Extended Abstracts of the 2012 International Conference on Solid State Devices and Materials, Kyoto, 2012, pp877-878

Low Leakage Current for 1.6kV Breakdown GaN HFET with 6um-thick Semi-insulating GaN on 6-inch Si

S. M. Cho, E. J. Hwang, J. M. Kim, J. H. Kim, J. H. Shin, Y. S. Eum, J. Park, Y. J. Jo, W. S. Kim, H. J. Lee, Kwang-choong. Kim and T. Jang*

IGBT part, System IC R&D, LG Electronics
38, Baumoe-ro, Seocho-Gu, Seoul 137-724, Korea
Phone: +82-2-526-4665 *E-mail: th.jang@lge.com

1. Introduction

The AlGaN/GaN-based heterostructure field effect transistor (HFET) can be operated under high-power, high-frequency, and high-temperature conditions compared to conventional Si-based electronic devices. However, GaN-based devices for high-power application were still under development due to high leakage current. Previous investigations of GaN revealed that properties of device were influenced by impurities in GaN [1] and they could be one of the origins for leakage path under high voltage operation. By growing semi-insulating GaN, leakage current could be reduced.

In this paper, high breakdown voltage on AlGaN/GaN HFETs structure of 1600V has been successfully achieved using thick and semi-insulating GaN. The lowest leakage current ever reported on a HFET structure of 5nA/mm at 600V has been measured. Crack-free and homogeneous 6μm-thick-GaN was grown on 6-inch Si (111) substrate by metal organic chemical vapor deposition (MOCVD), resulting in a low electric field at the gate of drain side. The leakage current range and the average value of breakdown voltage of the fully fabricated device were 5pA/mm~5nA /mm and 1573V, respectively.

2. Experimental

AlGaN/GaN HFET structure was grown by MOCVD on a 6-inch Si (111) substrate. The bare Si (111) substrate was first annealed in the reactor to remove the native oxide layer, followed by the growth of an AlN nucleation layer. The buffer layer consists of AlGaN buffer layers with three different Al compositions. This was followed by unintentionally doped (UID) GaN layer and 1nm AlN interlayer. Finally, 27nm $Al_{0.25}Ga_{0.75}N$ barrier and thin GaN capping layer were grown. The amount of C doping and the thickness of GaN layer were varied up to ~$4x10^{18}$ atoms/cc and ~6.0μm, respectively. The gate recess process was adopted to fabricate normally-off device [2]. After fabrication, the DC characteristics were measured to investigate the device performance and breakdown voltage was mapped to confirm the uniformity of each device over 6-inch wafer.

3. Results and discussion

Breakdown voltage of 1600V was obtained on a carbon doped-GaN HFETs with 6μm GaN and 0.3μm AlGaN buffer thickness. (Previously, 600V with a conventional epitaxial structure) This result indicated that carbon doping formed deep acceptor level and electric field was improved by thickness. Fig. 1 shows homogeneities of the Al content and thickness of AlGaN barrier. Atomic concentration of each element in GaN has been confirmed by secondary ion mass spectroscopy (SIMS). Cathodoluminescence (CL) measurement [Fig. 2] under low temperature (77K) has been carried out and showed that deep acceptor level [3] related emission was detected at 2.8eV between GaN (3.4eV) and broad yellow band (2.2eV) [4]. This suggested that deep acceptor level in GaN film was formed by carbon doping. Fig. 3 shows that leakage current was closely related with the amount of carbon doping concentration in GaN film. The record-low leakage current of $5x10^{-9}$A/mm was achieved at 600V. Breakdown voltage and thickness of GaN with different values of carbon doping concentration were shown in Fig. 4. Breakdown voltage was clearly proportional to the thickness of GaN and doping concentration of carbon. Fig. 5 shows a top-view image of crack-free-6μm-thick GaN grown on 6-inch Si substrate and fully processed wafer. To evaluate DC characteristics of these HFETs, I_D-V_{GS} and I_D-V_{DS} of devices were measured. [Fig. 6 (a) and (b)] The device size was 0.5mm x 2mm and the gate length and drain-gate distance were 2μm and 30μm, respectively. Threshold voltages was around 0.7V showing normally-off operation and a current capacity of 5A (V_{GS}=6V) was achieved. Fig. 7 shows uniform breakdown voltage over a 6-inch-wafer and the average value of breakdown voltage and the standard deviation were 1573V and 2.51%, respectively.

4. Conclusion

The relationship between the breakdown voltage or leakage current and the properties of epitaxial layer was investigated experimentally. The lowest leakage current of $5x10^{-9}$A/mm has been achieved with 6.0μm grown GaN on 6-inch Si substrate by carbon doping as a deep acceptor. The breakdown voltage would be increased by increasing the thickness of GaN layer and the amount of deep acceptors up to 1600V.

References

[1] W. Götz, et al., Appl. Phys. Lett. **68** (1996) 3144

[2] Z Li, TP Chow et al., Solid-State Electronics 56 (2011) 112

[3] J. L. Lyons., Appl. Phys. Lett. **97** (2010) 152108-2

[4] R. Armitage., Appl. Phys. Lett. **82** (2003) 3458

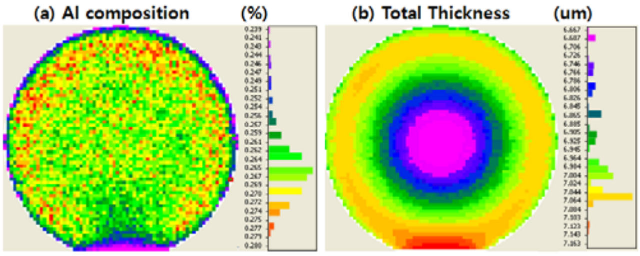

Fig 1. PL Mapping of (a) the Al composition and (b) thickness

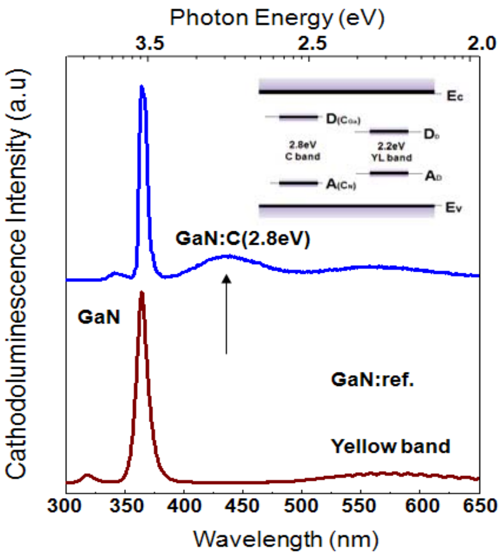

Fig 2. Low-temp.(77K) cathodoluminescence spectra of carbon-doped GaN(top) and UID-GaN(bottom)

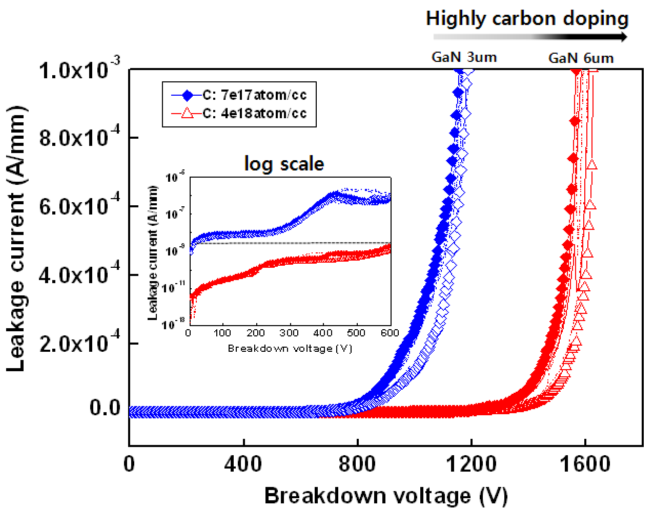

Fig 3. Leakage reduction with carbon concentration and GaN thickness

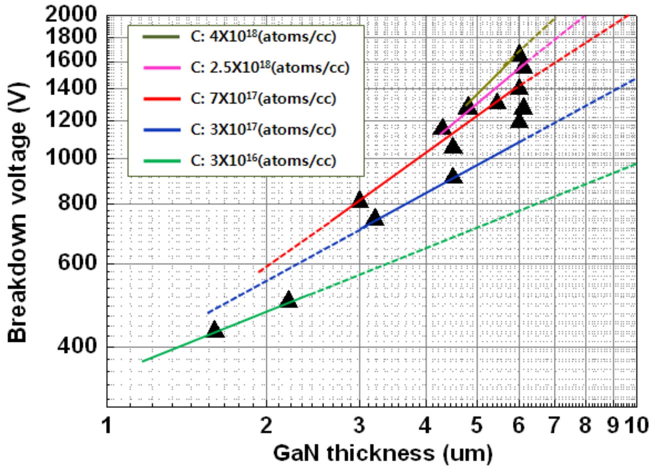

Fig 4. Breakdown voltage with carbon concentration and GaN thickness

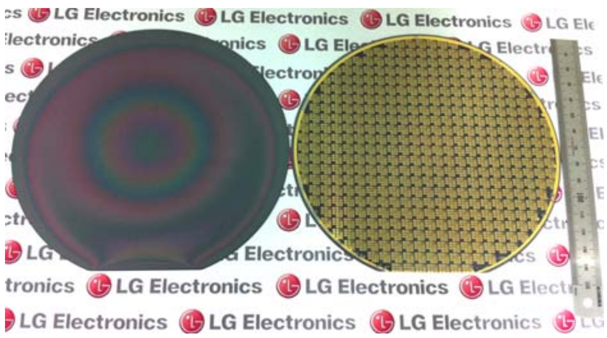

Fig 5. Top view image of crack-free-6μm-thick GaN on 6-inch Si substrate and fully processed wafer

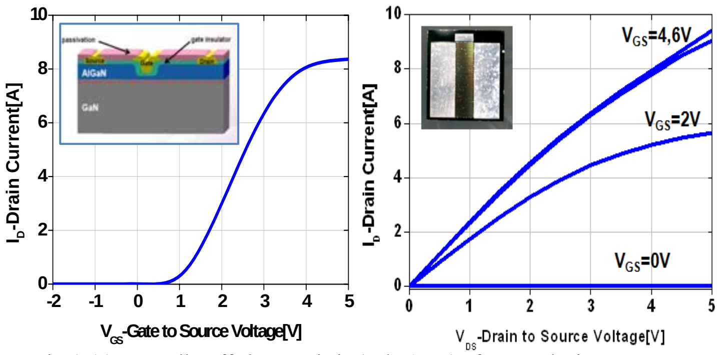

Fig 6. (a) Normally-off characteristic (Vth=0.7V) of HFET device

(b) Output Id-Vd characteristics (Id=5A) of HFET device

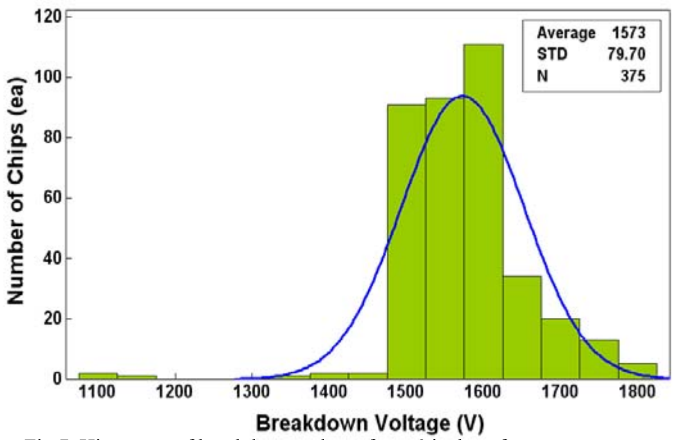

Fig 7. Histogram of breakdown voltage from 6-inch wafer