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Electrical Characteristic Simulation of Novel AlGaN/GaN Vertical HEMT with Multi-Aperture and SiO_2 Current Blocking Layer

Niraj Man Shrestha[1], Yuen Yee Wang[1], Yiming Li[2,*], Edward Yi Chang[1,*]
[1] Compound Semiconductor Device Laboratory, Department of Material Science and Engineering,
[2] Parallel and Scientific Computing Laboratory, Department of Electrical and Computer Engineering,
National Chiao Tung University, Hsinchu 300, Taiwan; E-mail: [*] ymli@faculty.nctu.edu.tw; [*] edc@mail.nctu.edu.tw

Abstract

To improve the performance of GaN vertical devices, for the first time, SiO_2 current blocking layer is introduced. Device simulation shows that a higher barrier of SiO_2 reduces the vertical leakage. Breakdown voltage of the device with purposed CBL is significantly higher than p-GaN blocking layer. Four parallel apertures with same total aperture thickness are used to reduce the aperture resistance. Thus, the conduction current is increased.

1. Introduction

High critical electric field, high electron mobility, and high density of the 2-D electron gas (2DEG), state-of-the-art AlGaN/GaN high-electron mobility transistors (HEMTs) exhibit high breakdown voltages. These power devices are useful for operation under a high voltage and high temperature environment, for example, in automotive applications. Due to the horizontal nature of the 2DEG in AlGaN/GaN heterostructures, majority of the work in this area has been concentrated on lateral device topology. However, to increase the operating voltage, gate drain distance must be increased which ultimately increase the on resistance. To explore this problem, vertical structures with source and drain electrodes on the opposite planes of a substrate could be useful and potential candidates. This type of device has low normalized on-resistance and small size. Additionally, in vertical devices, DC-RF dispersion induced by surface states may be alleviated because high-field regions can be buried below the gate electrode. Recent researches on vertical HEMT with mg doped current blocking layer (CBL) [1,2] were reported. However, CBL is very critical in the vertical HEMT. High drain voltage barrier of p-GaN layer is so week that leakage through p-GaN CBL is more severe [3]. Conduction flow of transport current through the bulk GaN may cause large resistance and suppress device performance.

In this work, for the first time, SiO_2 is used as a current blocking layer to reduce the vertical leakage and make the device more robust. In addition, multiple parallel apertures are designed and simulated which reduce the resistance as a result device current is increased.

2. Device Simulation and Results Discussion

Figures 1(a) and (b) are the schematic diagram of the GaN SiO_2 CBL vertical device with single and parallel multiple aperture respectively. Simulation device parameters adopted during simulation are tabulated in Table I. We have numerically studied electrical characteristics of the vertical HEMT with p-GaN and SiO_2 CBL and with multiple parallel apertures. The III-V device transport model with alloy scattering and low/high field mobility models for electrons and holes are solved to study the device's electrical characteristics.

Figure 2 shows the I_D-V_G transfer characteristic of AlGaN/GaN vertical HEMT at drain bias is 1 V. The result demonstrates that drain current of vertical HEMT with SiO_2 CBL is larger than that of p-GaN CBL. This is owing to the small effective thickness of GaN channel layer due to p-GaN/GaN p-n junction. Energy band profile of vertical HEMT with p-GaN and SiO_2 CBL layer, plotted in Fig. 3 and Fig. 4, shows that barrier in SiO_2 CBL layer is higher than that of p-GaN CBL layer. Therefore, confinement of carriers in channel layer is more pronounced and the drain current is comparatively high. Current flow lines, as shown in Fig. 5, reveal that at high drain bias, vertical leakage through CBL layer is much severe in p-GaN CBL vertical HEMT. Figure 6 shows that vertical leakage at higher drain bias can be controlled by using a SiO_2 CBL. This is due to an effective barrier of SiO_2 for the conduction current even at high bias condition. Therefore, the SiO_2 CBL is more effective at high drain bias. Off-state output characteristic of the device, as shown in Fig. 7, also explains the leakage suppress by using the SiO_2 CBL; and as a results, the voltage of off-state breakdown can also be effectively increased. This can be directly explained by the conduction band energy profile of the device at V_G = -4 V and V_D = 50 V, as shown in Fig. 8 and Fig. 9. Breakdown voltage for SiO_2 CBL vertical HEMT is 670 V (0.1A drain current), which is much higher than that of p-GaN CBL vertical HEMT.

In vertical HEMT structure, the current flow is through bulk GaN. Therefore, the aperture resistance is crucial factor to limit the performance of the device. It is known that the effective aperture resistance is decreased when each aperture is connected in parallel.

$$1/R_{tot} = \sum 1/R_i. \quad (1)$$

Keeping the total aperture width same as previous structure, the purposed parallel multiple apertures in this study have low resistance. This results increase in the drain current. Transfer and output characteristic, as plotted in Fig 2, shows that maximal drain current at V_D = 1 V and V_G = 1 V is much higher than that in single aperture. Similarly, the output characteristic of the single and multiple apertures SiO_2 vertical HEMTs, as plotted in Fig. 10 and Fig. 11, indicate that multiple aperture device has a higher drain current. Notably, except the increase of conduction current, the studied new structure does almost maintain the similar off state leakage and the breakdown voltage.

3. Conclusions

In summary, we have designed and simulated novel GaN vertical HEMT with SiO_2 CB layer which gives superior performance than that with p-GaN CB layer. The maximal drain current is significantly increased. The vertical leakage through CBL at high drain bias is effectively suppressed and breakdown voltage is effectively increased. The breakdown voltage of the device with purposed SiO_2 CBL, 630 V, is significantly higher than p-GaN blocking layer. In addition, the parallel multiple apertures reduce the aperture resistance and the drain current is effectively increased. We are currently fabricating sample.

Acknowledgement

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References

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3. I. B.Yaacov et al., J. App. Phys, 95 (2004) 2073.

Table I List of adopted simulation device parameters including thickness of each layer.

Parameters	Values
Gate Length(Lg)	2 μm
Gate Width (W)	100 μm
AlGaN thickness(T_{AlGaN})	15 nm
Al composition (%)	25
GaN channel thickness(T_{GaN})	50 nm
Aperture width	0.8 μm
CBL thickness (T_{CBL})	500 nm
GaN epilayer	5 μm

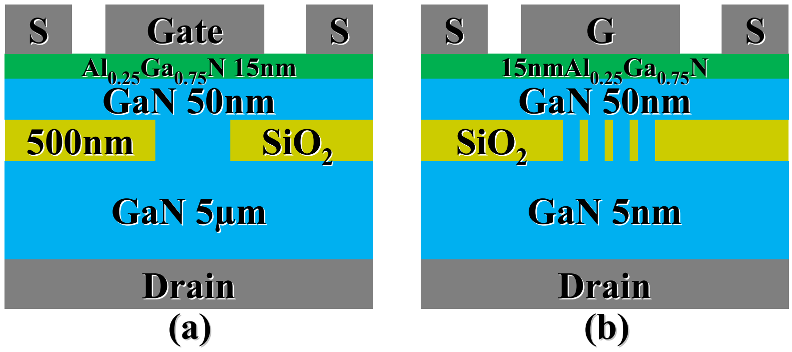

Fig. 1 Schematic cross sections of AlGaN/GaN vertical HEMT with SiO_2 current blocking layer: (a) single vertical aperture and (b) parallel multiple vertical apertures. The device with parallel multiple vertical apertures is the new study in this work.

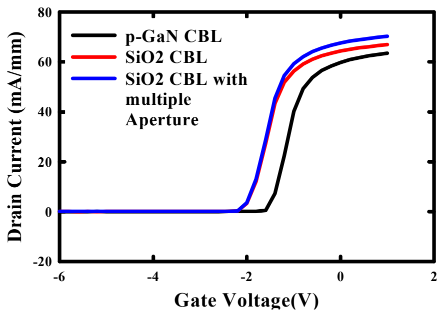

Fig. 2 Plot of I_D-V_G of vertical HEMT with P-GaN CBL and SiO_2 CBL with single and multiple apertures at $V_D = 1V$.

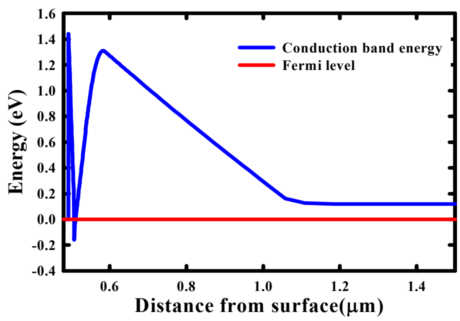

Fig. 3 Plot of the conduction band Profile for the conventional p-GaN CBL vertical HEMT.

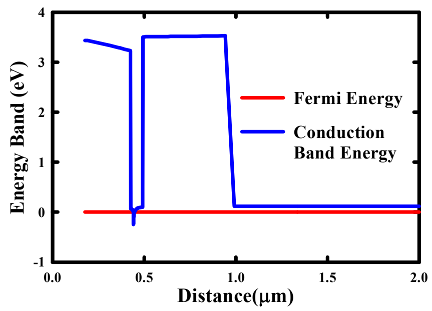

Fig. 4 Plot of the conduction band Profile for the new SiO_2 CBL vertical HEMT.

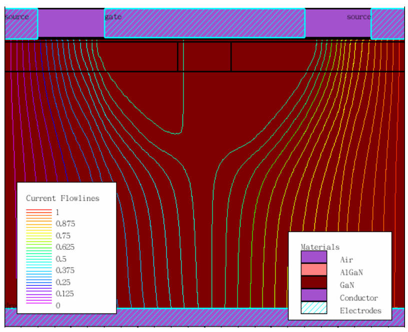

Fig. 5 Simulated current flow line of p-GaN CBL vertical HEMT at V_D = 50V and V_G= -4 V.

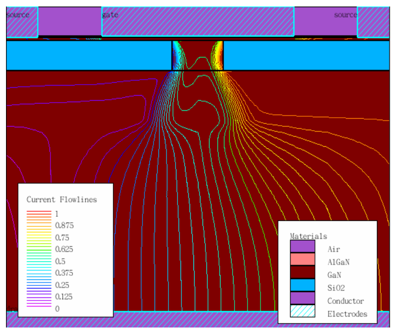

Fig. 6 Simulated current flow line of SiO_2 vertical HEMT at V_D = 50V and V_G= -4 V.

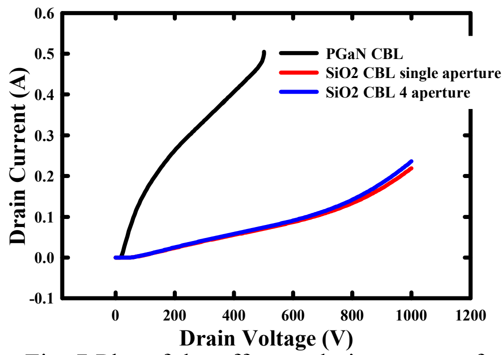

Fig. 7 Plot of the off-state drain current of vertical HEMT with p-GaN CBL and SiO2 CBL with single and multi apertures.

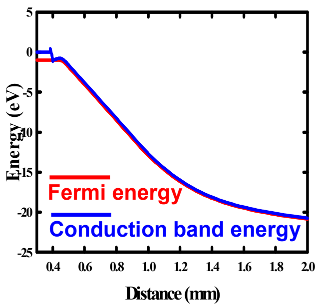

Fig. 8 Plot of conduction band energy profile of P-GaN CBL vertical HEMT at V_G = -4 V and V_D= 50 V. The barrier is reduced at large V_D because the nature of adopted materials.

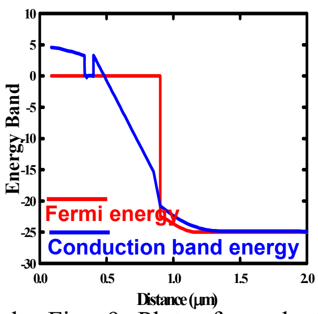

Fig. 9 Plot of conduction band energy profile of SiO_2 CBL vertical HEMT at V_G = -4 V and V_D= 50 V. The barrier is more effective at high drain bias.

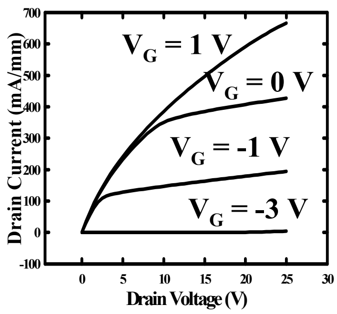

Fig. 10 Output characteristic of SiO_2 CBL and single aperture vertical HEMT.

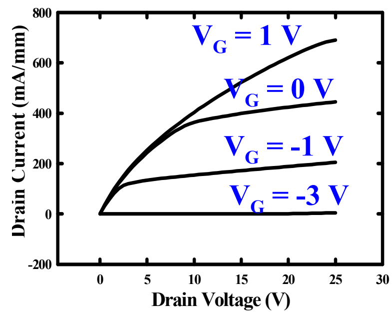

Fig. 11 Output characteristic of SiO_2 CBL and multiple apertures vertical HEMT.