Dependence of gate-to-drain distance on electron velocity in AlN/GaN HEMTs

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INTRODUCTION

GaN-based high-electron-mobility transistors (HEMTs) are receiving a considerable attention for ultra-high frequency applications [1]. A current gain cutoff frequency of 343 GHz has been achieved for the AlN/GaN HEMT with a scaled gate length of 20 nm [1]. For high frequency performance, the importance of scaling in gate length and source-to-drain distance has been pointed out. However, there is no theoretical study with respect to the impact of access region length.

In this paper, dependence of gate-to-drain distance on channel electron velocity has been investigated using a 2-D Monte Carlo simulator based on full-band model for AlN/GaN HEMTs. The results demonstrated enhanced velocity overshoot effects by the shrinkage gate-to-drain distance below 100 nm.

CALCULATION MODEL AND DEVICE STRUCTURE

In our full-band device model, Boltzmann transport equation was solved using an ensemble Monte Carlo algorithm coupled with 2-D Poisson equation. Band structures for wurtzite GaN, AlN, and AlGaN have been calculated based on an empirical pseudopotential method [2, 3]. The reciprocal wave vectors of 147 were employed for Fourier series expansions of the wave function.

Figure 1 shows band structure in GaN (a) and AlN (b). The bottom of conduction band was assumed to be electron energy of 0 eV. The scattering mechanisms considered were acoustic phonon scattering, polar and non-polar optical phonon scattering, and piezoelectric scattering [4].

Figure 2 shows the schematic cross section of an AlN/GaN/AlGaN HEMT simulated in this work. The structure consists of 3 nm undoped AlN top barrier, 20 nm undoped GaN channel, and 500 nm undoped $Al_{0.08}Ga_{0.92}N$ back barrier. The gate-to-drain distance (L_{gd}) was varied from 10 to 500 nm. For simplicity, source and drain ohmic contacts were placed directly on the channel layer.

RESULTS AND DISCUSSION

Figure 3 presents calculated I-V characteristics for the device with L_{gd} of 40 nm and L_g of 20 nm. The maximum drain current exceeded 4 A/mm at V_{GS}=2 V and V_{DS}=2 V. The peak transconductance was over 2 S/mm.

Figure 4 shows calculated potential distribution (V_{GS}=0.5 V and V_{DS}=5 V). The crowding in electric field is clearly observed near the gate edge in the drain side. At high electric fields (more than 3 MV/cm), band transition of hot electrons was observed from 1 to 2 (not shown here).

Figure 5 plots the channel electron velocity as a function of distance from the gate edge for varying L_{gd} from 10 to 200 nm. It was found that velocity overshoot effects are enhanced for devices with L_{gd} of sub-100 nm. A peak velocity of $7x10^7$ cm/s was achieved for L_{gd} =10 nm.

CONCLUSION

Full-band Monte Carlo simulations have been performed for AlN/GaN/AlGaN DH-HEMTs. The results demonstrated that the reduction in gate-to-drain distance is effective to enhance the velocity overshoot effect.

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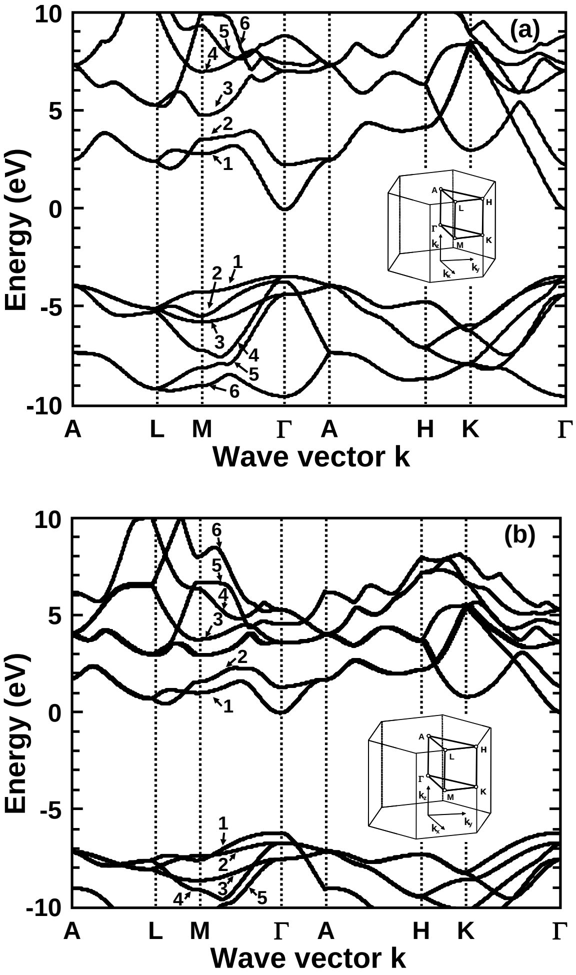

Fig. 1 Empirical pseudopotential band structure in wurtzite (a) GaN and (b) AlN. The insert in Fig. (a) shows the first Brillouin zone in wurtzite structure.

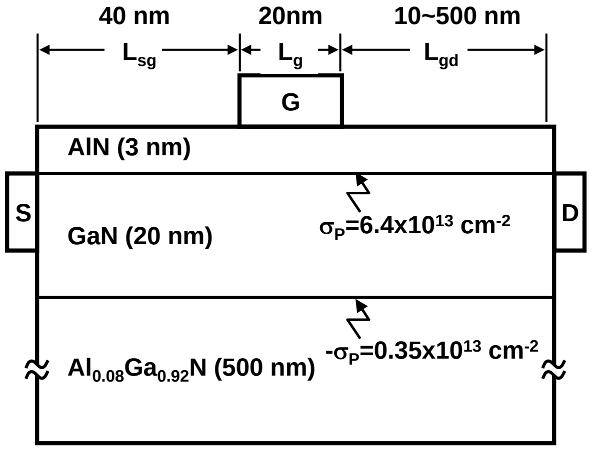

Fig. 2 Cross section of device structure simulated in this work. Neumann condition at all semiconductor surfaces was assumed to solve Poisson equation. The metal semiconductor interfaces was calculated based on Dirichlet condition.

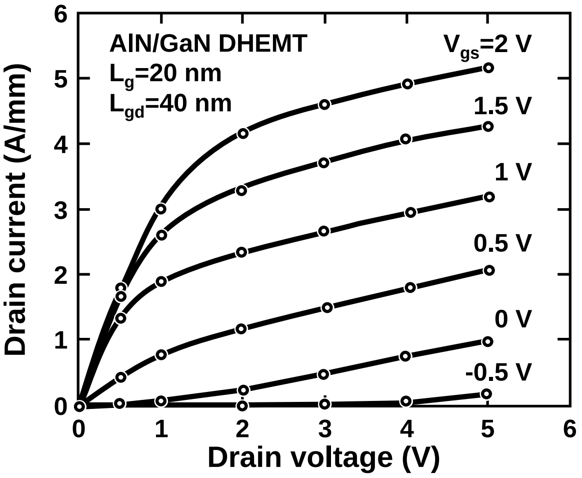

Fig. 3 I-V characteristics for AlN/GaN DHEMT with L_{gd} of 40 nm.

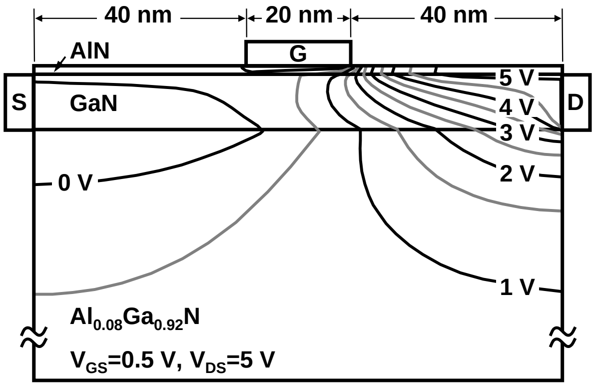

Fig. 4 Calculated potential distribution at V_{GS}=0.5 V and V_{DS}=5 V for the device with L_{gd} of 40 nm. The solid lines indicate equipotential with step of 0.5 V

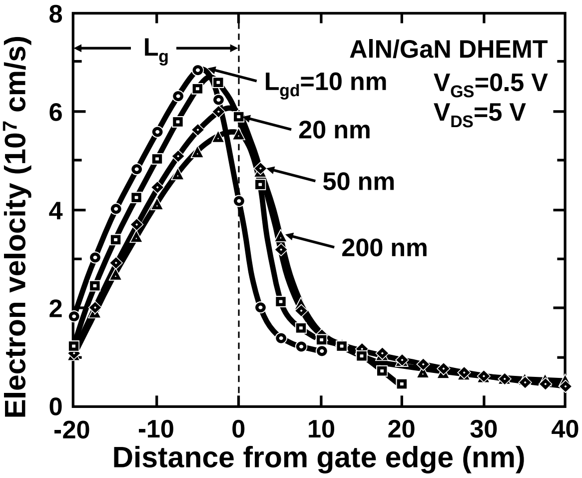

Fig. 5 Channel electron velocity as a function of distance from the gate edge for varying L_{gd} from 10 to 200 nm. Circle indicates the device with L_{gd} of 10 nm, square is L_{gd}= 20 nm, diamond is L_{gd}= 50 nm, and triangle is L_{gd}= 200 nm.