Study of transport in Multi-layered High Electron Mobility Transistors

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ABSTRACT SUBMISSION

In recent days there is a competition for finding alternatives to CMOS technology as CMOS transistor scaling approaches its limits. Among many of these competing new technologies is III-V based HEMTS for logic applications. As channel lengths of HEMTs approach ballistic lengths, it is therefore necessary to understand such devices with quantum transport formalisms. In this paper we intend to apply Non-Equilibrium Green's function formalism to study short channel HEMTs in ballistic regime. We also study C-V characteristics of these devices before moving to their Id-Vg characteristics

GEOMETRY & MATERIALS

The traditional HEMT structure consists of a single modulation doped junction. For the device under study we have a layered structure and a spacer layer as well to prevent remote scattering from dopants. The device structure is shown in fig 1. The 2 –dimensional electron gas is formed in the InAs channel and is confined by the higher barrier materials AlInAs(with Al ratio 0.48) and GaInAs (with Ga ratio 0.47). The total channel length is 30 nm and the region from 10nm to 20nm is controlled by the gate. The respective thickness of each layer is depicted in fig 1.The gate material is Ti , although a definite work function cannot is not known at the interface of AlInAs and Ti.

MODEL & METHODOLOGIES

a)Static C-V Calculations

We first begin with studying Capacitance Voltage characteristics without source drain bias. We build a simple 1D model calculations with the following set of formulae can help us calculate C-V characteristics. A diagram in fig 2 illustrates our model in mind and shows how the conduction band edge moves with change in applied gate voltage. The various dielectric layers have relative permittivity κ_i and contribute a capacitance

$$C_i = \frac{\kappa_i \varepsilon_0}{t_i} \tag{1}$$

The total insulator capacitance and the gate and semiconductor capacitance are given by :

$$\frac{1}{C_{ins}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \tag{2}$$

$$C_S = \frac{d\left(-Q_n\left(\psi_S\right)\right)}{d\psi_S} \tag{3}$$

$$\frac{1}{C_G} = \frac{1}{C_{ins}} + \frac{1}{C_S} \tag{4}$$

$$Q_n\left(\psi_S\right) = -qN_{2D}\ln\left(1+\left(n_S\left(\text{off}\right)/N_{2D}\right)e^{q\psi_S/k_BT}\right) \tag{5}$$

The symbol ψ_S is the surface potential and n_S the sheet charge density and N_{2D} is the density of states. The final C-V curves are shown in fig3.We also find good agreement with experimental data.

b) Transport Calculations with NEGF

Here we calculate the Id Vs Vg characteristics for different sets of applied Vds. In our calculations we assume transport within the channel is ballistic. While such a simulation has already been done by [1] , using formalism Quantum Transport through Barrier Materials , for developing transport with scattering it is necessary to adopt NEGF formalism. Our aim here is to demonstrate that NEGF can well handle ballistic calculations in HEMTs . Results of calculations are shown in fig 4.

DISCUSSION

In our calculations with NEGF we have used an effective mass approach. For our simulation we have used the bulk effective mass in each of the different materials. As pointed out by [1] , we have

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to calculate the effective mass for this strained and confined HEMT structure and then use it in NEGF calculations. We have already used Valence Force Field approaches to relax the structure and calculate the E-k to extract an effective mass of about 0.05 . The effective mass approximations, needs to be benchmarked against full band simulations. Thereafter we can also seek to understand scattering phenomenon in long channel HEMTs. As we notice in Fig 4 , the transistor is already turned on at 0 gate voltage. Therefore the work function at the gate needs to be better understood.

CONCLUSION

In this work we have demonstrated that NEGF formalism can provide means for simulation of HEMT in ballistic regime. With further developments we can progress to tackle scattering and longer channel devices which were not possible with the framework of QTBM as in [1].

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[1] Mathieu Luisier, Neophytos Neophytou, Neerav Kharche, and Gerhard Klimeck, "*Full-Band and Atomistic Simulation of Realistic 40 nm InAs HEMT*," IEDM, 2008.

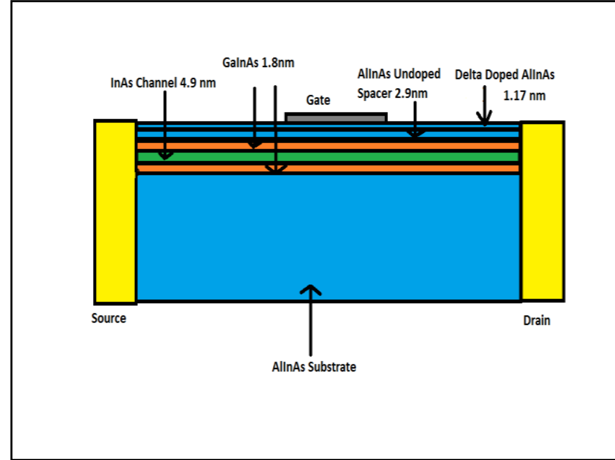

Fig. **1**. Device Structure

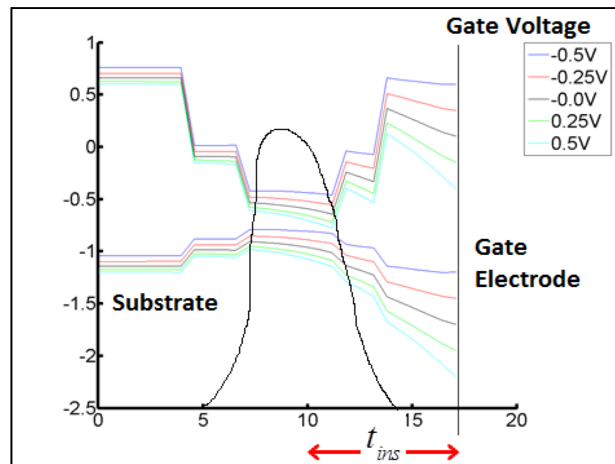

Fig. 2. Bandstructure and charge density along gate to substrate

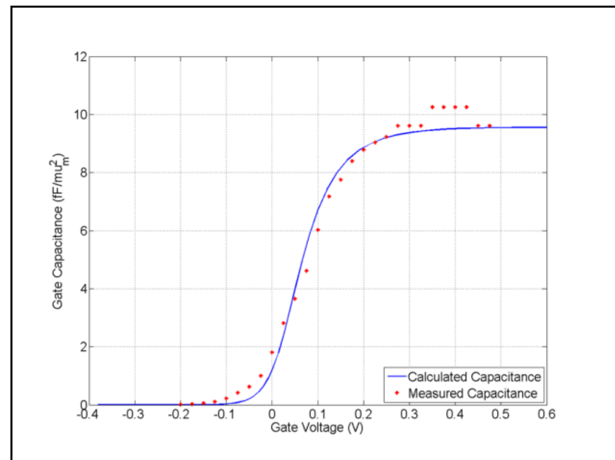

Fig. 3. C-V characteritics

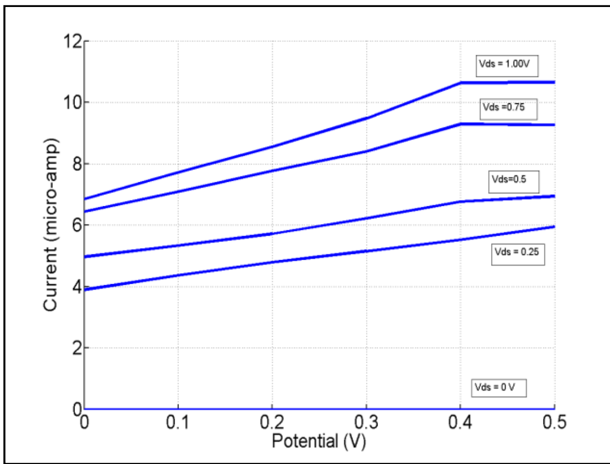

Fig. 4. Id Vs Vg Characteristics from NEGF simulation