Extended Abstracts of the 2009 International Conference on Solid State Devices and Materials, Sendai, 2009, pp234-235

Effect of GaN Growth Pressure on the Device Characteristics of AlGaN/GaN HEMTs on Silicon

Josephine Selvaraj*, S. Lawrence Selvaraj and Takashi Egawa

Research Center for Nano-Device and System, Nagoya Institute of Technology,
Gokiso-cho, Showa-ku, Nagoya 466-8555, Japan.
Phone: +81-52-735-5094; Fax: +81-52-735-5546; *E-mail: josephine.selvaraj@gmail.com

1. Introduction

So far there are profound reports on the relationship of growth pressure to the optical, structural and doping compensation of GaN.[1)] Reduced GaN growth pressures has been of considerable interest because of the effect of excess carbon and oxygen incorporation which is important in forming semi-insulating and highly resistive buffer layers.[2)] Besides the fact that resistivity of GaN can be easily controlled by varying the deposition chamber's pressure there have also been techniques involving an intentional carbon doping source for achieving reduced buffer leakage, high breakdown voltages (BV) for high power applications of high-electron-mobility-transistors (HEMTs).[3,4)] However there are only a few reports available on AlGaN/ GaN HEMTs influenced by unintentionally doped buffer layer. Here in this work we have shown significant results for the effect of GaN growth pressure on the characteristics of AlGaN/ GaN HEMTs. By lowering the growth pressure, we have obtained high resistive GaN buffer layers which served as an important element for obtaining reduced buffer leakage over one order of magnitude as well as enhanced BVs up to ~ 480 V.

2. Experiment

The common schematic showing the subsequent layers of fabricated $Al_{0.26}Ga_{0.74}N$/GaN heterostructures on 4 inch Si substrates is shown in Fig. 1. During the growth of 1.5 µm thick GaN buffer layer the metalorganic chemical vapor deposition (MOCVD) reactor pressure was adjusted to one of the pressures namely 760/600/300/200/100 Torr to produce five different samples respectively.

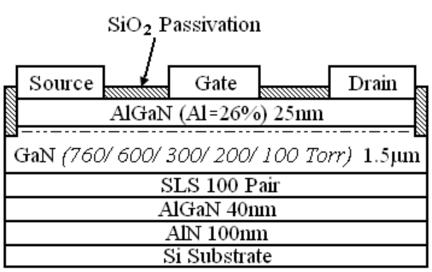

Fig. 1. Common layout of the fabricated AlGaN/GaN HEMTs.

Hall measurements were carried out using indium contacts and van der pauw geometry. Fig. 2a) shows the electron mobility decreasing along with growth pressure meanwhile Fig. 2b) shows a sharp increase in resistivity for the 100 Torr sample. The carrier density reduces nearly 1.4 % with every 100 Torr. SIMS analysis done for the unintentionally doped 200 Torr and 760 Torr samples revealed that the carbon concentration was about 2.8×10^{17} cm^{-3} and 1.4×10^{17} cm^{-3} respectively; and the oxygen concentration was nearly 5.5×10^{16} cm^{-3} and 2.0×10^{16} cm^{-3} respectively. Therefore growth conditions which produce a highly resistive and semi-insulating buffer layer usually enhance dislocation formation and are harmful to the channel conductivity. The Hall measurement results suggest the influence of the insulating property of the thick GaN buffer layer on the transport characteristics of samples of ≤100 Torr growth pressures.

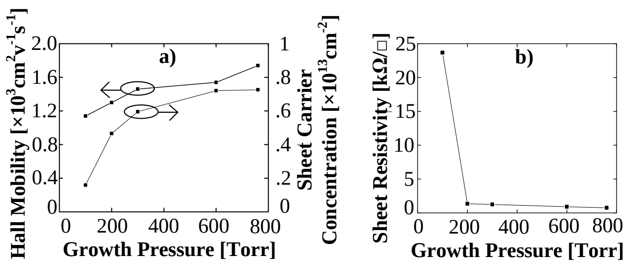

Fig. 2. Dependence of **a)** Hall mobility; Sheet carrier concentration and **b)** Sheet resistivity on GaN growth pressures.

3. Results and Discussion

The atomic-force-microscope (AFM) images of the AlGaN surface were studied to understand the surface morphology. The shallow pit density of the 760 Torr and 100 Tor samples are 7.6×10^9 cm^{-2} and 3.5×10^9 cm^{-2} respectively. The 760 Torr sample exhibits a higher root-mean-square roughness (0.4 nm) when compared to the 100 Torr sample (0.2nm). Previous works have shown that an increase in deposition pressure of the GaN buffer layer results in larger grain growth. This has reflected as increased roughness in the top surface of the sample.[1)] Room temperature photoluminescence spectra of band-emission (I_{BE}) and yellow luminescence (I_{YL}) for each of the samples will be presented during the conference. Yellow luminescence emission was detected around 500 nm (~photon energy of 2.48 eV), and it could be related to C related defects and/or impurities.[5)] As shown in Fig. 3a), with decreasing growth pressure there is an increasing trend in the (I_{YL}/ I_{BE}) ratio. This might be a result of degraded free carrier emission and increased dislocation density. HEMTs were successfully fabricated using the five different samples and the device characteristics are shown in Fig. 3b). The fabricated devices exhibited good pinch off characteristics. It was observed that the maximum drain current density (I_{Dmax}) and maximum transconductance (g_{mmax}) severely degraded for 100 Torr sample. This could also be due to the predicted increase in the dislocation density at lower growth pressures. The insulating property of the thick underlying GaN buffer layer is the key to eliminating the channel conductance at the interface. As shown in Fig 3a) it was also found that the sharp increase in R_d for the 100 Torr sample was mostly accompanied by a sharp increase in the channel resistance. Fig 4a) shows that the threshold voltage increases positively as growth pressure decreases. The AC I_{DS}-V_{DS} characteristics of 15 µm gate width (W_g) and 2 µm gate length (L_g) for all the AlGaN/GaN HEMTs are shown in Fig. 4b). The frequency of the AC current collapse measured using SONY Tektronix Curve Tracer was 120Hz. The increase in I_D collapse is due to the increase of collapse related traps by lowering the GaN growth pressure. The magnitude of current collapse also varied in proportion to (I_{YL}/ I_{BE}) suggesting that the defects causing YL in low growth pressure samples might be strongly related to the severe current collapse.[5] Fig. 5a) and b) shows the BVs of i-GaN at 10µm ohmic gap and the three terminal BV characteristics of the fabricated 15 µm width devices for all samples respectively. For example in the 200 Torr sample we have thus obtained without intentional doping of GaN, an off-state BV of nearly 420 V and I_{Dmax} of 314 mA/mm. There is also a significant decrease in the buffer leakage over one order of magnitude. The combination of the low leakage current of GaN and the observation of lower carrier density suggests the semi-insulting nature of GaN in the 100 Torr sample when compared with the conventional 760 Torr sample.

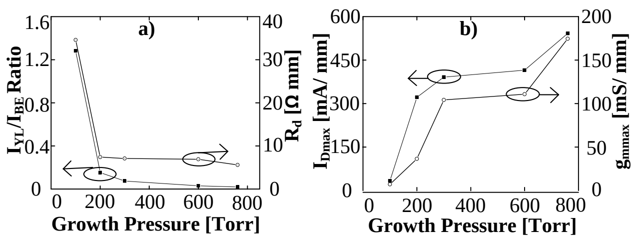

Fig. 3 a) I_{YL}/ I_{NBE} ratio correlated with R_d; **b)** Current-Voltage characteristics for all samples. (W_g / L_g/ L_{gd} = 15/ 2/ 4 µm).

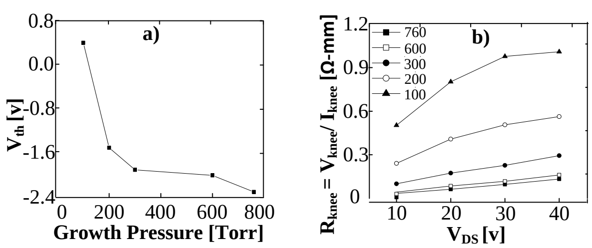

Fig. 4 a) Threshold voltage; and **b)** Knee resistance as a function of drain-source voltage.

4. Conclusion

The trend observed in the important device characteristics of AlGaN/ GaN HEMTs with respect to the GaN growth pressure is listed in Table 1. The unintentionally doped 100 Torr sample showed a high BV and a significant decrease in the buffer leakage over one order of magnitude. However the degradation of device performance and severe current collapse could be strongly associated with increasing resistive nature of GaN. Therefore compromises in the choice of growth pressure need to be made. From the demonstrated AlGaN/ GaN HEMT performance results, the dependence of channel conduction on growth pressure of GaN was understood.

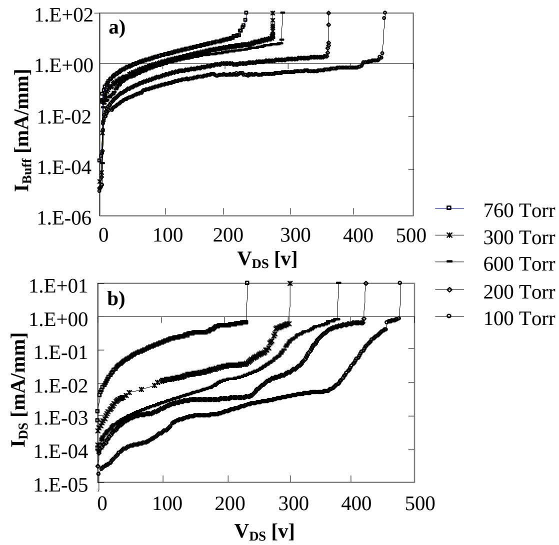

Fig. 5a) The BVs of i-GaN at 10 µm ohmic gap; and **b)** Off-state three terminal BVs for all samples. (W_g / L_g/ L_{gd} = 15/ 2/ 4 µm).

GaN Growth Pressure	C_{12}; O_{16} Density	BV	Current Collapse	Vth
760 Torr	Low	Low	Low	- 2.3
~	~	~	~	~
100 Torr	High	High	High	+ 0.4

Table 1. The trend observed in this work.

Acknowledgements

We would like to thank Mr. Y. Nomura and Dr. T. Ito for helping us in growth and measuring SIMS profile of the samples.

References

[1] C. Jun, Z. Shuming, Z. Shuming, Z. Baoshun, Z. Jianjun, F. Gan, D. Lihong, W. Yutian, Y.Hui and Z. Wenchen: SCIENCE IN CHINA (Series E), **46** (2003) 620-626.
[2] A. E. Wickenden, D. D. Koleske, R. L. Henry, M. E. Twigg and M. Fetemi: J.Crystal Growth **260** (2004)54-62.
[3] Y. C. Choi, M. Pophristic, B. Peres, M. G. Spencer and L.F. Eastman: J.Vac. Sci. Technol. B.**24** (6) (2006).2601-2605.
[4] S. Kato, Y. Satoh, H. Sasaki, I. Masayuki, S. Yoshida: J. Crystal Growth **298** (2007) 831-834.
[5] H. Fujimoto, W. Saito, A. Yoshioka, T. Nitta, Y. Kakikuchi and Y. Saito: CS MANTECH Conference April 14-17 (2008) Chicago, Illinois, USA.