by the stacking alternate layers of GaAlAs and GaAs of layer thicknesses d_1 and d_2 respectively, a periodicity is created along the growth direction with the periodicity length $D = d_1 + d_2$. An array of GaAs quantum-wells with layers of GaAlAs forming an array of barriers of energy Vo is formed that constitute the conduction band profile. The electrons in the superlattice have a dispersion relation [2]

$$\cos QD = \cos K_1 d_1 \cos K_2 d_2 - 0.5(Z+1/Z) \sin K_1 d_1 \sin K_2 d_2 \quad (1)$$

where

$K_1=([2m_1{}^*(E-Vo)/\hbar^2]-K^2_{11})^{1/2}$ and

$K_2=([2m_2{}^*E/\hbar^2]-K^2_{11})^{1/2}$, $Z=m_2{}^* K_1/m_1{}^*K_2$.

here Q and K_{11} are perpendicular and parallel components of the electronic wave vector, and $m_1{}^*$ and $m_2{}^*$ are effective electronic masses. The parameters for $Ga_{0.7}Al_{0.3}As/GaAs$ superlattice are $Vo=0.19eV$, $m_1{}^*=0.0879m_e$ and $m_2{}^*=0.063m_e$, where m_e is the mass of electron.

With LO phonons a modified Frohlich interaction has been considered and the phonon spectrum is obtained using a dispersive continuum model. The dispersion relation for the superlattice is given as [2]:

$$\cos qD = \cos K_1 d_1 \cos K_2 d_2 - 0.5(Y+1/Y) \sin K_1 d_1 \sin K_2 d_2 \quad (2)$$

where $K_i = [\omega_i^2 - \omega^2 - \beta_i^2 K^2_{11}]^{1/2}/\beta_i$ and $Y=\rho_1 k_2 \beta_i^2(k_1^2+k_{11}^2)/ \rho_2 k_1 \beta_2^2(k_2^2+k_{11}^2)$.

Here q and k_{11} are phonon wave vector components, β and ρ are the acoustic velocities and reduced mass densities and ω_i are the LO frequencies of material, i = 1,2.

The capture rate and mobility for various well widths have been calculated and given in the following section.

III. RESULTS AND DISCUSSION

The authors have calculated electron transition rate involving the emission of LO phonon modes .From the Knowledge of the capture rate and intersubband rates from reference [3].The relaxation time due to intersubband transitions of electrons for both superlattice and bulk type can be obtained from the phenomenological relation:

$$\tau = (1/\Gamma) \quad (3)$$

where Γ is the intersubband transition rate.

Next the author have computed the mobility from the relation.

$$\mu = e\tau/m^* \quad (4)$$

where $m^* = 0.063m_e$

The capture rate is calculated for both bulk and superlattice phonons for various well widths and the results have been displayed in the Figure 1. It is found that the capture rate has high value around 12.56 × $10^{11}s^{-1}$ for well widths with d_2 grater than 4 nm for bulk phonons. For superlattice phonons it is around 25.12× 10^{11} s^{-1} for d_2 greater than 4 nm. The capture rate decreases with increases well width up to 4 nm for both bulk and super lattice phonons. Then it increases monotonically with increases in well width which is due to enhanced electron-phonon interactions.

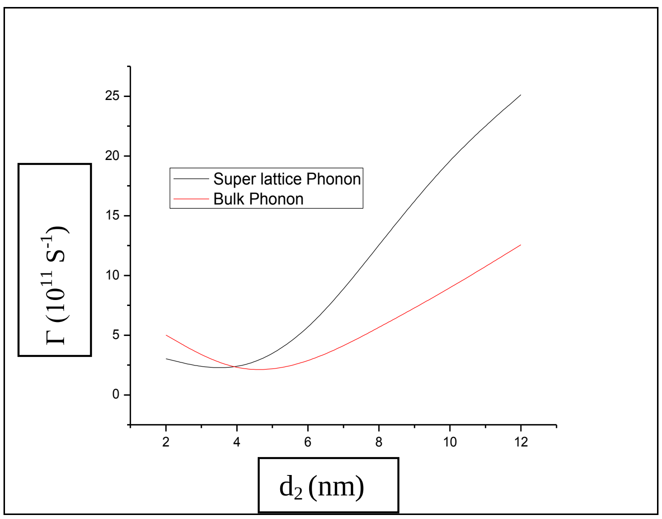

Figure 1: Variation of capture rate with well width d_2 in GaAlAs/GaAs superlattice.

Next we have made the calculations of mobility and have studied its variation with increasing well width d_2 for both superlattice and bulk phonons. It has been found that the mobility has peak at about 4 nm for super lattice phonons and is slightly higher in case of bulk phonons. The higher value of mobility for bulk phonons has obtained by the authors agree with the result in reference [1].

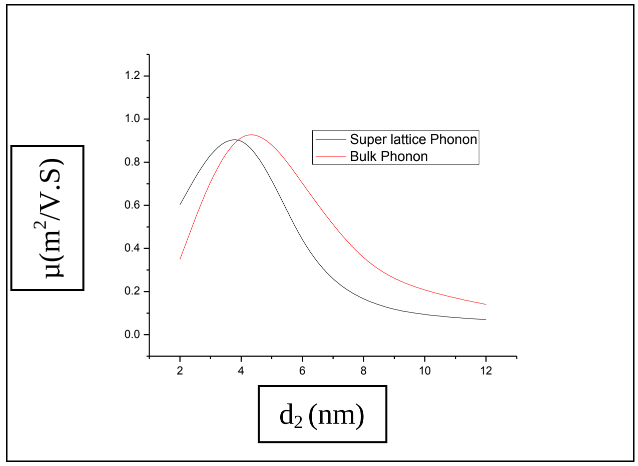

Figure 2: Variation of mobility with well width d_2 in GaAlAs/GaAs superlattice.

IV. CONCLUSION

In the present communication the authors have shown the variations of capture rate and intersunband transition rate for bulk and superlattice LO phonons with the well width for GaAs/GaAlAs superlattice. The capture rate is found to be high for broad well widths. The variation of mobility with well width has been studied which reveals that for superlattice phonons the mobility is comparatively high than the bulk phonons.

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