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Quasi-Normally-Off AlN/AlGaN/GaN MIS HEMTs Grown on 4 in. Silicon Substrate

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1. Introduction

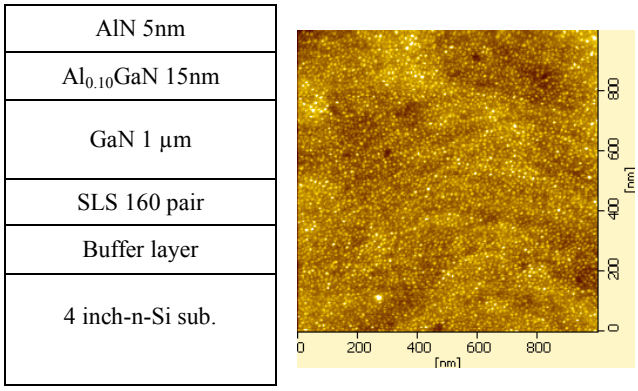
GaN-based normally–off high electron mobility transistors (HEMTs) have attracted much attention in recent years due to no negative gate voltage necessary to turn off the devices[1]. However, high polarization charge density at the interface between AlGaN and GaN limits the fabrication of normally-off HEMT devices. Theoretically a normally-off AlGaN/GaN HEMT requires reduced AlGaN thickness to several nanometer and about 20% of Al mole concentration[2]. In such normally-off devices, the maximum drain current is small because it is not possible to apply high gate voltage as it leads to excess gate leakage. GaN based metal-insulator-semiconductor (MIS) structure is expected to solve these problems because it is possible to apply a large gate forward voltage to the MIS gate. Recently, our group reported that AlN is effective in realizing low gate leakage and high breakdown voltage in AlGaN/GaN HEMTs[3]. Based on this result, we attempt to use AlN as gate insulator to fabricate GaN based normally-off HEMTs, which was grown by metal-organic chemical vapor deposition (MOCVD) technique Here, an initial result of the AlN/AlGaN/GaN MIS HEMTs grown on 4 inch silicon substrate was reported with quasi-enhancement mode.

2. Experimental

The AlN/AlGaN/GaN structure was grown on 4-inch n-Si substrate, as shown in Fig. 1(a), by metal organic chemical vapor deposition (MOCVD). 5 nm AlN cap was grown at 600 °C to form MIS structure. The HEMT devices were fabricated by conventional photolithographic lift-off method[3]. The mesa isolation process was performed by BCl_3 plasma reactive ion etching. Ti /Al/Ni/Au metal stack was selected as source drain contact by rapid thermal annealing. Pd/Ti/Au was used as Schottky gate electrode. The dc current was measured on Agilent 4156c semiconductor parameter analyzer. The breakdown measurement and current collapse were performed on Keithley pico-ammeters interfaced with a probe station and Sony-Tektronix CurveTtracer 370A, respectively.

3. Results and discussion

The AFM image (Fig. 1(b)) of AlN/AlGaN/GaN heterostructure on silicon shows that AlN cap was grown as uniform nanoscale grains with diameter of 10 nm, which fully covered on AlGaN/GaN heterostructure. The root mean square roughness is 0.7 and 0.3 nm for 3×3 and 1×1 μm^2 image, respectively, which is less than our previous report[3].



(a) (b)

Fig. 1 Schematic cross section (a) and AFM image (b) of AlN/AlGaN/GaN MIS HEMT

The typical I_{ds}-V_{ds} characteristics and transfer characteristics of the MIS HEMTs are displayed in Fig. 2 and Fig. 3, respectively. I_{dmax} is 87 mA/mm (at the gate voltage of +1.5 V) and g_{max} is 57 mS/mm (at the drain voltage of 4 V and gat voltage of 0.7 V). This peak g_m value on silicon substrate is lager than that of enhancement-mode devices fabricated with the same structure without AlN cap grown on sapphire template (23

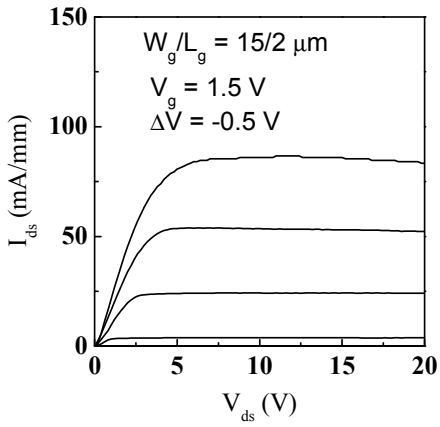


Fig. 2 I_{ds}-V_{ds} characteristics of the AlN/AlGaN/GaN MIS HEMT.

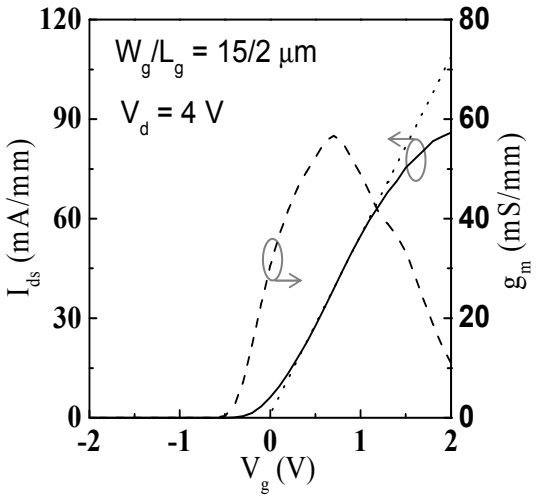
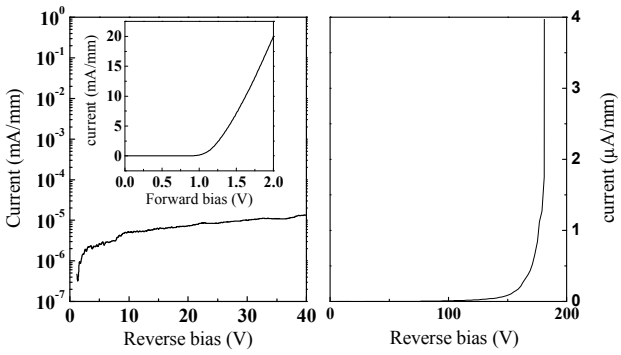


Fig.3 Transfer characteristics of the AlN/AlGaN/GaN MIS HEMT.



(a) (b)

Fig. 4 Two terminal gate I-V measurement (a) and breakdown measurement (b) of the MIS HEMT. The inset of 4(a) is forward I-V characteristics. (W_g/L_g = 15/2)

mS/mm)[4]. But the g_{max} value is still low, which is mainly due to the large drain and source resistance (~ 10 Ω·mm). From the the gate-bias intercept of the extrapolation of the drain current curve in the transfer characteristics, the threshold voltage is determined about 0 V. Thus the quasi-normally-off model operation was realized in the present device. This threshold voltage is much smaller than those of conventional AlGaN/GaN HEMTs, which are typically in the range of -2.5 V to -5 V. The main reason for this positive shift is the low Al composition in AlGaN barrier and thin AlGaN barrier resulting in low 2DEG carrier concentration[2]. On the other hand, the previous results[3] showed that AlN cap lead the channel to shift close to the interface of AlGaN/GaN heterostructure, which also result in positive shift of threshold voltage. The plot of two terminal gate leakage current and breakdown were displayed in Fig. 4. The leakage current is ~ 10^{-5} mA/mm at 40 V (shown in Fig. 4(a)), which is two order of magnitude lower than that of the conventional AlGaN/GaN HEMTs, indicating that the AlN cap can suppress gate leakage efficiently and enhance forward turn-on voltage (shown in inset of Fig. 4(a)). The breakdown is over 180 V, much larger than that of the conventional HEMTs, confirming the the improved breakdown by inserting of insulator[3].

To evaluate the current collapse, the AC I_{ds}-V_{ds} characteristics of the MIS HEMT was measurement and shown in Fig. 5. As can be seen, with AlN cap layer small current collapse occurs, which is believed due to the suppress of interfacial trap by AlN cap layer[3]. On the other hand, the week clockwise hysteresis loop can be observed indicating the high switching speed[5]. The pulse-gate measurement (not shown here) also shows less current collapse than the conventional AlGaN/GaN based HEMTs[6].

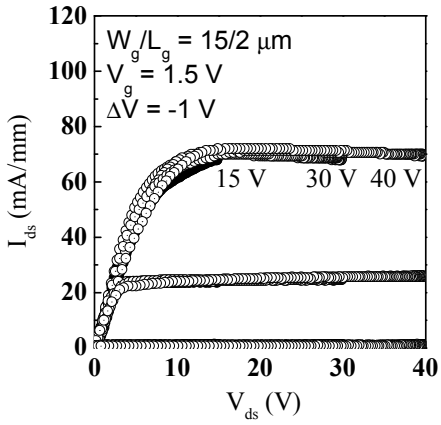


Fig. 5 The plot of AC I_{ds}-V_{ds} characteristics of the MIS HEMT.

3. Conclusion

A quasi-normally-off HEMT based on AlN/AlGaN/GaN MIS structure grown on 4 in. silicon was achieved. The performance of the normally-off HEMTs could be further improved by properly controlling the AlN growth and AlGaN/GaN heterostructure.

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References

[1] S. Sugiura, S. Kishimoto, T. Mizutani, M. Kuroda, T. Ueda, T. Tanaka, *Phys. Stat. Sol.* (c) **5** (2008) 1923.
[2] J. Lee, D. Liu, Z. Lin, W. Lu a, J. S. Flynn, G. R. Brandes, *Solid-State Electron.* **47** (2003) 2081.
[3] S. L. Selvaraj, T. Ito, Y. Terada, T. Egawa, *Appl. Phys. Lett.* **90** (2007) 173506.
[4] M. A. Khan Q. Chen, C. J. Sun, J. W. Yang, M. Blasingame, *Appl. Phys. Lett.* ***68*** (1996) 514.
[5] S. Arulkumaran, T. Egawa, H. Ishikawa, T. Jimbo, and Y. Sano., *Appl. Phys. Lett.* **84** (2004) 613.
[6] Y. Liu, H. Jiang, S. Arulkumaran, T. Egawa, B. Zhang, H. Ishikawa, *Appl. Phys. Lett.* ***86*** (2005) 223510.