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The investigation of p-GaN gate HFET on 6-inch silicon using AlN interlayer

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1. Introduction

AlGaN/GaN heterostructure field-effect transistor (HFET) is an excellent candidate for high power application because GaN has excellent properties such as high electric field, and high electron mobility compared with Si. However, normally-off operation is crucial because high power switching applications require fail-safe operation, gate signal noise immunity and ensuring compatibility with existing systems to simplify the design of driving circuits. Recently, several methods of fabricating normally-off HFETs have been suggested including gate recess [1], fluorine treatment [2] and p-type gate process [3,4]. Among three processes, p-type gate process has an advantage to gain stable and high threshold voltage (V_{TH}) than other methods when the gate is unbiased.

Increasing the V_{TH} can be obtained by reducing Al concentration in the AlGaN barrier or decreasing thickness of the AlGaN barrier, lowering electron density of two dimensional electron gas (2DEG). However, on-state resistance (R_{ON}) of the devices would be increased because of the low density of 2DEG. Thus there is trade-off characteristics between R_{ON} and V_{TH}. In this work, normally-off p-GaN gate HFET with AlN interlayer between AlGaN barrier and GaN channel is presented to improve the trade-off characteristics resulting in high V_{TH} while keeping low R_{ON}. By growing AlN interlayer between AlGaN barrier and GaN channel, high density of 2DEG could be maintained although the thickness of AlGaN barrier was reduced.

2. Fabrication & Experiment

p-GaN/AlGaN/AlN/GaN HFET structure was grown by metal-organic chemical vapor deposition (MOCVD) system on 6 inch (111) Si substrate. Al composition and thickness of AlGaN barrier was chosen to investigate the relationship between 2DEG density and V_{TH}. After metallization of p-GaN gate contact, p-GaN was etched selectively to reveal the source and drain region. Ti/Al ohmic contacts were used as a source and drain. The gate length and drain-gate distance were 2 μm and 15 μm, respectively. A schematic cross sectional view of HFET is shown in Fig. 1.

3. Result & Discussion

Fig. 2 shows the extracted V_{TH} value as a function of AlGaN barrier thickness for a p-GaN gate HFET. For a given Al composition, the V_{TH} moves toward positive value with decreasing the thickness of AlGaN barrier. Also, as Al composition decreased for a given barrier thickness, the V_{TH} increased. This result shows that the magnitude and increase of the V_{TH} value depend on the AlGaN barrier thickness and Al composition of the AlGaN layer. This result is primarily due to the reduction of 2DEG density resulting fully carrier depletion controlled by p-type gate. An additional feature of the calculated slope is that a V_{TH} increase rate is more sensitive to AlGaN barrier thickness than Al composition. However, the normally-off operation device which is enabled by 2DEG density reduction can be suffered from drain current reduction inevitably.

Fig. 3 shows the 2DEG density as a function of the AlGaN barrier thickness for a given Al composition ($Al_{x}Ga_{1-x}N$, x=0.25). The density of the 2DEG in the AlGaN/AlN/GaN structure does not vary significantly in comparison to the device without AlN interlayer. This could be attributed to the result of reduced interface scattering effects and increased built-in polarization [5,6].

Fig. 4 and 5 show the transfer and output I-V characteristics of the fabricated p-gate GaN HFET with AlN interlayer with the channel width of 24 mm and the L_{GD} of 15 μm(1mm^2). The devices showed enhancement-mode operation with the V_{TH} of +0.9V. Also, the V_{TH} of devices was uniform all over the 6inch wafer and the maximum drain current was over 5A at the gate voltage of +6V. In addition to these results the R_{ON} and breakdown voltage were 7.24 mΩ·cm^2, 690V, respectively.

Fig. 7 shows the trade-off characteristics of V_{TH} and R_{ON} for the p-gate GaN HFET which has AlN interlayer. In the calculation of the R_{ON}, the applied gate voltages were +6V. It is indicated that the devices using AlN interlayer have relatively low R_{ON} with normally-off characteristics. The inserting of AlN interlayer can not only reduce R_{ON} maintaining of the 2DEG density but also afford a wide margin of reducing AlGaN thickness for a carrier depletion.

4. Conclusions

The effects of AlN interlayer of p-GaN/AlGaN/AlN/GaN HFETs have been investigated. Low R_{ON} and high V_{TH} characteristics could be obtained by using AlN interlayer between AlGaN and GaN. A V_{TH} of +0.9V with R_{ON} of 7.24mΩ·cm^2 for 15μm gate-drain spacing was achieved by modulating the AlGaN/AlN/GaN growth scheme.

References

[1] M. Kanamura et al., IEEE Electron Device Lett., **31** (2010) 189.

[2] S. Huang et al.,Appl. Phys.Lett., **96** (2007) 233510.

[3] Y.Uemoto et al., IEEE Electron Device Lett., **28** (2007) 781.
[4] O.Hilt et al, the 23rd ISPSD (2011).
[5] I. P. Smorchkova et al., J. Appl. Phys., **90** (2001) 5196.
[6] L.Guo et al., Microelectronics Journal, **39** (2008) 777.

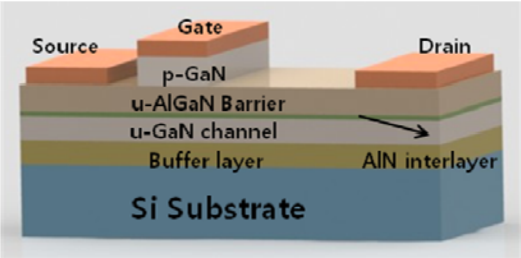

Fig. 1 Schematic cross-sectional view of p-GaN gate HFET

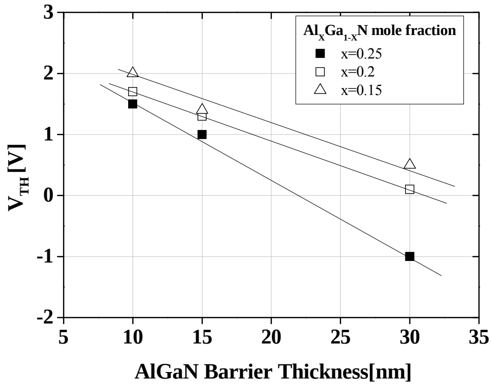

Fig. 2 Threshold voltage characteristics for changing Al mole fraction and thickness of AlGaN barrier

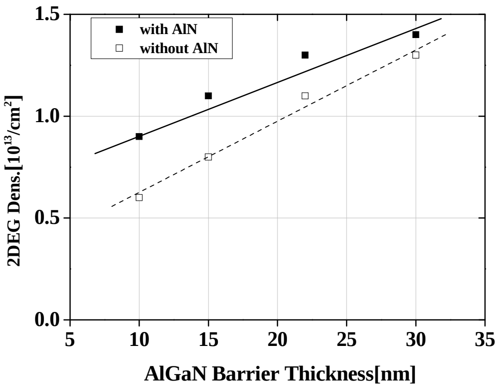

Fig. 3 2DEG density as a function of AlGaN barrier thickness

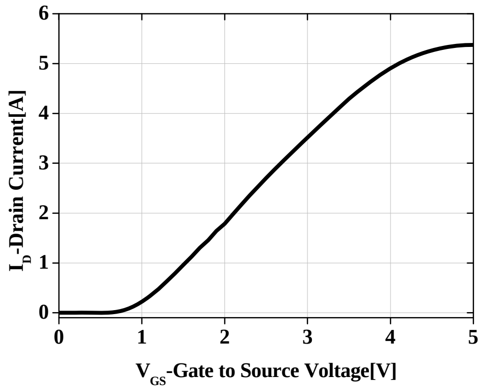

Fig. 4 Transfer characteristic for 24mm wide devices with L_{GD} =15um on a 6-inch Si substrate. V_{DS}=5V

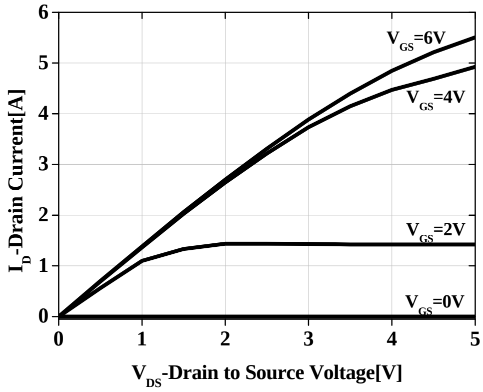

Fig. 5 Output characteristic for 24mm wide devices with L_{GD}=15um on a 6-inch Si substrate.

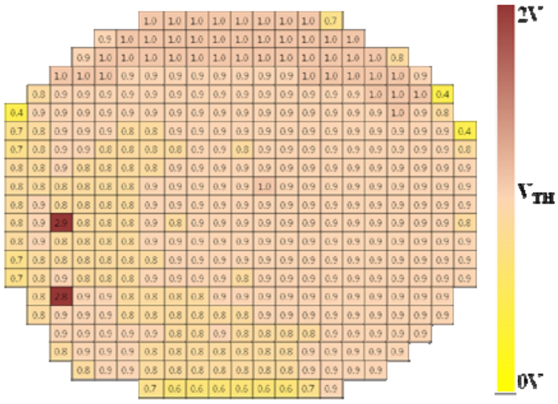

Fig. 6 The mapping data of V_{TH} characteristics of HFETs on 6-inch Si substrate

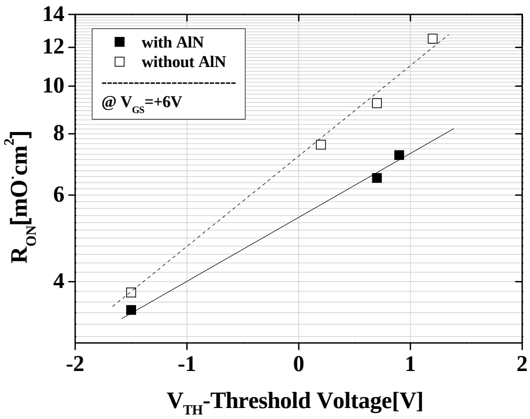

Fig. 7 Specific on-state resistance versus threshold voltage for normally-off p-GaN/AlGaN/GaN HFETs with and without AlN interlayer