Student Paper

MBE-Grown Buffer with High Breakdown Voltage for nitride HEMTs on GaN Template

Yu Cao, Tom Zimmermann, Huili Xing, and Debdeep Jena

Electrical Engineering Department, University of Notre Dame, USA, ycao1@nd.edu

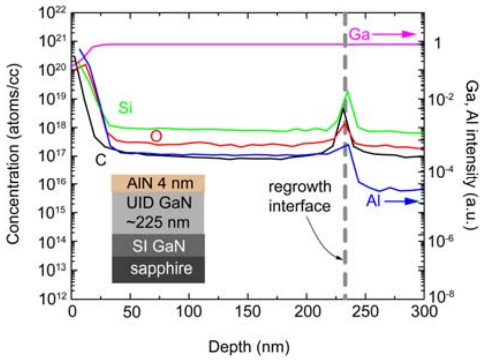
In the recent years very good power performance has been achieved from nitride-based high electron mobility transistors (HEMTs) [1]. Since great efforts have been put into improving the material quality by reducing the number of defects, to develop an insulating buffer has been one of the most challenging problems.

GaN templates are good for the MBE growth of HEMTs. High-quality Al(Ga)N/GaN heterojunctions can be achieved above only a few hundred nm GaN buffer layer, which greatly shortens the growth time and saves resources. Iron or beryllium can be introduced in the growths to create deep-level states in the GaN buffer layer, which helps to reduce the buffer leakage [2-3]. However, such dopants will cause the trapping effects for channel carriers. Therefore a dopant-free growth technique, which has not been developed before, is desired for the leakage reduction in MBE-grown HEMTs on GaN templates.

In this paper, all the samples were grown at the same thermocouple temperature of 660°C. The Ga flux was fixed at 1.33×10^{-7} Torr and the Al flux was fixed at 1.32×10^{-7} Torr. The size of the buffer pads is 100 μm*100 μm with the separation of 6 μm. In the control sample, where the 234 nm GaN buffer layer was directly grown on the GaN template, the buffer leakage current density reached 40 mA/mm at the DC bias of ±5 V. This leakage is very high and is only 2 orders less compared to the drain current density at ~1000 mA/mm in a working nitride HEMT. By making the secondary ion mass spectrometry (SIMS) measurements, we have identified that the unexpected silicon and oxygen impurity atoms at the template surface caused the buffer leakage. The leakage path is located at the regrowth interface as shown in Figure 1.

By introducing an ultra-thin 1 nm AlN nucleation layer grown in the intermediate regime, the buffer leakage is greatly reduced by ~8 orders in magnitude. The intermediate regime was achieved by using the RF plasma power of 400 W, which is much higher than the 275 W used for metal-rich growth. The 2DEG RT mobility is 1515 cm^2/Vs with the charge density of 2.08×10^{13} cm^{-2}. The leakage density in this sample is less than 20 nA/mm at the bias of 20 V. The measurement was also performed in the vacuum environment with the pressure of $\sim 4.5 \times 10^{-4}$ Torr. Excellent insulating property have been achieved with the leakage current density reaching 1 μA/mm at the bias of ~81 V and 1 mA/mm at ~200 V, which is shown in Figure 2. This result is comparable or superior to those obtained via using a doped buffer layer. The transfer characteristics shown in Figure 3 indicate the buffer leakage has been removed by using the new buffer. At the same time, the on/off ratio of the FETs is greatly improved. This directly leads to much steeper sub-threshold slopes in the HEMTs, and is an attractive route towards GaN-based digital devices in the future.

978-1-4244-6031-1/09/$26.00 ©2009 IEEE



Figuire 1

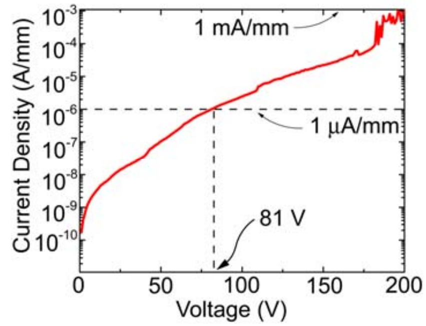


Figure 2

Figure 1: SIMS result shows the atomic concentration against the depth into the sample. Strong impurity peaks of silicon (green), oxygen (red) and carbon (black) are found at the regrowth interface. The intensity of Ga (pink) and Al (blue) is also shown.

Figure 2. Highly insulating buffer measured in the vacuum shows 1 μA/mm leakage at 81 V and 1 mA/mm leakage at 200 V.

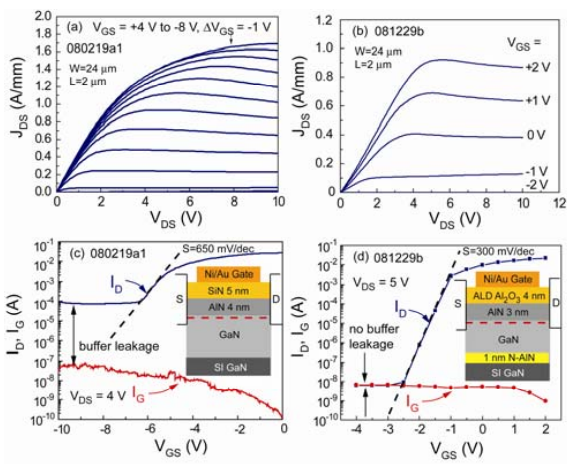


Figure 3. The DC operation of FETs shows good modulation on the source-drain current on samples (a) 080219a1 (leaky buffer) and (b) 081229b (insulating buffer). The transfer characteristics show that (c) the leakage in 080219a1 is mainly from the buffer, and (d) in 081229b the buffer leakage has been decreased lower than the gate leakage.

References

[1] R.M. Chu *et al.*, "V-Gate GaN HEMTs for X-Band Power Applications", IEEE Electron Device Lett., vol. 29, pp 974, 2008. (Journal Article)

[2] Y. Cordier *et al.*, "Subsurface Fe-doped semi-insulating GaN templates for inhibition of regrowth interface pollution in AlGaN/GaN HEMT structures", J. Crystal Growth, vol. 310, pp 948, 2008. (Journal Article)

[3] D.F. Storm *et al.*, "Reduction of buffer layer conduction near plasma-assisted molecular-beam epitaxy grown GaN/AlN interfaces by beryllium doping", Applied Physics Lett., vol. 81, pp 3819, 2002. (Journal Article)