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ONE DIMENSIONAL GaN NANOWIRE FETS

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Abstract

We have studied the variations of the drain current (I_d) with drain voltage (V_d) for one – dimensional 10nm GaN nanowire (NW) FET at different temperatures, namely, 20K, 50K and 77K respectively. The electron distribution function is assumed to be displaced Maxwellian in our model. Momentum and energy balance equations are solved to obtain the current – voltage characteristics. Interactions of the electrons with deformation potential acoustic and polar optic phonons are taken into account. It has been found that I_d is higher at low temperature, compared to that at high temperatures which agrees with the experimental worker. We have also studied electron mobility variation with temperature. Mobility decreases with temperature as usual due to the dominance of the polar optic scattering at higher temperature.

Keywords: Nanowire, One-dimensional FET, Displaced Maxwellian distribution, Acoustic phonon scattering, Polar optic phonon scattering.

I. INTRODUCTION

Recent studies on the transport properties of the quantum wires have revealed that field effect transistor on GaN nanowires (NWs) have been fabricated [1]. Work on the characteristics of electron transport in semiconductor quantum well wires already exists in the literature [2-3]. The one dimensional hot electron transport in quantum well is accomplished by assuming that the electrons occupy the lowest sub band. A displaced Maxwellian distribution for the carriers has been assumed to obtain velocity -field characteristics for electrons in quasi one dimensional semiconductor quantum well structures, which was reported in reference [2]. In low dimensional systems electron may be considered to be separated from their donors [4]. These electrons experience much less impurity scattering. Hence for large carrier concentration a displaced Maxwellian distribution is justified since electron –electron scattering dominates in energy and momentum exchanges. Deformation potential acoustic and polar optic phonon scattering are taken into account in our calculations.

II. ANALYTICAL MODEL

For a single band spherical effective mass model for the electrons which are confined to move along the z direction .i.e. along the length of the wire, energy eigen values are given by [2]

$$E_{nlk} = E_n + E_l + E_k \qquad (1)$$

where

$$E_n = \pi^2\hbar^2 n^2 / 2m^* a^2$$

$$E_l = \pi^2\hbar^2 l^2 / 2m^* b^2$$

$$E_k = \hbar^2 k^2 / 2m^* \ .$$

Here a and b represent the dimensions of the wire along the x and y directions respectively .k is the wave vector of the electron along the z direction. Considering a displaced Maxwellian electron Distribution in the z direction, the drift wave vector d and the electron temperature T_e can be determined from the momentum and energy balanced relations given below:

$$eF + < eP_F / dt >_C = 0 \quad (2)$$

$$eV_d F + < dE / dt >_C = 0 \quad (3)$$

Here e is the electron charge, F is the applied field in the z direction, V_d=ħd/m* is the electron drift velocity and $<eP_F/dt>_c$ and $<dE/dt>_c$ are the average rates of change of momentum and energy due to scattering. We have taken the expressions from [2]. In our calculations we have assumed a NW GaN FET channel length 10nm. We have calculated the drain current (I_d) at the different values of the drain voltage (V_d) from the velocity-field characteristics of 10nm GaN NW FET [5] which we have shown in Fig 2

The drain current is taken in the form

$$I_d = nev \quad (4)$$

The drain voltage is,

$$V_d = F \times L \quad (5)$$

and I_d =nev= neμF=neμV/d (6)

Where, F= electric field
L =length of the channel.
n= electron concentration,
e= electron Charge,
μ= mobility,
d=channel width,
and V= applied drain voltage.

III. RESULT AND DISCUSSIONS

We have considered the electron concentration to be n=10^{10}/m, m^*=0.218x10^{-31} kg and other parameters have the same values as in reference [4]. The velocity-field characteristics of 10nm GaN NW FET have been shown in Figure (1).

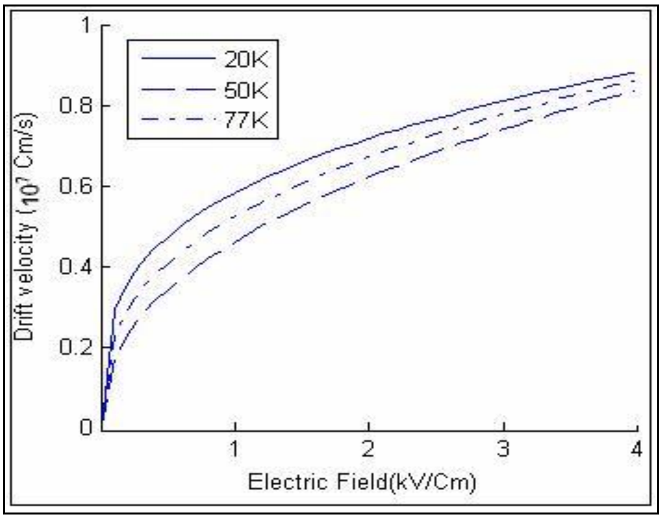

Figure 1: Velocity-Field characteristics of 10 nm NW GaN FET for different lattice temperatures.

Next, we calculate using equations (4) and (5), the values of drain currents at different drain voltages. Finally, the drain current and drain voltage characteristics have been plotted for temperatures 20K, 50K and 77K respectively, which is shown in the Figure (2).The I_d-V_d characteristics for the 10nm NW GaN FET as shown in Figure (2), agree with the results given in reference [1] .We have also calculated the electron mobility for the NW GaN FET which is found to be as high as 2100 cm^2/V.s.

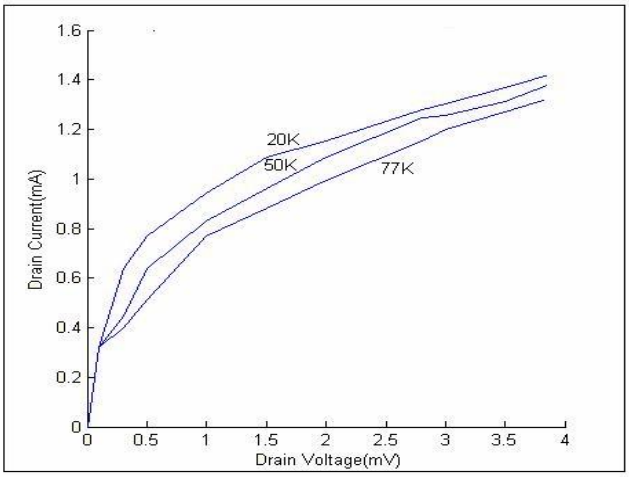

Figure 2: I_d-V_d characteristics of 10 nm NW GaN FET for different lattice temperatures.

The mobility is computed at different temperatures from the velocity field characteristics and the temperature dependence of mobility has been shown in Figure (3).

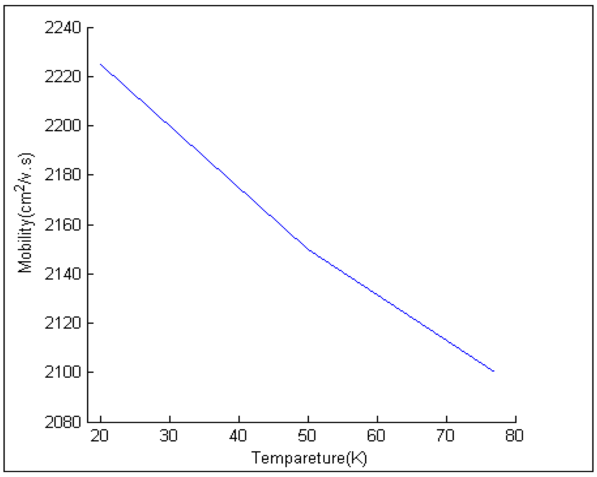

Figure 3: Mobility versus Temperature characteristics of 10nm GaN FETs

IV.CONCLUSIONS

We have shown the variations of the drain current (I_d) with the drain voltage (V_d) for 10nm GaN NW FET taking into account the acoustic phonon and polar optic phonon scatterings. We find that at the lower temperatures namely, 20K and 50K, the drain current is comparatively higher than that at 77K which may be attributed to be dominance of polar optic phonon scattering at higher temperatures. Our results for I_d-V_d characteristics for the 10nm NW GaN FETs will provide a better understanding of the carrier dynamics in such nanowire devices. The electron mobility as calculated by us for such NW GaN FET has been found remarkably high as 2100 cm^2/V.S which will enable the growth of ultra fast devices. Mobility decreases with temperature as usual due to the dominance of the polar optic scattering at higher temperature

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