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Improved effective channel electron velocity in AlGaN/GaN HEMTs with sub-100 nm gate-to-drain distance

Kazuki Kodama, Yusuke Naito, Hirokuni Tokuda, and Masaaki Kuzuhara

Graduate School of Engineering, University of Fukui
3-9-1 Bunkyo, Fukui, 910-8507, Japan
Phone: +81-776-27-9714, E-mail: k.kodama59@gmail.com

1. Introduction

GaN-based high-electron-mobility transistors (HEMTs) are attracting enormous attention for ultra-high frequency applications [1, 2]. A current gain cutoff frequency of 343 GHz with an effective channel electron velocity of 1.5×10^{7} cm/s has been achieved by introducing a scaled gate length of 20 nm, a thin AlN top barrier thickness of 2 nm, and an AlGaN back barrier structure [1]. Furthermore, the importance of scaling in source-to-drain distance has been pointed out. However, no theoretical studies have been made with respect to the impact of access region length on the high-frequency characteristics.

In this paper, the effects of gate-to-drain distance on the high-speed performance have been discussed using a 2-dimentional AlGaN/GaN HEMT simulator based on full band Monte Carlo model. The results demonstrated pronounced electron velocity overshoot effects by reducing the gate-to-drain distance down to sub-100 nm.

2. Device structure and calculation model

Figure 1 shows the schematic cross section of an AlGaN/GaN/AlGaN DH-HEMT simulated in this work. The structure consists of 6 nm undoped $Al_{0.35}Ga_{0.65}N$ top barrier, 20 nm undoped GaN channel, and 500 nm undoped $Al_{0.08}Ga_{0.92}N$ back barrier. The source-to-gate distance (L_{sg}) and gate length (L_g) were assumed to be 40 nm and 20 nm, respectively. The gate-to-drain distance (L_{gd}) was varied from 10 nm to 200 nm. For simplicity, source and drain ohmic contacts were placed directly on the channel layer.

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 both wurtzite GaN and AlGaN have been calculated based on an empirical pseudopotential method [3]. The scattering mechanisms considered were acoustic phonon scattering, polar and non-polar optical phonon scattering, and piezoelectric scattering [4].

3. Results and discussion

Figure 2 presents calculated potential distribution along the GaN channel for devices with L_{gd} of 100 nm (a) and 200 nm (b), respectively (V_{GS}=0 V and V_{DS}=5 V). The crowding in electric field is clearly observed near the gate edge in the drain side. Note that the potential distribution near the gate edge is almost unchanged for both devices, indicating identical channel electric field distribution for devices with L_{gd} of over 100 nm.

Figure 3 shows the channel electric field as a function of distance from gate edge in the drain side. By decreasing L_{gd} to sub-100 nm, one can clearly see the increase in the channel electric field. The peak value amounts to as high as 3 MV/cm when L_{gd} is scaled down to 10 nm. The increased peak electric field resulted in the overall increase in the channel electric field under the gate region. Consequently, scaling of L_{gd} down to sub-100 nm effectively suppresses spreading of potential profile toward the drain side, leading to increased electric field profile near the gate edge as well as under the gate region.

Figure 4 plots the channel electron velocity as a function of distance from the gate edge. Reflecting the increased peak electric field with a steeper change rate, more pronounced velocity overshoot effects are evident for devices with L_{gd} of sub-100 nm. A peak velocity of 6.7×10^{7} cm/s was achieved for L_{gd} =10 nm.

Figure 5 shows current gain cutoff frequency (f_T) and effective electron velocity (v_{eff}) as a function of L_{gd}. v_{eff} was determined by averaging channel electron velocity over the distance of L_g and its extension ΔL_g, defined as the distance from gate edge to the position where electron velocity reduces to 10 % of the peak velocity. f_T is expressed as

$$f_T = v_{eff} / 2\pi(L_g + \Delta L_g) .$$

The results demonstrate that the reduction of L_{gd} down to sub-100 nm is effective to increase the average channel electron velocity and thus to enhance the intrinsic current gain cutoff frequency in the range of beyond THz.

5. Conclusion

An ensemble Monte Carlo simulation has been performed for AlGaN/GaN/AlGaN DH-HEMTs. The results demonstrated that the reduction in gate-to-drain distance is effective to enhance the velocity overshoot effect, leading to beyond THz operation with L_{gd} of below 40 nm.

Acknowledgements

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References

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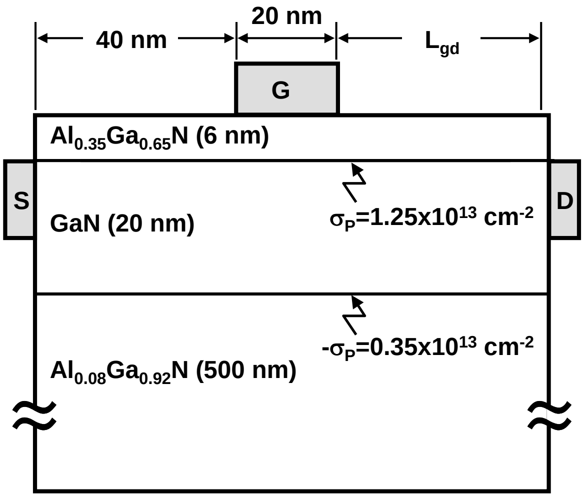

Fig. 1 Schematic diagram of AlGaN/GaN/AlGaN HEMT.

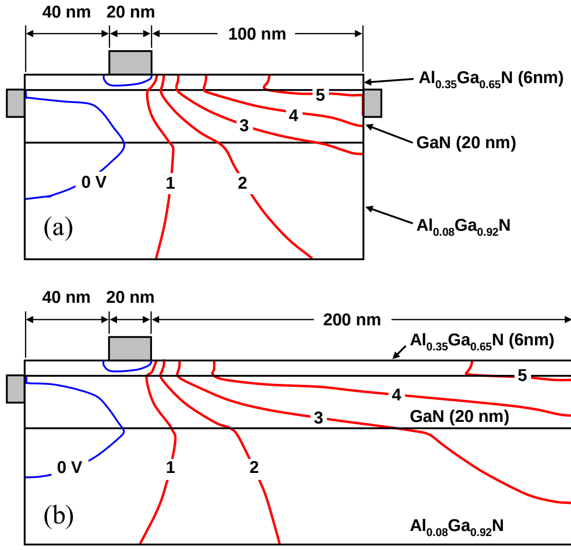

Fig. 2 Potential distribution in devices with L_{gd} of 100 nm (a) and 200 nm (b) at V_{GS}=0 V and V_{DS}=5 V.

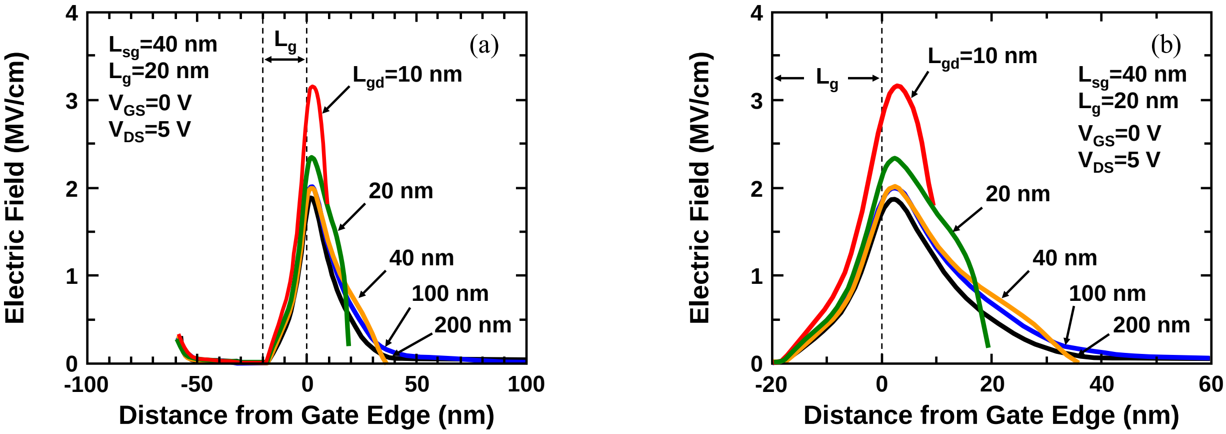

Fig. 3 Electric field as a function of distance from gate edge in drain side.

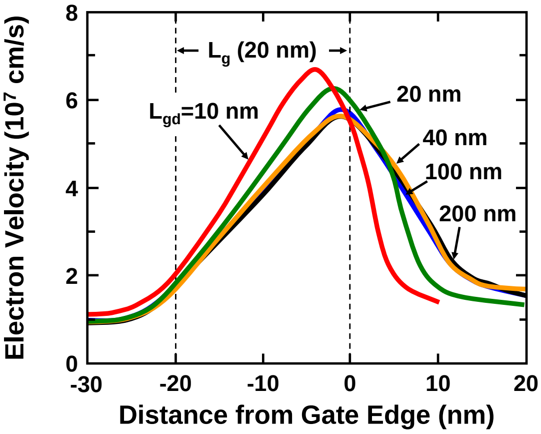

Fig. 4 Channel electron velocity as a function of distance from gate edge at V_{GS}=0 V and V_{DS}=5 V.

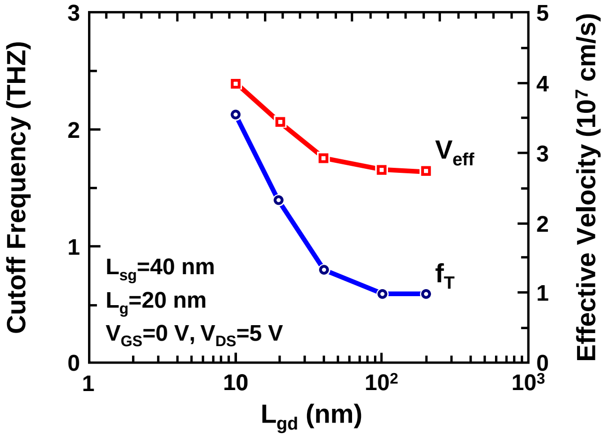

Fig. 5 Current gain cutoff frequency and effective channel electron velocity as a function of gate-to-drain distance.