Journal of Electron Devices, Vol. 16, 2012, pp. 1384-1387

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Journal of Electron Devices
www.jeldev.org

DRAIN CURRENT VERSUS DRAIN VOLTAGE CHARACTERISTICS FOR SUPERLATTICE MOSFET

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Received 10-12-2012, online 14-12-12

Abstract

The drain current versus drain voltage characteristics for GaAlAs/GaAs superlattice MOSFET has been studied taking into account both bulk and superlattice phonon interactions with the electrons. The drain current is high for low drain voltages less than 0.42 mV for both bulk and superlattice phonons. The drain current increases slightly at first with increase in drain voltage for bulk phonons and then it decreases monotonically with increase in drain voltage. For superlattice phonons, the drain current decreases sharply at the beginning with increase in drain voltage up to 0.44 mV. Then the drain current starts increasing which continues till 0.46 mV, after which it decreases with further increase in drain voltage.

I. INTRODUCTION

The study of carrier transport mechanism in superlattice MOSFETs and understanding its vital feature like current – voltage characteristics in GaAlAs/GaAs superlattice has been a motivating and interesting field of research for many years[1-8]. The rate of emission of polar longitudinal optical (LO) phonons controls the rate of electron transitions in semiconductor quantum wells [2]. In this context, the authors have studied the variation of drain current with drain voltage for GaAlAs/GaAs superlattice MOSFET taking into account interactions of electrons with both bulk and superlattice phonons. The important feature of electron-phonon interaction in GaAlAs/GaAs superlattice is the rates of the lowest order processes involving LO phonons and electrons in the superlattice. The electron energy relaxation rates via LO phonons in layered polar semiconductor heterostructures is controlled mainly by two factors. Firstly, there is a alteration in both acoustic and optical mode frequencies of lattice vibrations which results in the phonon band structure. Secondly, due to the presence of layers in a superlattice there occurs a modification in the electronic energy levels and eigenfunctions. The conductivity in GaAs/GaAlAs superlattice for various well widths has been shown in reference [1]. The variation in intersubband and capture rates of electrons with well widths has been given in reference [3]. The authors have used the simple relationship between current and conductivity for the GaAlAs/GaAs superlattice and have obtained the drain current vsersus drain voltage characteristics for the superlattice MOSFET. The results have been presented in this communication and comparison has been made with the bulk phonon model.

II. THEORETICAL MODEL

An array of GaAs quantum-wells with layers of GaAlAs barriers have been fabricated over a Si substrate to form a MOSFET as shown in the Figure 1.

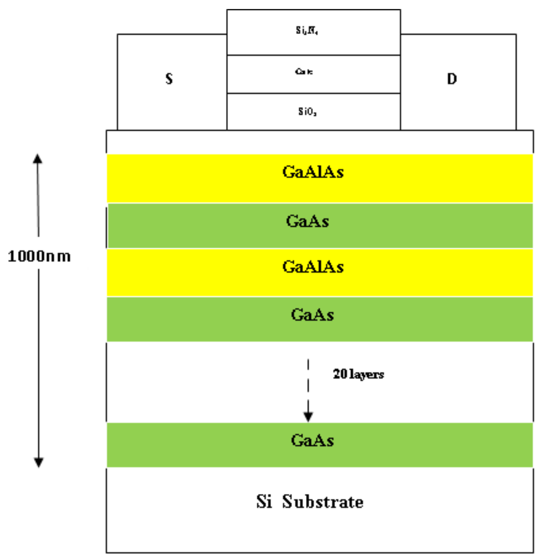

Figure 1: Structure of superlattice MOSFET

As shown in the figure 1 there are 20 alternate layers of GaAlAs/GaAs each of thickness 50 nm, which have been implanted on Si substrate. Thus a total thickness of 1000 nm of GaAlAs/GaAs superlattice structure for the MOSFET has been designed.

We consider that the alternate layers of GaAlAs and GaAs as shown in the figure 1 have thickness d_1 and d_2 respectively. Thus a periodicity is created along the growth direction with the periodicity length $D = d_1 + d_2$ for the binary alloy superlattice GaAlAs/GaAs. The electronic band structure in the GaAs/GaAlAs superlattice had been shown in reference [3]. An array of GaAs quantum-wells with layers of GaAlAs forming an array of barriers of energy Vo is thus formed that constitute the conduction band profile. The electrons in the superlattice have a dispersion relation [3]:

$$\cos QD = \cos k_1 d_1 \cos K_2 d_2 - 0.5(Z+1/Z) \sin k_1 d_1 \sin K_2 d_2 \quad (1)$$

where $K_1 = (2m_1^*(E-Vo)/h^2\,]-K^2_{11})^{1/2}$,

$K_2 = ([2m^*_2 E/h^2\,] - K^2_{11})^{1/2}$, and

$Z = m_2^* K_1 / m_1^* K_2$. Here Q and K_{11} are perpendicular and parallel components of the electronic wavevector, and m_1^* and m_2 * are effective electronic masses in material 1 (GaAlAs) and material 2 (GaAs). Here the parameters which are used for $Ga_{0.7}Al_{0.3}As$/GaAs superlattice are :

Vo = 0.19 eV, $m_1^* = 0.0879\ m_e$ and $m_2^* = 0.063\ m_e$, where m_e is mass of the electron.

For the superlattice LO phonons a modified Frohlich interaction has been considered and the phonon spectrum is obtained using a dispersive continuum model. The dispersion relation for the LO phonons in the superlattice is given as [3]:

$$\cos qD = \cos k_1 d_1 \cos k_2 d_2 - 0.5(Y+1/Y) \sin k_1 d_1 \sin k_2 d_2 , \quad (2)$$

where $k_n = [\omega_n^2 - \omega^2 - \beta_n^2 k_{11}^2]^{1/2}/\beta_n$, (n=1, 2) and $Y = \rho_1 k_2 \beta_1^2 (k_1^2 + k_{11}^2)/\rho_2 k_1 \beta_2^2 (k_2^2 + k_{11}^2)$. Here the phonon wave vector components are q and k_{11} . β and ρ are the acoustic velocities and reduced mass densities and ω_n are the LO frequencies of material n. For the $Al_{0.3}Ga_{0.7}As$/GaAs system, GaAs-like

modes are characterized by the following pertinent parameters:
ω_1 = 280 cm^{-1}, ω_2 = 294.6 cm^{-1} , β_2 = 5.0×10^5 cm s^{-1}, $\beta_1/\beta_2 \equiv 0.89$. Subscript 1 refers to the barrier and 2 to the well. The intersubband transitions of electrons between subband 1 and 2 with emission of superlattice and bulk phonons have been given in reference [4]. The rate of emission changes with increase in well width d_2 and due to this there is also variation of mobility with the change in well width due to both bulk and superlattice phonons.

The mobility (μ) and conductivity (σ) due to intersubband transitions of electrons for both superlattice and bulk phonons has already been demonstrated in reference [1]. On application of drain voltage the drain current (J) is controlled by the relation:

$$J = ne\mu E \quad (3)$$

where n is the electron concentration in the well which is taken as $10^{12}m^{-2}$, e is the charge of electron and E is the applied electric field. We rewrite the equation (3) in terms of conductivity (σ) as follows :

$$J = \sigma E \quad (4)$$

Here the applied drain voltage (V) is expressed as :

$$V = Ed_2 \quad (5)$$

We have taken E=1mV/m for our numerical computations.

III. RESULTS AND DISCUSSION

The drain current versus drain voltage characteristics of the superlattice MOSFET has been shown in the Figure2.

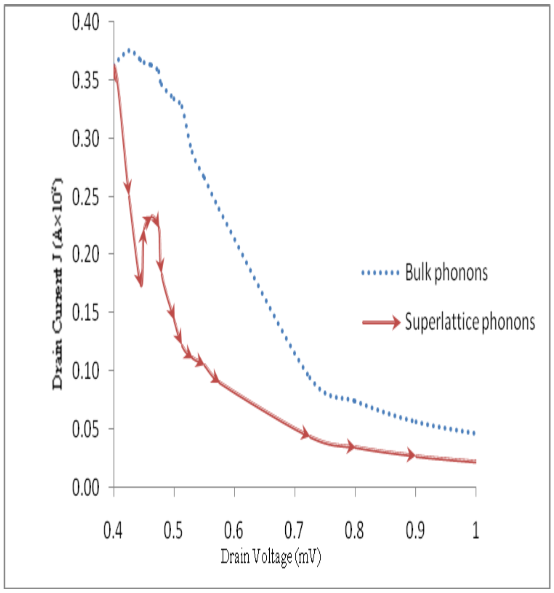

Figure 2: Drain current vs Drain voltage Characteristics

From the Figure 2 it is found that at 0.40 mV the drain current due to superlattice phonons is as high as $0.36\times10^{+2}$ amp which is same in magnitude with that for the bulk phonons. The current increases up to about $0.37\times10^{+2}$ amp with slight increase in voltage of magnitude 0.42 mV and then it decreases with increase in voltage. Whereas in case of superlattice phonons the current at first decreases up to $0.17\times10^{+2}$ amp at 0.44 mV and then increases to $0.24\times10^{+2}$ amp for a slight increase in voltage up to 0.46 mV. Then the current monotonically decreases with further increase in voltage. With the increase in well width the electron – phonon interaction increases, which causes the drain current to decrease with higher drain voltages for both of bulk and superlattice phonons.

IV. CONCLUSION

In the present communication the authors have theoretically designed a GaAlAs/GaAs superlattice MOSFET on Si substrate and have shown the corresponding drain current versus drain voltage characteristics . The drain current is found to be considerably high for small drain voltages for both bulk and superlattice phonons which shows the promise for the design of high power devices with such superlattice MOSFETs,

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