Extended Abstracts of the 2007 International Conference on Solid State Devices and Materials, Tsukuba, 2007, pp. 162-163

G-2-2

Reduced gate leakage for AlGaN/GaN HEMTs grown on a-plane $(11\bar{2}0)$ sapphire

S. Lawrence Selvaraj[1] and Takashi Egawa[2]

Research Center for Nano-Device and System, Nagoya Institute of Technology, Showa-Ku, Gokiso-Cho,

Nagoya 466-8555, Japan

Phone: +81-52-735-5540 Fax: +81-52-735-5546

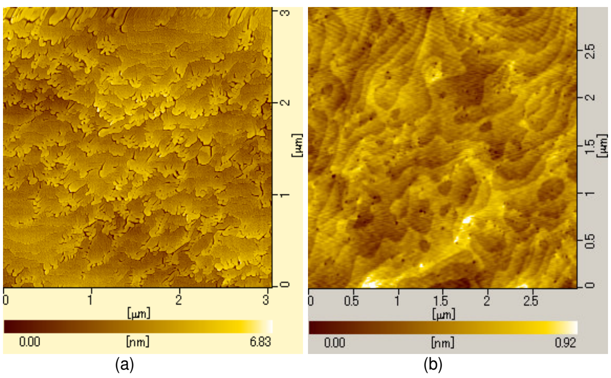
Email : [1]slselvaraj@yahoo.com [2]egawa.takashi@nitech.ac.jp

1. Introduction

The majority of the GaN based device structures were grown on (0001) c-plane sapphire substrates. Currently there have been reports on the growth of GaN on a-plane and r-plane sapphire using MBE and MOCVD [1]. It is difficult to grow high-quality GaN on a-plane than on c-plane sapphire. Koike et. al [2] have demonstrated a ZnMgO/ZnO heterostructure field-effect transistor on a-plane sapphire. But no report is available to this day, about the device characteristics of GaN based transistors grown on a-plane sapphire substrates. Hereby we report the HEMT device properties of AlGaN/GaN HEMTs grown on $(11\bar{2}0)$ a-plane sapphire substrate by metalorganic chemical vapour deposition (MOCVD).

2. AlGaN/GaN HEMTs on a-plane sapphire

The heterostructures (HSs) 25 nm i-$Al_{0.26}Ga_{0.74}N$/3µm i-GaN/25 nm LT GaN were grown on commercially available 4 in. a-plane and c-plane sapphire. The AFM picture (Fig. 1) shows the surface morphology of the AlGaN/GaN HSs grown on (a) c-plane and (b) a-plane sapphire. The AFM picture for the HSs on a-plane has smooth morphology than the HSs on c-plane sapphire. The root mean square (RMS) surface roughness and peak-valley (*P-V*) distance values listed in table I indicates that the surface morphology of the growth was improved for a-plane sapphire. It is also found in the literature that the GaN growth on the a-plane sapphire has the best morphology when compared to the growth over c-plane and r-plane sapphire [3]. The XRD spectrum measurements on the structures also found that the crystalline quality of the



(a) (b)

Fig. 1. AFM picture of the surface of AlGaN/GaN heterostrure on (a) c-plane and (b) a-plane 4-inch Sapphire: Scan area 3×3um²

Table I. XRD, surface, HALL and device properties of AlGaN/GaN HEMTs on c-plane and a-plane sapphire

Parameters	c-plane	a-plane
FWHM (arc. sec): (0004)	277	241
FWHM (arc. sec): $(20\bar{2}4)$	1158	543
P-V (nm)	11.43	1.75
RMS roughness (nm)	0.998	0.128
I_{DSmax} (mA/mm)	384	510
g_{mmax} (mS/mm)	154	115
V_{th} (V)	-2.2	-3.6
R_s (Ω.mm)	2.03	4.56
$N_{D\text{-}2DEG}$ (x 10^{20} cm^{-3})	1.4	1.9
$I_{g\text{-leak}}$ (mA/mm)	7.3 x 10^{-4}	7.1 x 10^{-6}
μ_H (cm^2/V.s)	985	1070
n_s (×$10^{13}$$cm^{-2}$)	1.17	0.907

growth improved for the AlGaN/GaN HSs when they are grown over a-plane sapphire [4].

The MOCVD grown samples on a- and c-plane sapphire were subjected to HEMT device process simultaneously. The devices were passivated with 100 nm SiO_2 deposited by electron beam evaporation method. Ohmic contacts (Ti/Al/Ni/Au) patterned using lithography, annealed at N_2 ambient at 775 °C, followed by gate metal contact (Pd/Ti/Au). The I_{DS}-V_{DS}, two terminal gate leakage measurements were carried out using Agilent 4156c semiconductor parameter analyzer.

The dc I_{DS}-V_{DS} measurement shown in Fig. 2 illustrates that there is an enhancement of drain current density for the HEMTs grown on a-plane sapphire. Though Fig. 2 shows the I_{DS}-V_{DS} curves for V_G starting at +1.5 V, a-plane grown HEMTs are operational even at high gate voltage (V_G = +2.5V) without gate leakage. On the contrary the HEMTs on c-plane sapphire shows large gate leakage for V_G = +2.5V, thereby restricting the gate voltage operation for c-plane HEMTs. This indicates that HEMTs grown on a-plane sapphire has large gate voltage swing over the HEMTs on c-plane sapphire. The enhanced carrier concentration reduces the transconductance maximum [5] for a - plane HEMTs. The device threshold voltage for the HEMTs have negative shift probably due to the enhanced carrier density. The 2DEG carrier concentration measured from *C-V* also confirms the increased carrier density for the HEMTs on a-plane sapphire.

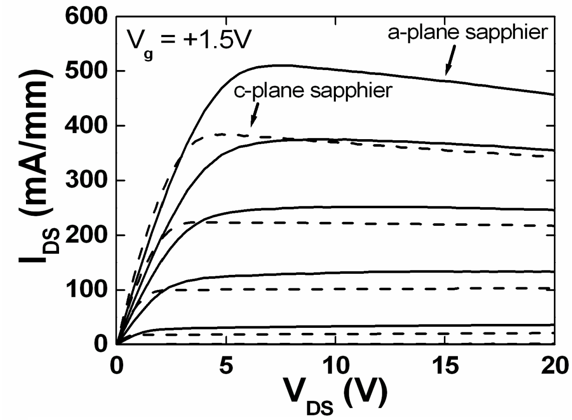


Fig. 2. dc I_{DS}-V_{DS} measurements for 15 μm HEMTs

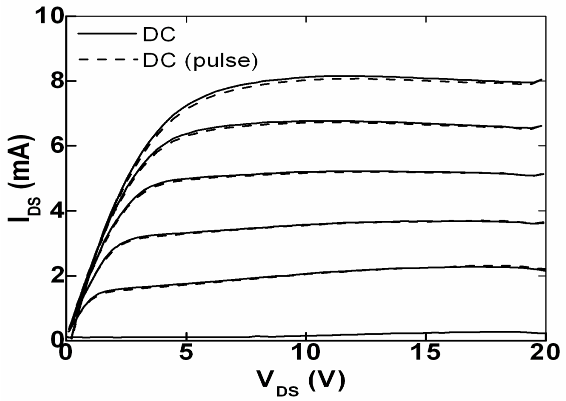


Fig. 4. dc-current collapse for HEMTs on a-plane sapphire

Thus improving the surface morphology which reduces the interface states yields a high electron concentration at the 2DEG channel [6].

The two terminal gate leakage measurements for the 200 μm HEMTs on the a-plane sapphire shows about 2 orders of magnitude decrease in gate leakage. As the surface of GaN grown on a-plane has the best morphology [3], this eliminates surface trapping which is one of the cause for gate leakage. The morphology of the HEMTs on a-plane in the present growth is good compared to that on c-plane sapphire. Therefore the excellent surface morphology of the AlGaN/GaN growth on a-plane is the reason behind gate leakage reduction

The current collapse measurements of the devices were measured using Sony Tektronix 370A. SiO_2 passivated AlGaN/GaN HEMTs undergo severe current collapse as reported by many in the literature. But the AlGaN/GaN HEMTs grown on a-plane sapphire are found to be current collapse free as it can be seen from Fig. 4. The lattice mismatch of GaN grown on a-plane is smaller than grown on c-plane sapphire [1]. This eliminates the possibility of trapping at the interstates which is one of the cause for severe current collapse.

The Hall measurements listed in table I illustrates that mobility is high for the AlGaN/GaN on a-plane. Reduced

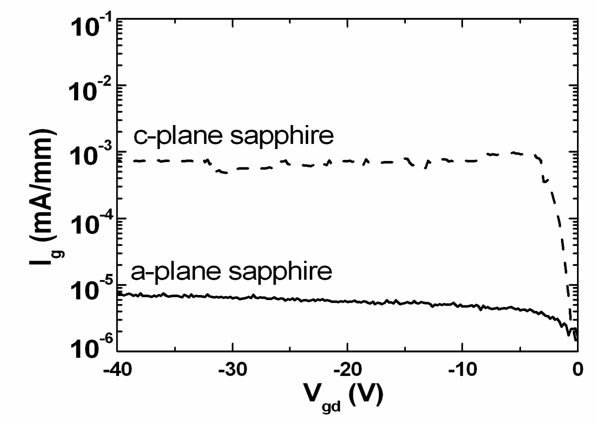


Fig. 3. Two terminal gate leakage measurements

interface scattering at the heterostructure brings an increase in the mobility. In general we found that the morphology of the GaN growth was greatly improved over the a-plane sapphire. The reduced surface roughness and high crystalline nature are the important factors behind demonstrating an ideal device which are free from drain current collapse and gate leakage. As the GaN HEMTs on a-plane sapphire meet those requirements, the use of a-plane sapphire as substrate for future devices is recommended.

3. Conclusions

AlGaN/GaN HEMTs were grown on a-plane sapphire substrates and the morphology and device performance are compared to that of the HEMTs grown on c-plane sapphire. The GaN growth on a-plane has the best surface morphology with reduced surface roughness. The HEMTs on a-plane shows increase in drain current density with two order of magnitude less gate leakage. The a-plane HEMTs are free from drain current collapse due to reduced lattice mismatch of GaN during growth. The a-plane sapphire substrates could be used as an alternate for c-plane sapphire in device structures to overcome the existing problems in the III-Nitride based devices.

Acknowledgements

We would like to thank T. Iwasaki for his help in the MOCVD growth. One of the authors (SLS) thank the Venture Business Laboratory for the research fellowship.

References

[1] D. Doppalapudi, E. Iliopoulos, S. N. Basu and T. D. Moustakas, J. Appl. Phys. 85 (1999) 3582.
[2] K. Koike, I. Nakashima, K. Hashimoto and S. Sasa, Appl. Phys. Lett. **87** (2005) 112106.
[3] T. D. Moustakas, T. Lei and R. J. Molnar, Physica B **185** (1993) 36.
[4] S. Arulkumaran et. al., to be published
[5] S. L. Selvaraj and T. Egawa, Appl. Phys. Lett. **89** (2006) 193508.
[6] S. L. Selvaraj, T. Ito, Y. Terada and T. Egawa, Appl. Phys. Letts. 90 (2007) 173506.