Journal of Electron Devices, Vol. 13, 2012, pp. 957-959

© JED [ISSN: 1682 -3427]

Journal of Electron Devices
www.jeldev.org

I-V AND CONDUCTANCE CHARACTERISTICS OF NANO-SCALE 1D GaAs FETs

Madhumita Sarkar [1],Shovon Nandi[2] and Aniruddha Ghosal[3]
[1]B.P.P.I.M.T, Kolkata-700052, India; (e-mail: s.madhumita@ yahoo.co.in)
[2]B.I.T, Kolkata-700150, India; (e-mail: shovon.nandi@gmail.com)
[3]Institute of Radio Physics and Electronics, C.U, 92 A.P.C. Road, Kolkata-700009, India. aghosal2008@gmail.com

Received 22-02-2012, online 05-03-2012

ABSTRACT
The drain current versus drain voltage characteristics of nano-scale 1D GaAs FETs at two different lattice temperatures, namely, 30K and 300K have been investigated. We have assumed a displaced Maxwellian model for the hot electron transport in the GaAs quantum wells, and have incorporated deformation potential acoustic and polar optic phonon scatterings. The results obtained from our theoretical model for a channel length of 10nm and 50 nm 1D GaAs FET have been shown. The variations of conductance with lattice temperatures at different channel lengths have also been exhibited.

Index Terms: Displaced Maxwellian model, Quantum Wire (QW), Polar Optic Phonon (POP) Scattering.

I. INTRODUCTION

RESEARCH over decades has established that GaAs is a very common growth material, especially for microwave field effect transistors and diode lasers [1, 2]. Recently, attempts have been made toward the realization of a wire semiconductor QW structure in which the electron gas is quantized in two transverse directions [3]. Electron transport in this structure is essentially one-dimensional (1D) and takes place in the longitudinal direction. [4] The deformation potential acoustic, impurity and polar optic phonon (POP) scatterings play important roles in electron transport in such structures and thereby have been taken into account in our analysis. However, interaction with POP merits special attention, the large energy exchange between carriers and lattice vibrations influences considerably transport at room temperature. Moreover, the POP interaction is the major scattering mechanism responsible for hot electron effects [5, 6].

In this paper we consider the extreme quantum limit (EQL) condition, which implies that the electrons occupy only the lowest sub-band. Owing to the weakness of ionized impurity scattering, e-e interactions may dominate in energy and momentum exchanges in quantum wells for sufficiently large carrier concentrations to enforce a drifted Maxwellian distribution function characterized by a drift wave vector and an electron temperature [7, 8, 9]. From the knowledge of the velocity-field characteristics for 1D electron in GaAs QW at two different lattice temperatures namely 30K and 300K, given in [4], the drain current vs. drain voltage characteristics of 1D GaAs FETs have been plotted for the corresponding lattice temperatures in the Fig.1 and Fig.2 respectively.

II. ANALYTICAL DETAILS

We consider an infinite square well and the electrons are assumed to be confined in the lowest subband. A displaced Maxwellian model for the hot electron transport in 1D GaAs QW has been assumed. The electron energy is given by [4],

$$E_t = E + Eo$$

where, $E = \hbar^2 k_x^{\,2}/2m^*$ (1)

$$E_o = \hbar^2\Pi^2/2m^*(1/L_x^{\,2}+1/L_y^{\,2}) \quad (2)$$

Here 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 are the traverse dimensions of the quantum well wire.

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

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

and

$$e\upsilon_d F + \langle dE/dt \rangle_c = 0 \quad (4)$$

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 rates of change of electron momentum and energy due to scattering. The expressions for $\langle dp_F/dt \rangle_c$ and $\langle dE/dt \rangle_c$ are obtained from [5].

If ħω represents the optic phonon energy, we have [6],

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

and

$$\left(\frac{\partial p}{\partial t}\right)_{POP} = \Sigma_{q_a} \hbar q_a \left(\frac{1}{\tau_a}\right) - \Sigma_{q_e} \hbar q_e \left(\frac{1}{\tau_e}\right) \quad (6)$$

where τ_a^{-1} and τ_e^{-1} 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; Σ denotes summation over the possible values of q_a and q_e. The detailed expression of τ_a^{-1} , τ_e^{-1}, q_a and q_e are obtained from the reference [6].

Using the velocity-field characteristics for 1D electron in GaAs quantum well at lattice temperatures 30K and 300K as given in [4], we have obtained the drain current vs. drain voltage characteristics for 1D GaAs nano–scale FETs for the corresponding above lattice temperatures. These characteristics are obtained for a fixed gate bias of 0.1V which is so chosen as to obtain a fair agreement with the experimental results [10].

The drain current is computed using the relation:

$$I_d = nev_d \quad (7)$$

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

We have calculated the drain voltage by using the relation

$$V_d = F \times L \quad (8)$$

and the conductance of this 1D quantum wire from the expression,

$$G = dI_d/dV_d \, . \quad (9)$$

III. RESULTS AND DISCUSSIONS

Authors have considered the electron concentration n = 10^7 m^{-1}, effective mass of the electron m^* = 0.6103x 10^{-31} kg, optical phonon temperature T_{po}=419K, and the other parameter values of GaAs are kept the same as in reference [4]. The lengths of the channel (L) are taken as 10nm and 50nm respectively. The drain current (I_d) and drain voltage (V_d) are calculated at 30K and 300K temperatures using equation (7) and (8) respectively. The nature of I_d–V_d curve is

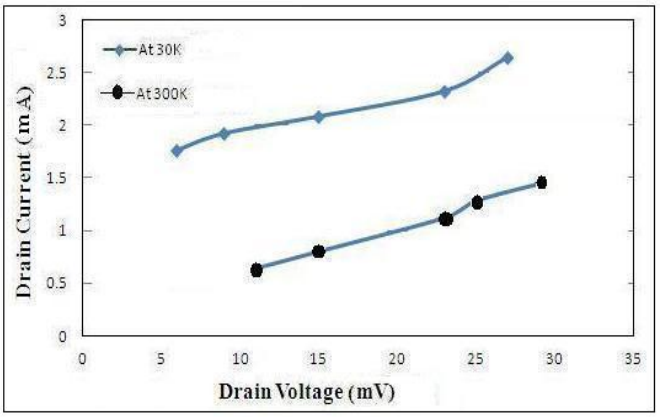

Figure 1: Drain current-drain voltage Characteristics of 1D GaAs nano wire FET computed at channel length L=10nm.

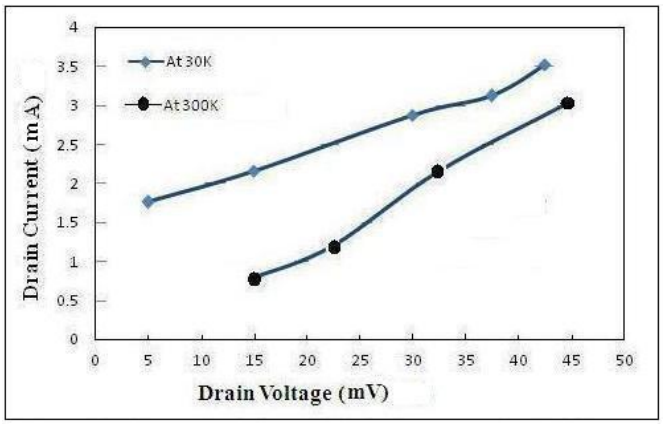

Figure 2: Drain current-drain voltage Characteristics of 1D GaAs nano wire FET computed at channel length L=50nm.

displayed in Fig.1 and Fig.2 respectively.

It is evident from Fig.1 and Fig.2 that the drain current is higher at lower lattice temperature (i.e. 30K represented by line with diamond symbol) which may be attributed to the fact that Polar Optic Phonon (POP) scattering dominates at higher lattice temperature (i.e. 300K represented by line with circular dot) reducing the drain current. The I_d – V_d curve is more prominent at larger channel length (i.e. 50nm) compared to lower channel length (i.e. 10nm). Using equation (9) the

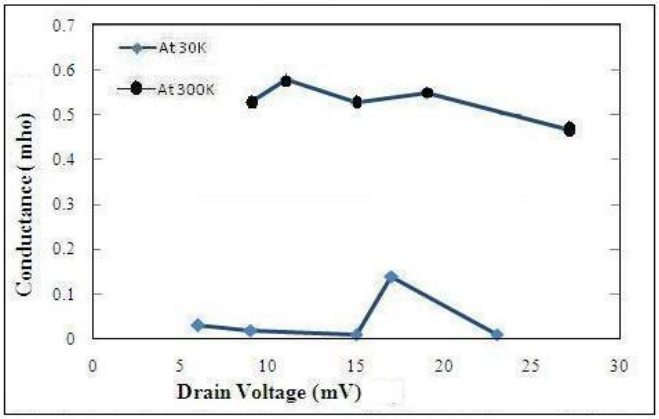

Figure 3: Variation of conductance with drain voltage of 1D GaAs nano-wire FET computed at channel length L=10nm.

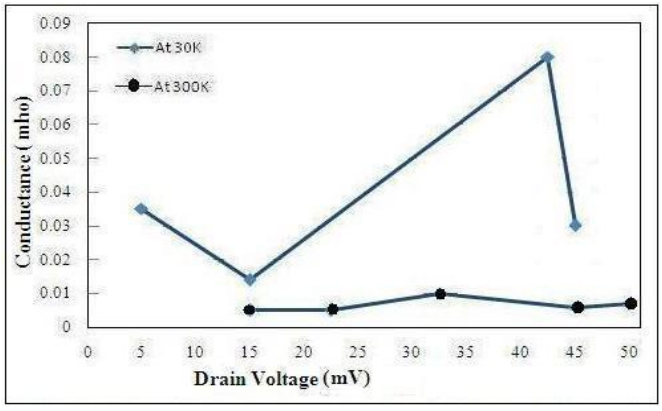

Figure 4: Variation of conductance with drain voltage of 1D GaAs nano-wire FET computed at channel length L=50nm.

conductance of 1D QW wire has been determined in mho. The curve for drain voltage vs. conductance for 1D QW wire is shown in Fig.3 and Fig.4 respectively which shows a stair case quantized structure. These results agree with the experimental ones reported in the literature on the conductance of 1D QW [11]. The stair case nature of the conductance curve is due to the quantization effect of the conductance in 1D nano-wire [12].

IV. CONCLUSIONS

In Fig.1 and Fig.2 we have shown the variation of the drain current with the drain voltages of 1D GaAs FET computed at two different temperatures incorporating deformation potential acoustic phonon and Polar Optic Phonon (POP) scattering. Fig.3 and Fig.4 display the conductance variation with lattice temperatures. This theoretical study of $I_d - V_d$ characteristics of 1D GaAs FET of nano-scale dimensions of channel length 10nm and 50nm as made by the authors will throw sufficient light in understanding the electron transport mechanism in nano-scale devices.

References

[1] Wei Lu, Ping Xie and Charles M.Lieber, "Nanowire Transistor Performance Limits and Applications", IEEE Trans. On Electron Devices, **55**, 2859 (2008).

[2] Lee and H.N.Spector, "Impurity-limited mobility of semiconductor thin wire", J.Appl.Phys.**54**, 3921 (1983).

[3] Kasala Suresha, S.S.Kubakaddi, B.G.Mulimani, Shyi Long Lee, "Acoustic wave amplification in one dimensional quantum well wires", Physica E, **33**, 50 (2006).

[4] A.Ghosal, D.Chattopadhyay and A.Bhattacharyya, "One-dimensional hot-electron transport in quantum-well wires of polar semiconductors", J.Appl.Phys.**59,** .2511 (1986).

[5] Shovon Nandi and Madhumita Sarkar, "Theoretical Investigation of I-V and Mobility Characteristics of 2D GaAs Quantum Well", JED, **12**, 700 (2011).

[6] J.P.Leburton, "Size effects on polar optical phonon scattering of 1D and 2D electron gas in synthetic semiconductors", J.Appl.Phys. **56**, 2850-2855 (1984).

[7] A.Ghosal and D.Chattopadhyay, "Low-temperature electronic transport in CdSe single quantum wells", Indian J. Phys.**78**, 915 (2004).

[8] P.M.Petroff, A.C.Gossard, R.A.Logan and W.Wiegmann, Appl. Phys. Lett., **41**, 635 (1982).

[9] K.Hess, "Ballistic electron transport in semiconductors", IEEE Trans. On Electron Devices, **28**, 937 (2005).

[10] Anisur Rahman, Jing Guo, Suprio Datta, "Theory of Ballistic nanotransistors" IEEE Trans. On Electron Devices, **50**, 1853 (2003).

[11] E.Bielejec, J.A.Seamons, M.P.Lilly, J.A.Simmons, J.L.Reno, "0.7 structure in long quantum wires", Superlatt. and Microstruct. **34**, 493 (2003).

[12] A Report on "One-Dimensional Electron Transport" in the website http://www.phy.cam.ac.uk published by Dept. of Physics, Cavendish Laboratory, UK. (2008).