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Ensemble Monte Carlo Simulation of AlGaAs/GaAs Heterostructure MIS-Like FET

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The method of Monte Carlo simulation of an heterostructure MIS-like FET is presented in which two dimensionality of electron gas in the heterostructure is taken into account by the lowest three subbands. An AlGaAs/GaAs heterostructure MIS-like FET with a submicron-long gate was investigated by the method developed. The electron transport in the MIS-like FET is discussed in detail. Also discussed is the dependence of device performances on the gate length and the thickness of AlGaAs semi-insulating layer.

1 Introduction

Heterostructure MIS-like FETs and heterostructure modulation doped FETs have been of interest and been investigated. It has been believed that the high mobility of quasi two-dimensional electron gas (2DEG) contributes to the high performances of these FETs. However, with the advance of the recent lithographic technology, it is possible to realize these heterojunction FETs whose gate length is in the submicrometer range. In such circumstances, it is supposed that the electron transport in such a submicron FET is not totally quasi two-dimensional, since the electric field component parallel to the heterointerface becomes very high, accordingly hot-electron transport may take place in the device. Therefore, there is a need to study theoretically the electron transport in submicron heterostructure FETs, so that the operation and design principles of the FETs are made clear.

The theoretical analyses of heterostructure FETs have been undertaken mainly for high electron mobility transistors (HEMT)[1-5]. In this paper, a new method of Monte Carlo modeling of a heterostructure MIS-like FET is reported. Also reported are some results obtained for the electron transport in a submicron channel of an AlGaAs/GaAs heterostructure MIS-like FET and the device performances.

2 Simulation Method and Assumption

Fig.1 shows the model of AlGaAs/GaAs hetero-structure MIS-like FET. The model consists of a semi-insulating GaAs substrate, a couple of heavily doped n-type GaAs regions for the source and drain reservoirs and a semi-insulating AlGaAs layer for MIS-like structure. The lowest three sub-bands are taken into account for the transport of 2DEG. Our treatment for 2DEG is, so to speak, 'a gradual approximation' in which the electronic states of 2DEG are assumed to depend solely on the potential profile perpendicular to the heterointerface. Since we ignored higher excited subbands more than the third-excited one, we introduced rather an artificial electron transfer between 2D and 3D electronic states. The barrier height of AlGaAs layer is assumed to be infinite to make the calculation associated with 2DEG be simpler.[6] We took into account only the acoustic and polar optical phonons for the scattering processes of 2DEG. The phonons are assumed to be 3-dimensional ones. The degeneracy of 2DEG and 3DEG is ignored. Also ignored is the size-quantization of electrons in the L-valleys. The X-valleys are not taken into account in the model for saving computing time.

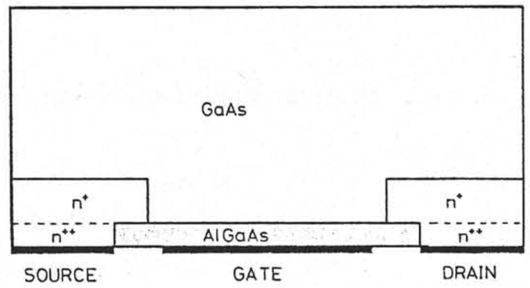

Fig.1 Model of heterostructure MIS-like FET. The doping densities of n^+ and n^{++} layers are 5 x 10^{17} cm^{-3} and 1 x 10^{18} cm^{-3}, respectively. The gate length L_g is either 0.34μm or 0.7μm. The thickness of AlGaAs semi-insulating layer D is varied from 175Å to 500Å. The lattice temperature T is assumed to be 77K.

3 Result and Discussion

Fig.2 shows the density profiles, along the channel, of 2DEG plus electrons which situate in the Γ-valley and within a distance of 200Å from the heterointerface. It is seen that the electron density changes substantially with the change of the gate voltage.

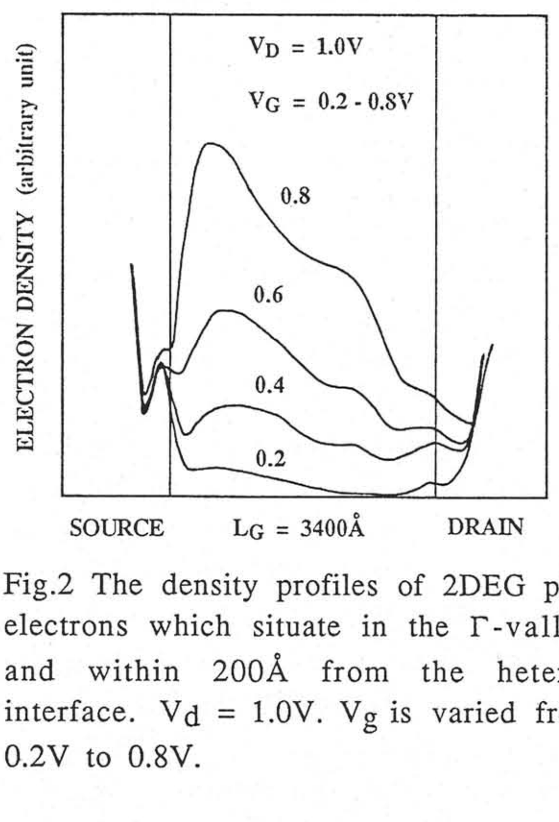

Fig.2 The density profiles of 2DEG plus electrons which situate in the Γ-valley and within 200Å from the hetero-interface. V_d = 1.0V. V_g is varied from 0.2V to 0.8V.

Fig.3 shows the corresponding profiles of the mean electron velocity. The mean electron velocity steeply increases in the vicinity of the source n^+ region, showing only slight overshoot in the channel. It is also seen that the mean electron velocity does not change appreciably with the change of the gate voltage. It is concluded from the results obtained that the control of the drain current of this MIS-like FET is mainly due to the modification of the electron density by the gate voltage.

Fig.4 shows the potential profiles along the heterointerface. It is seen in the figure that the slopes of the potential profiles are steep near the source and drain ends of the channel, showing that the high electric field regions are present there. The high field region near the source contributes to the steep increase of the mean electron velocity therein. The electric field in the channel, except in the high field region mentioned above, does not change appreciably with the change of the gate voltage. This is due to the fact that the potential in the vicinity the hetero-interface is substantially affected by the

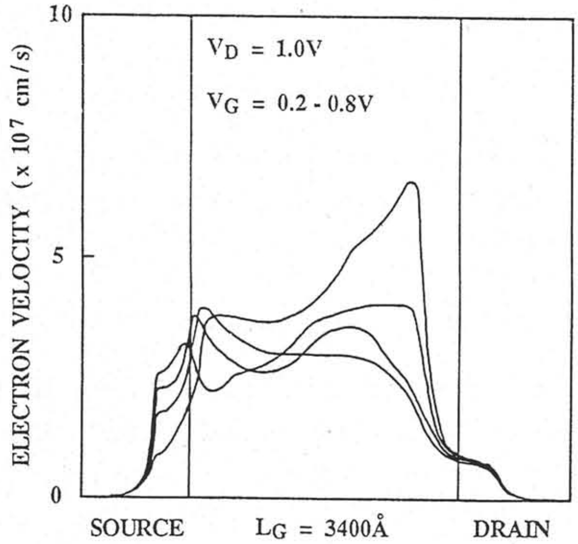

Fig.3 The profiles of the mean velocity of 2DEG plus electrons which situate in the Γ-valley and within 200Å from the heterointerface in the channel. V_g is varied from 0.2V to 0.8V. V_d = 1.0V.

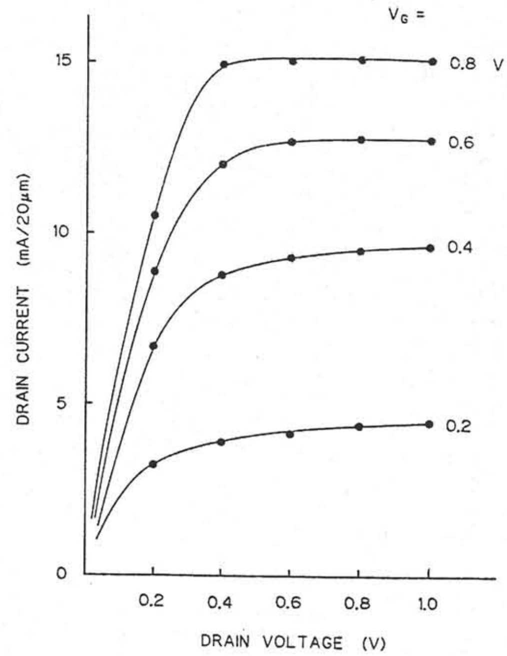

Fig.5 The current-voltage charateristics of 0.34μm-long gate FET. D=175Å.

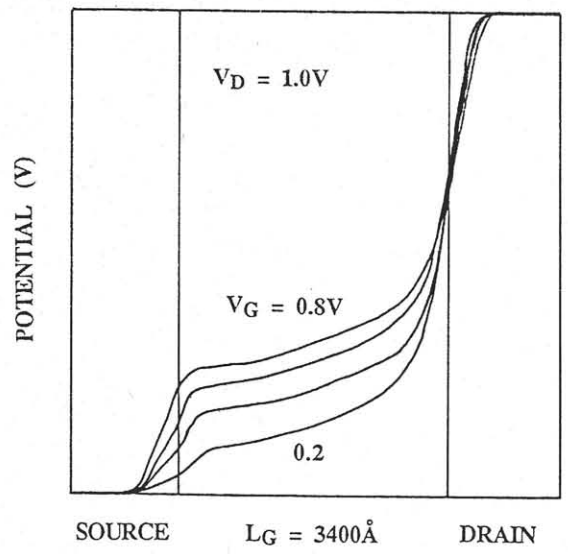

Fig.4 The potential profiles along the channel. V_g is varied from 0.2V to 0.8V. V_d = 1.0V.

equipotential of the gate metal. This result clearly reveals why the mean electron velocity in the channel does not change appreciably with the change of the gate voltage.

Fig.5 shows the current-voltage characteristics of a 0.34μm-long gate MIS-like FET. The simulations for various FETs with different gate length and thickness of AlGaAs layer were also carried out. The values of g_m for 0.7μm-long gate FETs are smaller by a factor of about 2/3 than those for 0.34μm-long gate FETs, while the values of C_g for 0.7μm-long gate FETs are larger by a factor of about 2 than those for 0.34μm-long gate FETs, resulting in the values of the unity-current-gain cut-off frequency f_T for 0.7μm-long gate FETs to be about 1/3 of those for 0.34μm-long gate FETs as shown in Fig.6. f_T does not change appreciably with the change of the thickness of AlGaAs layer, however rather moderate maxima of f_T's shown in the figure suggest that there will be different optimum thickness of the semi-insulating AlGaAs layer for FETs with different gate length.

4. Conclusion

The method and results of Monte Carlo simulation of heterostructure MIS-like FET are reported. The following features are observed in the results:

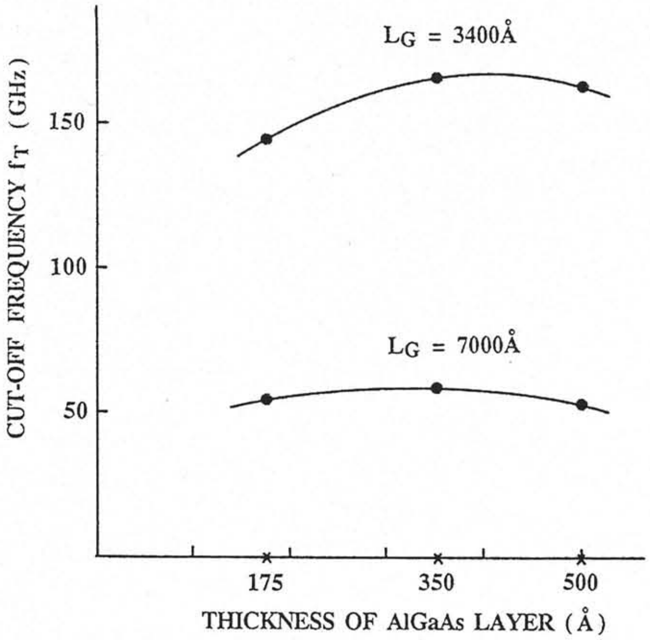

Fig.6 The unity-current-gain cut-off frequency of MIS-like FETs.

The electric potential in the channel of the present MIS-like FET is substantially affected by the equipotential of the gate metal. This causes typical potential profiles which have high electric field regions at both ends of the channel near the source and drain n^+ regions. The electrons in the channel are mainly accelerated in the high field region built-up near the source n^+ region. The mean electron velocity in the channel of MIS-like FET does not change appreciably with the change of the gate voltage.

The control of the drain current is mainly due to the control of the electron density by the gate voltage.

f_T obtained for 0.34μm-long gate FET reaches as high as 160GHz. f_T obtained for 0.7μm-long gate FETs are about 50GHz which is less by a factor of about 1/3 than those for 0.34μm-long gate FETs.

Acknowledgement

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Reference

1) D. Delagebeaudeuf and N. T. Linh: IEEE. Trans. on Electron Dev. ED-29 (1982) 955.

2) D.Widiger, K.Hess and J.J.Coleman: IEEE. Electron Dev. Lett. EDL-5 (1984) 266.

3) J.Yoshida and M.Kurata: IECE. Trans. J67-C (1984) 802.

4) M.Tomizawa, A.Yoshii and K.Yokoyama: IEEE. Electron Dev. Lett. EDL-6 (1985) 322.

5) U.Ravaioli and D.K.Ferry: IEEE.Trans. on Electron Dev. ED-33 (1986) 677.

6) J-P.Polonovski and K.Tomizawa: Jpn. J. Appl. Phys. 24 (1985) 1611.