Extended Abstracts of the 2011 International Conference on Solid State Devices and Materials, Nagoya, 2011, pp206-207

High-Voltage AlGaN/GaN HEMTs on Si Substrate with Implant Isolation

Chen-Ju Yu[1], Chih-Fang Huang[1*], Po-Ju Chu[1], Kuan-Yu Chen[1], Shawn Shuo-Hung Hsu[1], Hsian-Chin Chiu[2], and Feng Zhao[3]

[1]Institute of Electronics Engineering, National Tsing Hua University
Hsinchu 30013, Taiwan, R.O.C.
Phone: +886-3-574-2438 E-mail: cfhuang@ee.nthu.edu.tw
[2]Department of Electronic Engineering, Chang Gung University
Tao-Yuan 33302, Taiwan, R.O.C.
[3]Department of Electrical Engineering, University of South Carolina,
Columbia, SC 29208, U. S. A.

1. Introduction

Gallium nitride (GaN) has attracted attention for high power, high frequency applications [1]. The high critical electric field of GaN enables high voltage (HV) operations. HV GaN devices have been demonstrated on various kinds of substrates including GaN, silicon, silicon carbide, and sapphire. Silicon substrate is considered as the most economically viable option because of the size and the cost of the wafer. 2.45 kV AlGaN/GaN MIS-HFETs on Si were reported with a 7.3 µm epi-layer thickness and mesa isolation [2]. Implant isolation has been proven effective for HV device isolation [3]. In this study, we report experimental results of HV AlGaN/GaN HEMTs on silicon substrate. High breakdown voltages are enabled through Zn implant isolation and a thick voltage supporting layer consisting of a 1.5-µm GaN and a 3.3-µm buffer.

2. Experiments

AlGaN/GaN epi-layers grown on the (111) face of a Si p-type wafer were provided by DOWA. The epi-layer structure was composed of a 1-nm GaN cap, a 20 -nm $Al_{0.25}Ga_{0.75}N$ barrier, a 1.5-µm device layer, and a 3.3-µm buffer layer. The buffer layer was made of nucleation layers and supper lattice structures. All these layers were unintentionally doped. The room temperature 2DEG density was 8.9×10^{12} cm^{-3} and the mobility was 1513 cm^2/Vs. The sample was dipped in diluted hydrochloride acid to remove native oxide. Then, a layer of Ti/Al/Ti/Au was deposited and sintered at 850 °C for 30 seconds to form source and drain contacts. Zn was implanted at room temperature to form device isolation. The implant dose is 2.82×10^{14} cm^{-2} and the implant depth is estimated to be 0.3 µm. A 0.3-µm-thick PECVD oxide was deposited as the field oxide and the passivation layer. The gate and the source/drain windows were etched. A layer of Ni/Au was deposited to form the gate, the pad, and the field plates. A schematic of the device structure is depicted in Fig. 1.

3. Results and Discussion

Fig. 2 illustrates the on-state characteristics of a device with W = 110 µm, L_{ch} = 3 µm, L_{gd} = 40 µm, and L_{fg} = 2 µm. The specific-on resistance is 14.1 mΩ-cm^2. Fig. 3 shows the I_d and I_g versus V_{gs} plot when V_{ds} is 5 V. The extracted threshold voltage is -2.8 V. Fig. 4 summarizes the off-state leakage currents when V_{gs} = -4 V and V_{ds} below 95 V at different temperatures. The drain leakage current is mainly from the gate and it increases monotonically with temperature. These HV HEMTs are tested to breakdown under three different conditions: (1) substrate floating and without fluorinert immersion; (2) substrate floating and with fluorinert immersion; (3) substrate grounded and with fluorinert immersion. Fig. 5 summarizes the measured breakdown characteristics of devices with L_{gd} = 40 µm. The best breakdown voltage (BV) is 2340V when the device is in condition (2). Fig. 6 summarizes the BV and $R_{on,sp}$ of devices with different L_{gd}. BV is limited to around 500 V without fluorinert. With fluorinert and substrate grounded, BV is limited to about 1300 V in the vertical direction with a critical electric field about 2.7 MV/cm. With fluorinert and substrate floating, BV is extended 2340 V.

4. Conclusions

This paper reports the fabrication and the characterization of high-voltage AlGaN/GaN HEMTs on Si with Zn implant isolation. A BV of 2340V was achieved on a device where L_{gd} = 40 µm using fluorinert immersion and a floating substrate. The $R_{on,sp}$ of this device is 14.1 mΩ-cm^2, resulting in a $BV^2/R_{on,sp}$ of 388 MW/cm^2. This study shows that breakdown voltage is limited in the vertical direction, and the Schottky gate is responsible for the drain leakage current in these devices at both high voltages and high temperatures.

Acknowledgements

The authors are grateful to National Nano Device Laboratories and National Tsing Hua University Center for Nanotechnology, Materials Science, and Microsystems. This work is supported by National Science Council of Taiwan, R. O. C. under Contract No. NSC 99-2218-E-007-004 and NSC 100-3113-E-007-006.

References

[1] U. K. Mishra et al., Proc. IEEE **90** (2002) 1022.
[2] W. Saito et al., Jpn. J. Appl. Phys. **43** (2004) 2239.
[3] N. Ikeda et al., *Proceedings ISPSD* (2009) 251.

[4] D. Visalli et al., Jpn. J. Appl. Phys. **48** (2009) 04C101.
[5] A. M. Ozbek et al., IEEE Electron Device Lett. **32** (2011) 300.

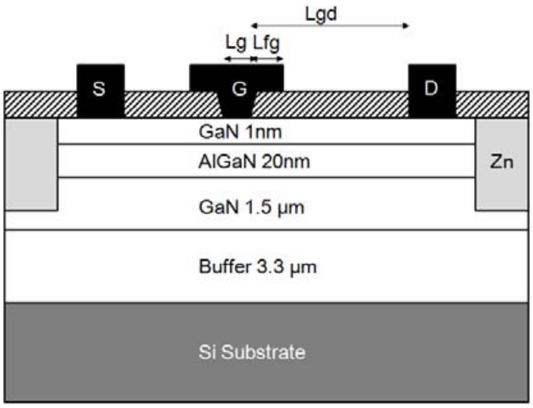

Fig. 1 Device structure of a high-voltage AlGaN/GaN HEMT on a p-type Si substrate

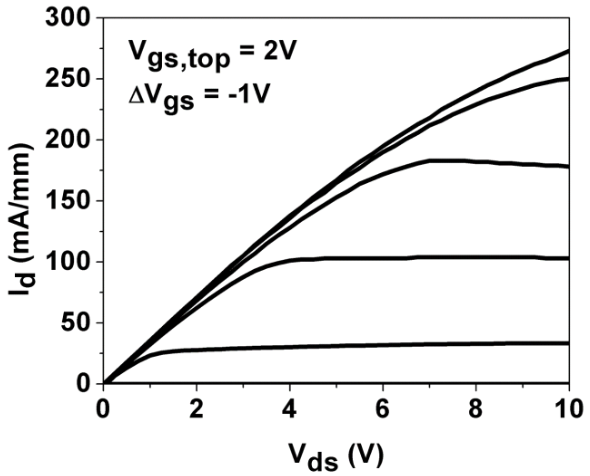

Fig. 2 On-state characteristics of a device with W = 110 μm, L_g = 3 μm, L_{gd} = 40 μm, and L_{fg} = 2 μm.

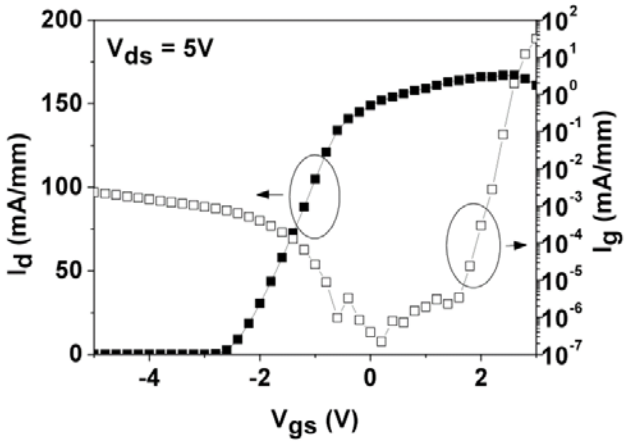

Fig. 3 I_d-V_{gs} and I_g-V_{gs} plots of the device in Fig. 2

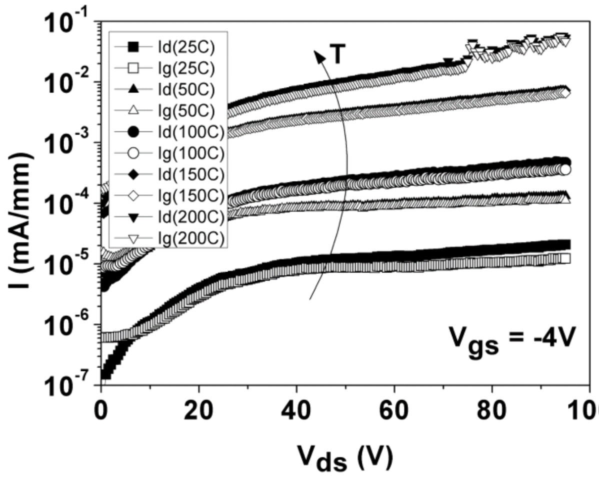

Fig. 4 Leakage current at different temperatures when $V_{ds} \leq 95$ V and V_{gs} = -4 V.

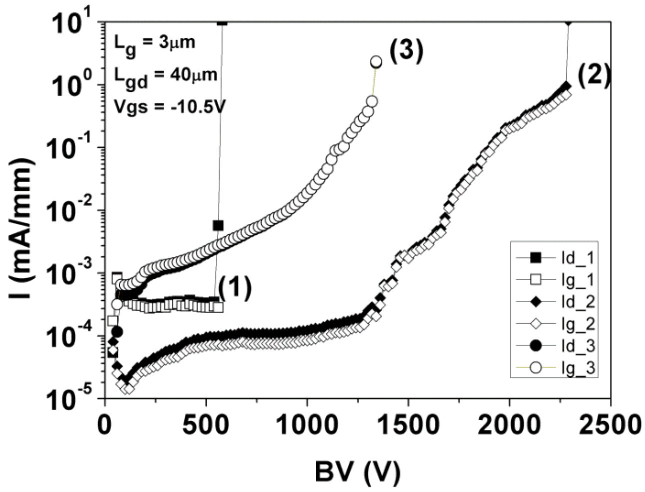

Fig. 5 Breakdown characteristics for L_{gd} = 40 μm devices under different test conditions: (1) substrate floating and without fluorinert; (2) substrate floating and with fluorinert; (3) substrate grounded and with fluorinert.

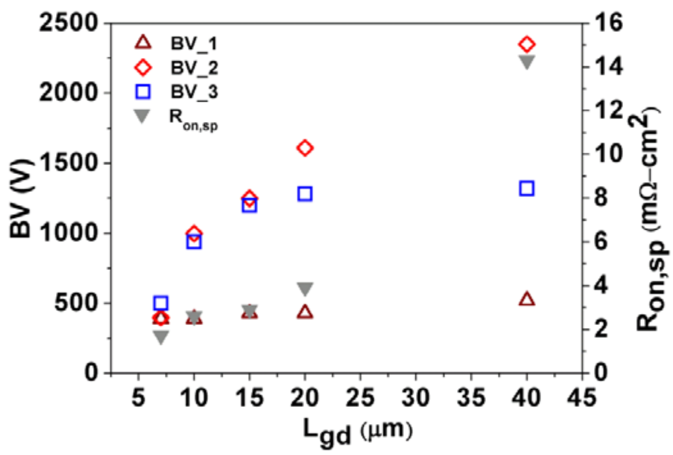

Fig. 6 A summary of breakdown voltages under different test conditions and $R_{on,sp}$ for devices with different L_{gd}.