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STUDY OF CONDUCTIVITY AND POWER DISSIPATION IN GaAlAs/GaAs SUPERLATTICE DUE TO ELECTRON-PHONON INTERACTION

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Abstract

The variation of conductivity with well width in GaAlAs/GaAs superlattice has been studied taking into account both bulk and superlattice phonon interactions with electrons. The conductivity is high for narrow well widths less than 4.7 nm for both bulk and superlattice phonons. Then it decreases monotonically with increasing well width. Also the variation of power with well width has been studied and it has been found that the power dissipation is high around 4.4 nm for superlattice phonons and is much higher in case of bulk phonons.

I. INTRODUCTION

The study of electron transport mechanism and understanding its various aspects like conductivity and power dissipation in superlattice and semiconductor quantum wells has been a motivating and interesting field of research for many years[1-7]. 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 conductivity and power dissipation well width of 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 is 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, there is a alteration in both acoustic and optic mode frequencies of lattice vibrations which results to phonon band structure. Secondly, because of the presence of layers in a superlattice there occurs a modification in the electronic energy levels and eigenfunctions. The solutions of the Schrodinger wave equation are matched at the interfaces of superlattice and the electrons are treated in the effective mass approximation. The LO phonon field is quantized with mode functions matched at layer interfaces and Bloch's theory is used to retain periodicity along the growth axis. From the knowledge of the variation in intersubband and capture rates of electrons with well widths as given in reference[2], the authors have calculated the conductivity and power dissipation in GaAs/GaAlAs superlattice for various well widths. The results have been presented in the present communication and comparison has been made with the bulk phonon model.

II. THEORETICAL MODEL

By stacking alternate layers of GaAlAs and GaAs of layer thickness d_1 and d_2 respectively, a periodicity is created along the growth direction with the periodicity length $D = d_1 + d_2$ for the binary alloy superlattice GaAlAs/GaAs. The electronic band structure in the GaAs/GaAlAs superlattice had been shown in reference [2]. An array of GaAs quantum-wells with layers of GaAlAs forming an array of barriers of energy V_o is formed that constitute the conduction band profile. The electrons in the superlattice have a dispersion relation [3]:

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

where $K_1=([2m_1^*(E-V_o)/h^2]-K_{11}^2)^{1/2}$, $K_2=([2m_2^* E/h^2]-K_{11}^2)^{1/2}$ and $Z=m_2^* K_1/m_1^* K_2$. Here Q and K_{11} are perpendicular and parallel components of the electronic wavevector, and m_1^* and m_2^* are effective electronic masses in material 1 (GaAlAs) and material 2 (GaAs). Here the definite parameters are for $Ga_{0.7}Al_{0.3}As/GaAs$ superlattice are V_o = 0.19 eV, m_1^* = 0.0879 m_e and m_2^* = 0.063 m_e, where m_e is the mass of electron.

For the superlattice 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 [3]:

$$\cos qD = \cos k_1 d_1 \cos k_2 d_2 - 0.5(Y+1/Y) \sin k_1 d_1 \sin k_2 d_2 , \quad (2)$$

where $k_n=[\omega_n^2 - \omega^2 - \beta_n^2 k_{11}^2]^{1/2}/\beta_n$, (n=1, 2) and $Y=\rho_1 k_2 \beta_1^2(k_1^2 + k_{11}^2)/\rho_2 k_1 \beta_2^2(k_2^2 + k_{11}^2)$. Here the phonon wave vector components are q and k_{11}. β and ρ are the acoustic velocities and reduced mass densities and ω_n are the LO frequencies of material *n*. For the $Al_{0.3}Ga_{0.7}As/GaAs$ system, GaAs-like modes are characterized by the following pertinent parameters: ω_1 = 280 cm^{-1}, ω_2 = 294.6 cm^{-1}, $\beta_2 = 5.0\times10^5$ cm s^{-1}, $\beta_1/\beta_2 \equiv 0.89$. Subscript 1 refers to the barrier, 2 to the well. The intersubband transitions of electrons between subband 1 and 2 with emission of superlattice and bulk phonons have been shown in Figure 1, in accordance with reference [3]. The rate of emission changes with increase in well width d_2 and due to this there is also variation of mobility due to bulk and superlattice phonons with the change in well width.

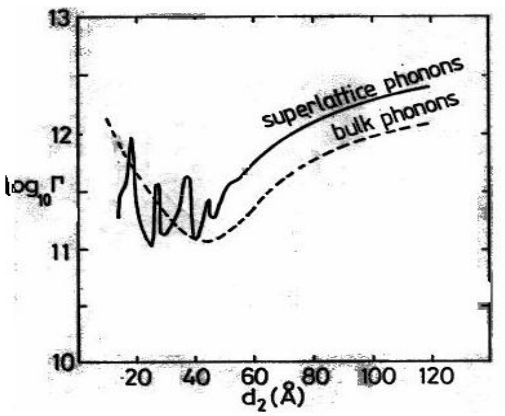

Figure 1: Intersubband rate from subband 2 to subband 1 with varying well width d_2 by emission of proper superlattice GaAs – like phonons (full curve) and by emission of bulk phonons (dotted curve) .

III. RESULTS AND DISCUSSION

The mobility due to intersubband transitions of electrons due to LO phonons for both superlattice and bulk type can be obtained from the phenomenological relation:

$$\mu = e\tau/m^* \quad (3)$$

where m^* = 0.063m_e and τ is the relaxation time given by

$$\tau = (1/\Gamma) \quad (4)$$

where Γ is the intersubband transition rate.

Next we proceed to calculate conductivity with the help of the relation:

$$\sigma = ne\,\mu \quad (5)$$

where n is the electron concentration in the well and is taken as $10^{12}m^{-2}$.

The relation for power dissipation in the superlattice is given as:

$$P = ne\,\mu\,E^2 \quad (6)$$

where E is the electric field given by

$$E = V/d_2\,, \quad (7)$$

V is the potential and we have taken V = 0.01 mV for our calculations.

The conductivity is calculated for both bulk and superlattice phonons for various well widths and the results have been displayed in the Figure 2. It is found that the conductivity is high around 3.65 × 10^{-4} Siemens for narrow well widths with d_2 less than 4.6 nm for bulk phonons. For superlattice phonons it is around 2.34 × 10^{-4} Siemens for d_2 less than 4.7 nm. The conductivity decreases monotonically with higher well widths for both bulk and superlattice phonons. For higher well widths the decrease in conductivity is due to enhanced electron – phonon interactions.

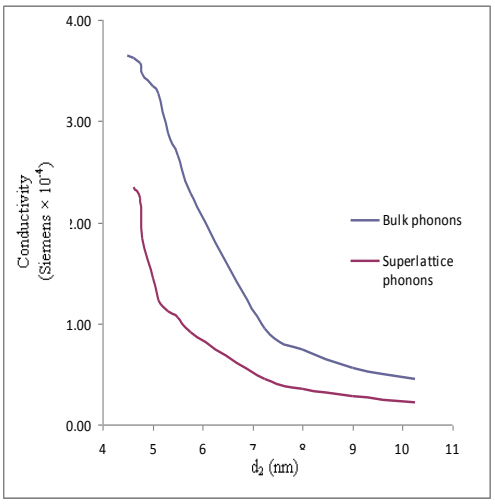

Figure 2: Variation of conductivity with well width d_2 in GaAlAs/GaAs superlattice

Next we have made the calculations of power dissipation and have studied its variation with increasing well width d_2 for both superlattice and bulk phonons. It is found that the power dissipation is high for narrow well width at around d_2 = 4.5 nm for both superlattice and bulk phonons as shown in the Figure 3. It is evident from the Figure 3 that the power dissipation value decreases with increasing well widths for both bulk and superlattice phonons which agrees with the works of previous researchers[1].

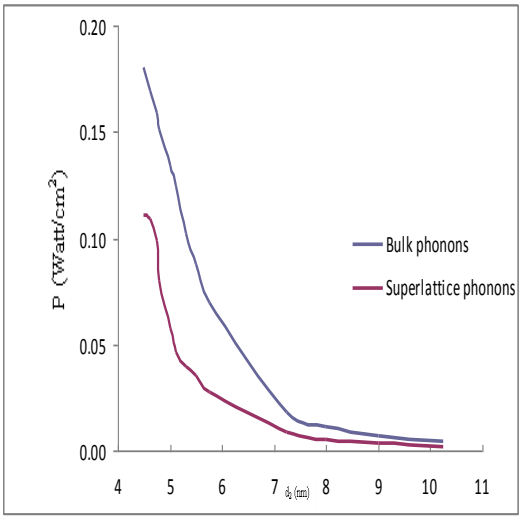

Figure 3: Variation of power dissipation with well width d_2 in GaAlAs/GaAs superlattice

IV. CONCLUSION

In the present communication the authors have shown the variations of conductivity of bulk and superlattice phonons mediated by intersubband transitions of electrons with the well widths for GaAs/GaAlAs superlattice. The conductivity is found to be high for narrow well widths. The variations of power dissipations with well width has been studied which reveals that for bulk phonons the power dissipation is comparatively high than the superlattice phonons.

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