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VELOCITY- FIELD AND CONDUCTANCE CHARACTERISTICS OF GaN QUANTUM WELL WIRE

[1]Saswata Chakraborty, [2]Arindam Biswas, [3]Aniruddha Ghosal, [4]A.K Bhattacharjee
[1]Kanksa Academy of Technology & Management, Panagarh-713148, Dist.-Burdwan, West Bengal, India
[2]Dr. B.C Roy Engineering College, Fhuljhore More, Durgapur-06
[3]Institute of Radio Physics and Electronics, University of Calcutta, 92 A.P.C Road, Kolkata-700009
[4]Dept. of ECE, National Institute of Technology, Durgapur-09
[2]mailarindambiswas@yahoo.co.in

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ABSTRACT
The variation drift velocity and current density with electric field have been theoretically investigated for one dimensional GaN nanowires at different electron concentrations and temperatures. The electron distribution function is assumed to be drifted Maxwellian in our model. Interaction of electrons with polar optical phonons (POP) and deformation potential acoustic phonons has been considered and also electron-electron (e-e) interactions have been taken into account. It has been observed that the conductivity has quantized nature in one dimensional wire. Comparison has been made with experimental results.
Key word: Quantum Well Wire, Drifted Maxwellian Distribution, Polar Optic Phonon Scattering.

I. INTRODUCTION

Recent Studies on transport properties of the quantum wires have revealed that nanowire (NW) FETs have been fabricated [1]. Work on the transport characteristics of hot electrons in semiconductor quantum well wires already exists in literature [2, 5-10]. The one dimensional hot electron transport in quantum well is accomplished by assuming that the electron occupy the lowest sub band. A drifted Maxwellian distribution for carriers has been assumed to obtain velocity-field characteristics for electron for quasi one dimensional semiconductor quantum well structure, which is reported in ref. [6]. In low dimensional system electrons may be separated from their parent donors [3]. The electron experience much less impurity scattering. Hence the latter gives the features associated with the pure POP scattering. Owing to the weakness of the ionized impurity scattering, e-e interaction may dominate in the energy and momentum exchanges in the quantum wells for sufficiently larger carrier concentrations which justifies a drifted Maxwellian distributed function for the electrons.

II. ANALYTICAL MODEL

Authors use infinite well approximation and assume the extreme quantum limit condition [EQL], i.e the electrons occupy the lowest sub band.
The electron energy is given by,

$$E_t = E + E_0 \quad (1)$$

with $E = \hbar^2 k_x^2/2m^*$, $E_0 = \hbar^2\pi^2/2m^* \, (1/L_x^2 + 1/L_y^2)$ and ħ is Plank's constant divided by 2π, k_x is the longitudinal of electron wave vector, m* is the effective mass and L_x and L_y the traverse dimensions of the quantum well wire.
The electron temperature T_e and the drift wave vector d associated with the distribution function are determined from the energy and the momentum balance equations [6]. For the 1-D transport problem, these balance equations read

$$e v_d F + \frac{1}{\sqrt{\pi k_B T_e}} \int_0^\infty \left(\frac{\partial E}{\partial t}\right)_{POP} \exp\left(\frac{-E}{k_B T_e}\right) E^{-1/2} \, dE \quad (2)$$

and

$$eF + \left(\frac{2m}{\pi}\right)^{\frac{1}{2}} \frac{v_d}{(k_B T_e)^{\frac{3}{2}}} \int_0^{\infty} \left(\frac{\partial p}{\partial t}\right)_{POP} \times exp\left(\frac{-E}{k_B T_e}\right) dE = 0 \quad (3)$$

where F is the electric field applied along the longitudinal direction of the wire structure, e is the electron charge, k_B is the Boltzmann constant, v_d is the drift velocity given by $v_d = hd/m^*$, and $(\partial E/\partial t)_{POP}$ and $(\partial p/\partial t)_{POP}$ are the rates of change of electron energy and momentum due to the POP scattering. If ħω represents the optic phonon energy, we have [7].

$$\left(\frac{\partial E}{\partial t}\right)_{POP} = \hbar\omega \left(\sum_{q_a} \frac{1}{\tau_a} - \sum_{q_e} \frac{1}{\tau_e} \right) \quad (4)$$

$$\left(\frac{\partial p}{\partial t}\right)_{POP} = \sum_{q_a} \hbar q_a \left(\frac{1}{\tau_a}\right) - \sum_{q_e} \hbar q_a \left(\frac{1}{\tau_e}\right) \quad (5)$$

where $(1/T_a)$ and $(1/T_e)$ are the scattering rates out of the state k_x due to the absorption and emission of phonons with longitudinal wave vector components q_a and q_e respectively; denotes summation over the possible values of q_a and q_e. The detailed expressions of $(1/\tau_a)$,$(1/\tau_e)$, q_a and q_e are obtained from Ref. [8].

Next, we have calculated the current density for the electrons as described below.

The current density is

$$J = nev \quad (6)$$

where,

n is the electron concentration,
e is the electron charge,
v is the drift velocity.

We have also calculated conductance G = I/V .

In 1D quantum wire we consider two ideal reservoirs with chemical potential μ_1 and μ_2 repectively, μ's are order of the Fermi level E_F. Ballistic channel is formed between two reservoirs though which transport of carriers takes place with out any scattering.

The value of the current due to the motion of electrons may be calculated in the following manner.

$$I = \int_{\mu_1}^{\mu_2} ev(E)[2 \times g_{1D}(E)]dE \quad (7)$$

$$I = 2e/h\ (\mu_1 - \mu_2) = 2e\ (eV)/h \quad (8)$$

where, v is a function of E v(E) and , $g_{1D}(E)$ is the 1D charge density.

Thus for 1D quantum wire, the conductance is expressed as,

$$G = 2e^2/h\ . \quad (3)$$

So conductance for 1D system is constant and independent of length L of the wire.

III. RESULTS

We have used the following data in our calculations: effective mass of electron m*= 0.218 m_0. The other parameter values for GaN are taken from Ref. [11].

Fig 1 shows the variation of the drift velocity with electric field. The drift velocities at the lattice temperature of 30 K are found to be higher than those at 300 K owing to the reduced electron-phonon interactions at a lower temperature.

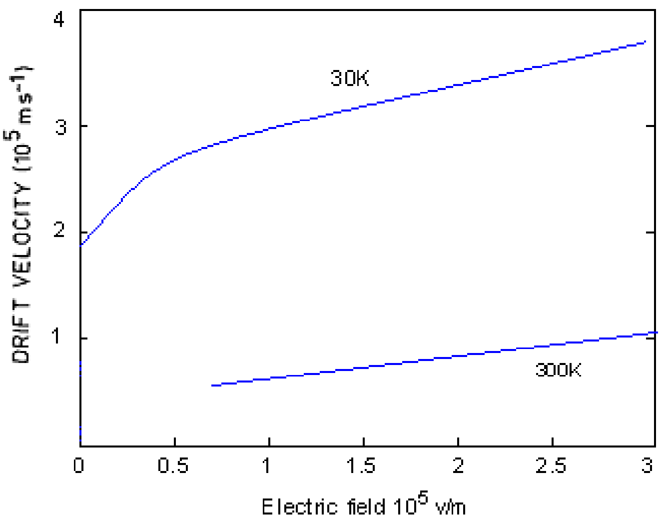

Fig 1: Variation of drift velocity with electric field in a quantum well wire at lattice temperature of 300K and 30K.

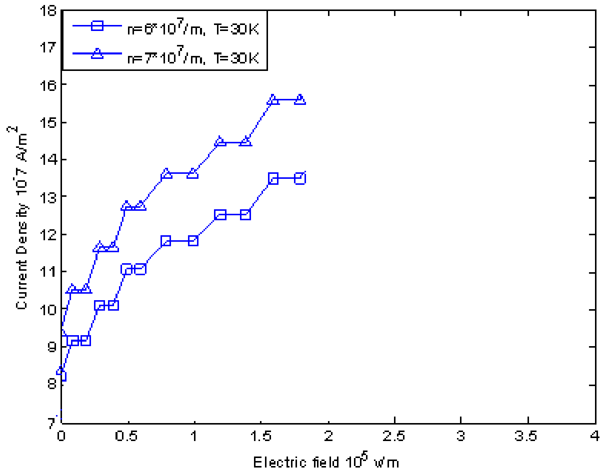

Fig. 3: Current Density and electric field Characteristics of 1D GaN Quantum well wire

Authors have calculated the current density for different values of electron concentration in GaN quantum wires at temperature 30K and 300K with drifted Maxwellian distribution for carriers and other parameter are taken from ref [6-8]

We have taken the length as L_x=L_y=L_0

The current density vs. electric field characteristics shows a stair case structure, as shown in the above fig1. and fig.2. respectively. These results agree fairly well with the experimental results [9]. We have also calculated the conductance which is found to be a fraction of 10^{-4} Siemens.

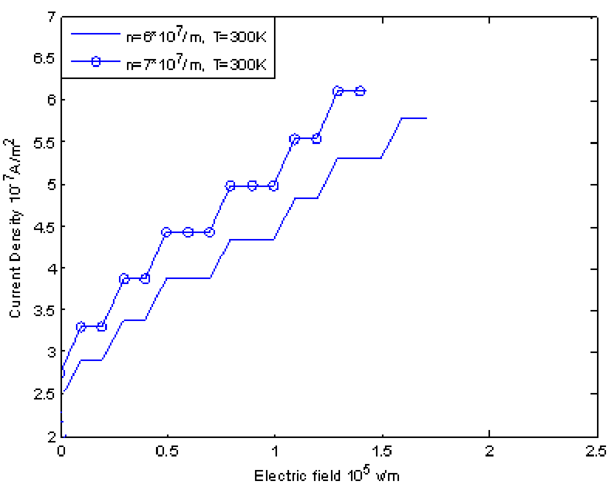

Fig.2: Current Density and electric field Characteristics of 1D GaN Quantum Well Wire.

IV. CONCLUSION

The features of the POP scattering in EQL do not produce NDR in a quantum well wire. In the present paper, authors have shown the curves of current density versus electric field for different values of electron concentrations and temperatures in GaN. Average value of conductance as calculated by us is of the order of 10^{-4} Siemens which is equal to the experimental value obtained for the conductance.

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