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THEORETICAL INVESTIGATION OF I-V AND MOBILITY CHARACTERISTICS OF 2D GaAs QUANTUM WELL

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Abstract

This paper reviews hot carrier effects in 2D polar semiconductors (quantum wells), with special emphasis on the GaAs system due to its higher electron mobility and direct wider band-gap. After briefly introducing the basic concepts of electron transport mechanism, we discuss theoretical calculations of current density-channel voltage characteristic for hot electrons in this quantum well structures at different lattice temperatures, namely 27K,50K, 77K and 120K on a displaced Maxwellian model, incorporating deformation potential acoustic and polar optic phonon scattering. The results are obtained from our calculations for quantum well size 100 Å. The electron mobility variations with these temperatures are also shown.

Keywords: Displaced Maxwellian Model, Lattice Temperature, Quantum Well, Nano Channels, Acoustic and Polar Optic Phonon Scattering.

I. INTRODUCTION

Hot electron transport in semiconductor has become the subject of much research for decades. When this transport is caused by an electric field, electrons are continuously supplied with energy from the source of the electric field at a rate J.F; where J is the Current density and F is the Electric field. The heat capacity of the electron being much smaller than that of the lattice atoms, electron temperature rises much faster as the after-effect of applied electric field.[1,2] The typical time taken by the electrons to reach steady state is about 10^{-9} to 10^{-12} sec.[3]

Current progress in the growth of fine layers of semiconductors has produced quantum wells (QW) in which a smaller band-gap material is confined between the layers of a larger band-gap material. The growth of such layers of semiconductor materials tens to hundreds of Angstroms thick and the electron motion is quantized in the direction normal to the layers in this QW structures.[4,5,6] The deformation potential acoustic and polar optic phonon (POP) scattering are considered and have been used in the analytical expressions obtained on the basis of a momentum conservation approximation.[7] The drift velocity of the two-dimensional hot electrons is calculated at different lattice temperatures. In low dimensional system electrons may be considered to be separated from their parent donors and experienced much less impurity scattering.[4] Hence for large carrier concentration a displaced Maxwellian distribution may be justified since electron-electron (e-e) scattering dominates in energy and momentum exchanges. The current density vs. channel voltages have been plotted at different lattice temperatures, say 27K, 50K, 77K and 120K. For two-dimensional hot electron transport in quantum wells, it is assumed that the electrons are confined in the lowest sub band.[8] The graphs for mobility are also seen at the temperatures stated above, showing that the electron mobility is decreased with increasing temperatures.

II. ANALYTICAL DETAILS

Here, a displaced Maxwellian distribution for the carriers has been assumed to obtain I-V characteristics for electrons in 2D quantum well structures. The use of such a distribution, leads to the results which favorably compare to the numerical solution which is discussed below.

It is assumed that all the electrons occupy the lowest quantum level if k is the component of the wave vector in the plane parallel to the layer interfaces (xy plane) the electron energy is given by[8],

$$E = E_k+E_0 = \hbar^2k^2/2m^*+E_0 \qquad (1)$$

where

$$E_0 = \hbar^2\pi^2/2m^*L^2 \qquad (2)$$

here, ħ is reduced Planck's constant, which is simply Planck's constant divided by 2π, m* is the effective mass of electron and L is the width of the QW.

The electron distribution, in the xy plane to be a displaced Maxwellian with a drift wave vector d and an electron temperature T_e are determined from the momentum and the energy balanced relation, which are

$$eF+\langle dp_F/dt\rangle_c = 0 \qquad (3)$$

and

$$e\upsilon_dF+\langle dE/dt\rangle_c = 0 \qquad (4)$$

Here, e is the electronic charge; F is the applied field in the xy plane; $\upsilon_d=\hbar d/m^*$ is the electron drift velocity; and $\langle dp_F/dt\rangle_c$ and $\langle dE/dt\rangle_c$ are the average rate of change of electron momentum and energy due to scattering effect, calculated from eq.1 and momentum conservation approximation.[8]

Assigning a value of the electron temperature T_e, the field F and the electron drift velocity υ_d may be obtained from eq.3 and eq.4.

The layer thickness or the width of the QW (L) is taken to be 100 Å. It is already assumed that the electrons are in the lowest quantum level is satisfied for this thickness. The velocity-field characteristics for electrons in 2D semiconductor quantum well were derived. Calculations do not show any negative differential resistance at high fields although polar mode scattering predominates.[7] Now the current-voltage characteristics have been determined over the temperature range 27-120K.

We used, for the current density the relation:

$$J = ne\upsilon_d \qquad (5)$$

where, n is the electron concentration; e is the electronic charge and υ_d is the electron drift velocity.

In this case, the channel length or the layer thickness is fixed. As it is for nano channel, that's why the concentration $n = 10^{12}\ m^{-2}$ (Considered), which is quite high.

We have also calculated the channel-voltage(V) by using the relations:

$$V = F\times L \qquad (6)$$

$$\mu = \upsilon_d/F \qquad (7)$$

where, F is electric field, L is the width of the QW or the length of the channel and μ the mobility..

The calculations are done from the obtained model where the average drift velocity of the entire electron system is found to increase rather than decrease with increasing field [7].

III. RESULT

We have considered the length of the channel L to be 100Å. The assumption that the electrons are in the lowest quantum level is satisfied for this thickness. Using eq.5 and eq.6 we have characterized the current-voltage curves over the temperature range 27K-120K in our experiment. Our calculated result is shown in Fig.1 at 27K (low temperature), where current density is comparatively higher. In Fig.2 the same characteristic curve is plotted at 120K (high temperature), where current density is gradually decreased. Finally, the current-voltage characteristics for different temperatures have been plotted in Fig.3 as a comparative study. We have also determined the electron mobility by eq.7 for 2D quantum well structure at different lattice temperature and the mobility vs. temperature curve is plotted in Fig.4.

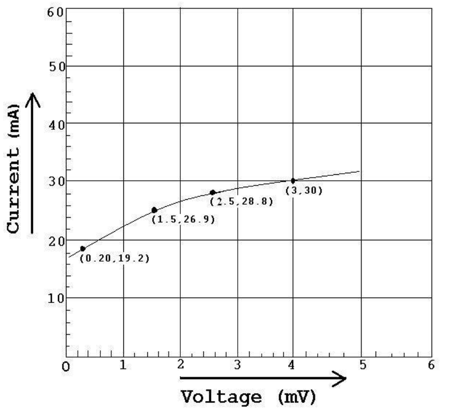

Fig.1. V-I Characteristics Curve for GaAs at 27K

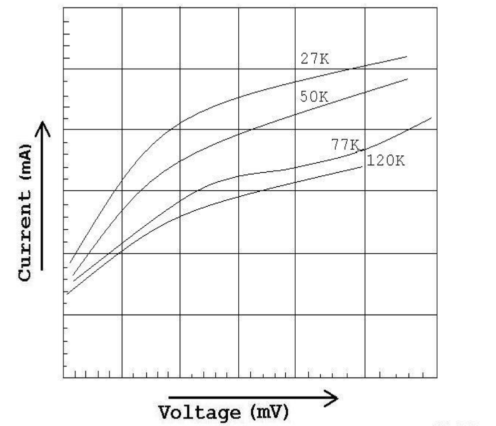

Fig.3. V-I Characteristics Curve for GaAs at different Lattice Temperatures

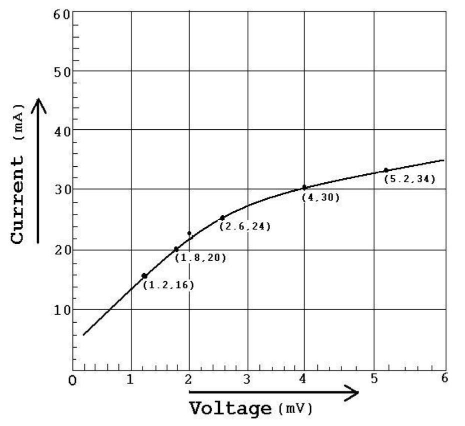

Fig. 2. V-I Characteristics Curve for GaAs at 120K

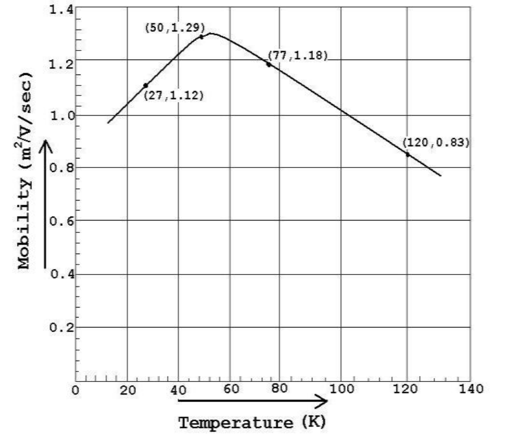

Fig.4. Mobility - Temperature Characteristic Curve for GaAs

IV. CONCLUSION

In this paper we have shown the variation of current with the channel voltages of two dimensional quantum well structures for nano-channels at different lattice temperatures. The current is found to be higher at low temperatures, namely 27K and 50K due to the polar optic phonon scattering effect and reverse scenario is going on for higher temperatures (120K). The current-voltage characteristic agrees with the standard current-voltage characteristic of the MOSFET. We also conclude that in case of mobility variation at low temperatures, mobility increases with ionized impurity scattering and decays at higher temperatures because of combined effect of acoustic phonon scattering and polar optic phonon scattering. The peculiarities of polar mode scattering in 2D transport in quantum well are found not to produce a negative differential resistance.[8] The possible sources of negative differential resistance in such structures are either transition to satellite valleys or spatial transfer out of the quantum well.[4]

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