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Mobility of 1-D GaAs Quantum Wire Limited by Polar Optic Phonon Scattering

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ABSTRACT: The polar optical phonon (POP) scattering limited mobility in 1-DEG quantum wire of GaAs has been investigated. The variation of mobility with well width for 1D GaAs quantum wire has been studied. The mobility dependence on the transverse dimension of quantum wire for different values of electron energy has been also been investigated. The results obtained at 300K for GaAs wire reveal that the variation is almost linear in nature.

KEYWORDS: Polar optic phonon, scattering, 1DEG, Quantum Wire, Mobility, Electron energy.

I. INTRODUCTION

Over the last 30 years there has been a very remarkable development in the attempts towards developing a "Wire" semiconductor quantum well structure where the electron gas is quantised in two transverse directions [1, 2]. The electrons can move in only one dimension whereas it is confined in other two dimensions. GaAs-AIAs quantum well wires have already been realized [1] and other structures based on field effects have also been made feasible [3, 4].
The 1-D electron mobility is found to be greater than 106 cm2 /V s [5] due to presence of reduced number of final states(forward and backward scattering) [6], which makes it useful for high speed devices. The study of existing literature reveals that mobility calculations in such structures have been done taking into account the scattering mechanisms like impurity scattering [5, 7], acoustic phonon scattering [8], optical phonon scattering [2]. It has been established that the dominant scattering mechanism in such structures for the temperature range of interest is the polar optic phonon (POP) scattering [9, 10]. The dependence of the mobility on the size of quantum wire has not been studied by many workers. So we have the scattering rates of POP scattering with the electron energy for different dimensions of the of the 1DEG quantum Wire. Our results show that the mobility of 1DEG vary linearly with the rectangular cross sectional length of the quantum wire.

Paper is organized as follows. Section II describes automatic text detection using morphological operations, connected component analysis and set of selection or rejection criteria. The flow diagram represents the step of the algorithm. After detection of text, how text region is filled using an Inpainting technique that is given in Section III. Section IV presents experimental results showing results of images tested. Finally, Section V presents conclusion.

II. THEORY

We have used the infinite-well approximation and assume the extreme quantum limit condition (EQL), i.e., the electrons occupy the lowest subband. The electron energy is given by

$$E_{1-D} = E + E_o, \tag{1.1}$$

where

$$E = \frac{\hbar^2 k_x^2}{2m}, \tag{1.2}$$

and

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$$E_o = \frac{\hbar^2\pi^2}{2m}\left(\frac{1}{{L_z}^2} + \frac{1}{{L_y}^2}\right), \qquad (1.3)$$

Here $\hbar$ is Planck's constant divided by 2π, k_x is the longitudinal component of the electron wave vector, m is the effective mass, L_y and L_z are the transverse dimensions of the quantum-well wire and L_x is the length of the wire, such that $L_x > L_z , L_y$ (Fig.1).

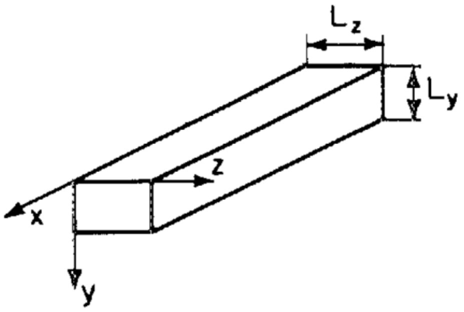

Fig. 1: Schematic representation of a 1-D structure.

The $1/\tau_a$ and $1/\tau_e$ are the scattering rates out of the state k_x due to the absorption and emission of phonons with longitudinal wave vector components q_o and q_e respectively. The detailed expressions of $1/\tau_a$, $1/\tau_e$, q_o and q_e have been taken from the Ref. [9].

The phonon absorption and emission scattering rates have been already been studied for GaAs at 300K by Leburton [9], the phonon emission rate exhibits a singularity at $E = \hbar\omega$ as a consequence of the 1-D electron density of states [2, 9]. Thus, strong energy relaxation via phonon emission is the dominant scattering which controls mobility in 1-D structures. Beyond this singularity, the emission rate drops off rapidly with increasing electron energy. While avoiding the singularity by assuming that the scattering rate in the energy range $E = \hbar\omega$ and $E = 1.07\hbar\omega$ is equal to that at $E = 1.05\hbar\omega$, the variation of the drift velocity with the electric field in the GaAs quantum well wire has been shown in Fig. 2 [10].

The authors have used the results of the absorption and emission scattering rates as a function of electron energy for GaAs from the Ref. [9]. These results have been used in the calculation for the electron mobility in the GaAs 1-D structure.

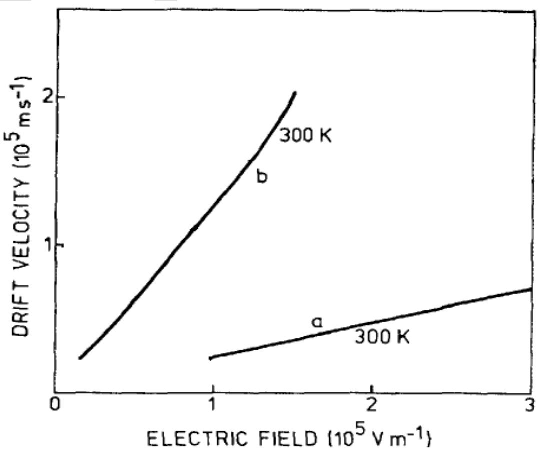

Fig.2: Variation of drift velocity with electric field in a quantum-well wire at lattice temperatures of 300K [10].

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In the above Fig.2, the curve (a) is for $L_y = L_z = L_o(1,1)$ whereas the curve (b) is for $L_y = L_z = 5L_o(5,5)$, the results have been calculated on the basis of the drifted Maxwellian model where $Lo = (\hbar/2m\omega)^{1/2}$.

III. CALCULATION FOR MOBILITY

The formula for the mobility is

$$\mu = q\tau/m, \quad (2)$$

Here τ is the relaxation time which has been taken as inverse of the rate of emission scattering in 1-D structure, q is the charge of the carrier and m is the effective mass. The relation of the scattering rate with the electron energy from Ref. [9] has been used in the calculation of the mobility for GaAs quantum wires. The variation of mobility with the well width L_o for different electron energy has been shown in Fig.3.

The calculations have been done for GaAs where we have taken effective mass $m = 0.067m_e$ for electrons.

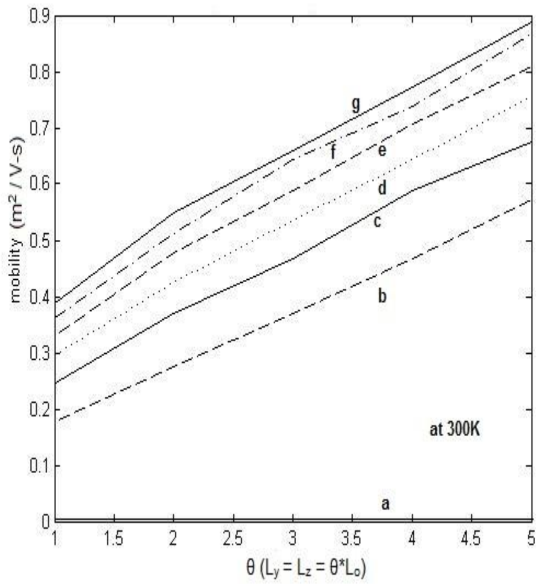

Fig.3:Variation of mobility with well width L_o for 1D GaAs wire at 300K.

In the above Fig.3, on the x-axis we have θ which is the related to L_y and L_z as:

$$L_y = L_z = \theta L_o, \quad (3.1)$$

such that

$$\theta = \{1, 2, 3, 4, 5\}, \quad (3.2)$$

Mobility for different well width has been plotted for the range of values $L_y = L_z = L_o(1,1)$ and $L_y = L_z = 5L_o(5,5)$ for different electron energy at 300K. Different curves are drawn for different electron energy: curve (a) is for $E = \hbar\omega$, curve (b) is for $E = 2\hbar\omega$ and so on upto curve (g) which is for $E = 7\hbar\omega$.

IV. CONCLUSION

In this paper the authors have investigated the mobility variation with the quantum wire dimensions due to the POP scattering in 1-D structure of GaAs. The mobility of 1-D GaAs structure has been found to vary almost linearly with the well width at particular electron energy. As the electron energy is increased the electron mobility is also increased which is evident from different curves from (a) to (g) in Fig.3.

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