MOCVD Growth of AlGaN/GaN Heterostructures on 150 mm Silicon

Jie Su*, Hongwei Li, Seungjae Lee, Balakrishnan Krishnan, Dong Lee, George Papasouliotis, and Ajit Paranjpe

Veeco MOCVD Operations, 394 Elizabeth Avenue, Somerset, NJ 08873, USA
*Phone: (732) 560-5300, Email: jsu@veeco.com

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Abstract

Growth of crack-free AlGaN/GaN heterostructures on 150mm Si by metal-organic chemical vapor deposition is presented. The two-dimensional-electron-gas is formed at the AlGaN/GaN interface. Average Hall mobility values are more than 2000 cm^2/V.s and sheet resistance less than 400 Ohm/sq with a 1nm AlN spacer. Run-to-run repeatability of AlGaN/GaN structural qualities, wafer bow, and 2DEG properties shows the potential manufacturing possibility.

INTRODUCTION

Due to the low cost and availability of Si substrates with larger diameters (> 150 mm) compared with sapphire and SiC substrates, AlGaN/GaN based High Electron Mobility Transistors (HEMTs) on Si have emerged as a promising candidate for high frequency power amplification and high voltage power switching applications.

With the large mismatch of lattice constant and thermal expansion coefficients between Si and GaN, epitaxy on Si leads to problems such as cracks and high density misfit and threading dislocations. Many techniques have been utilized to relieve the stress and create crack-free GaN on Si, such as low-temperature AlN layer [1], graded AlGaN buffer layers [2-3], AlN/GaN superlattices [4], SiC intermediate layer [5], and SiN interlayer [6]. In addition, large wafer bow caused by the compressive stress from GaN during growth hinders the uniform temperature control across the wafer, which results in the non-uniform composition/thickness, layer stress and device performance. With the growth challenges of heteroepitaxy of GaN on Si, device quality GaN and manufacturability have to be demonstrated for the potential mass production and broad applications of AlGaN HEMTs on Si.

EXPERIMENTAL RESULTS AND DISCUSSION

Here we report the growth of crack-free AlGaN/GaN heterostructures on 150 mm (111) oriented silicon substrates by metal-organic chemical vapor deposition (MOCVD). The epitaxy process is carried out in a 5x150mm multi-wafer Veeco Turbodisc K465i production MOCVD system equipped with a DRT-210 *in-situ* process monitor (integrated pyrometer-reflectometer-deflectometer unit) for wafer temperature, reflectance and wafer curvature.

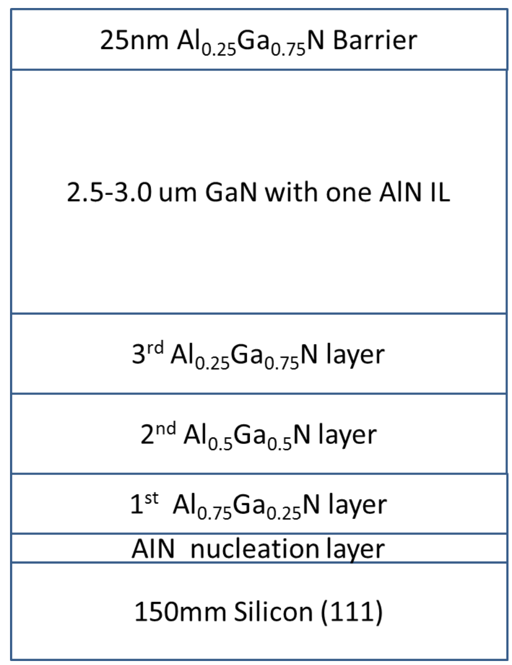

Fig. 1: Schematic of AlGaN/GaN heterostructures on 150 mm (111) Si

The schematic of the AlGaN/GaN heterostructure is shown in Fig. 1. The growth does not require any pre-growth wafer conditioning. The starting Si wafer is first annealed at 1050 °C under hydrogen ambient for about 5 min, which is followed by the pre-flow of TMAl without the presence of ammonia. The buffer layers consist of a 100-200 nm AlN nucleation layer and three step-graded $Al_xGa_{1-x}N$ intermediate layers with x=0.75, 0.5, and 0.25. The total thickness of the three $Al_xGa_{1-x}N$ layers is ~800 nm. The growth conditions for AlN and AlGaN buffer layer are above 1000 °C at a pressure of 75-100Torr. About 2-3 μm GaN layer is grown on top of the AlGaN buffer layers with one optional stain-relieving AlN interlayer. The unintentionally doped $Al_{0.25}Ga_{0.75}N$ barrier layer is grown without a GaN cap in order to inspect the AlGaN surface morphology. An optional 1-nm thick AlN spacer can be inserted between the AlGaN/GaN interfaces to improve the performance of the two-dimensional electron gas (2DEG).

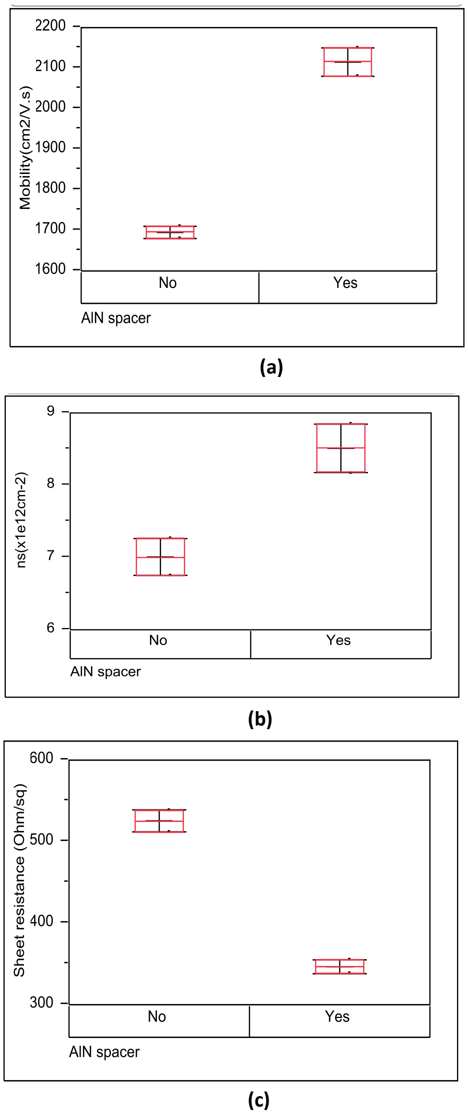

Fig. 2: Electrical properties of the two-dimensional-electron-gas of AlGaN/GaN heterostructures with and without 1nm AlN spacer. (a) Mobility, (b) Sheet carrier concentration, (c) Sheet resistance

The crystalline quality of GaN layer is measured using high resolution X-Ray Diffraction (HRXRD) for (002) symmetrical and (102) asymmetrical Bragg reflections. The thickness of epilayers is measured by white light interference and Al composition by photoluminescence. The surface morphology of the AlGaN is studied by Atomic Force Microscope (AFM), and the electrical properties of the 2DEG are evaluated by Van der Pauw-Hall measurement using indium dots as the Ohmic contact.

As grown AlGaN/GaN heterostructures are uniform and free of cracks from the edge to the wafer center. Typically uniformity of <1.5%, 1σ is measured for thickness, and uniformity of <1.5%, 1σ for Al composition. For a 25nm $Al_{0.25}Ga_{0.75}N$ barrier, the AlGaN/GaN heterostructure exhibits an average 2DEG mobility (μ_H) > 1500 cm^2/V.s, sheet carrier concentration (n_s) >6.0x$10^{12}cm^{-2}$, and an average sheet resistance (R_{sh}) <600 Ohm/sq. With the insertion of a 1nm AlN spacer at the AlGaN/GaN interface, the average mobility μ_H is >2000 cm^2/V.s, n_s >8.0x$10^{12}cm^{-2}$, and R_{sh} <400 Ohm/sq, as shown in Fig. 2 (a), (b) and (c). The enhancement of 2DEG performance compared to those without AlN spacer could be due to the produced large effective conduction band offset between AlGaN and GaN (ΔE_c), reduction of the alloy disorder scattering, and improved polarization. [7]

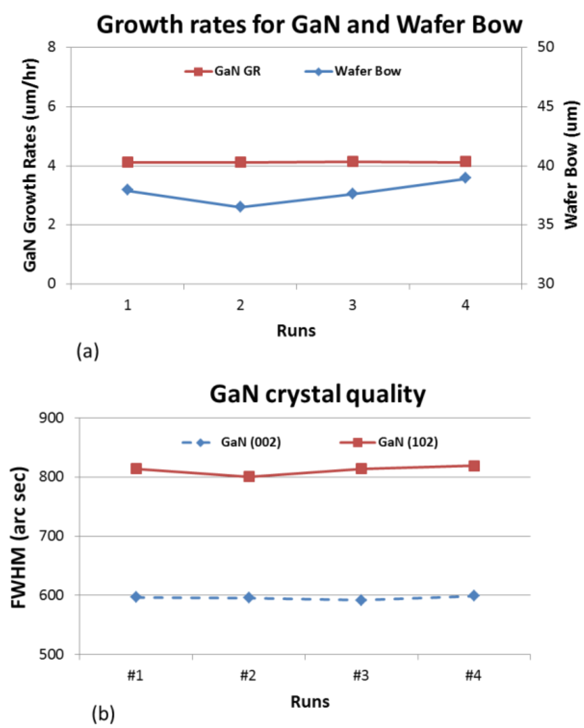

Fig. 3: Run-to-run repeatability for AlGaN/GaN heterostructures without AlN spacer. (a) Growth rates of GaN and wafer bow, (b) GaN crystal quality of FWHM (002) & FWHM (102)

Fig. 3 shows the Run-to-run (RtR) repeatability for the AlGaN/GaN heterostructures without AlN spacer. The growth rates of GaN show variation of < 0.3%, 1σ from the 4 repeat runs. The GaN crystalline quality is analyzed by HRXRD. The full width at half maximum (FWHM) for rocking curves of (002) and (102) diffraction planes of GaN show an average of 595 and 812 arc sec, with variation of

<1.2%, 1σ. The wafer bows are consistently <50um measured at room temperature for the ~3µm stack. The *in-situ* measurement shows repeatable reflectivity and wafer curvature for all the runs. The reflectivity of the repeat runs is shown in Fig. 4.

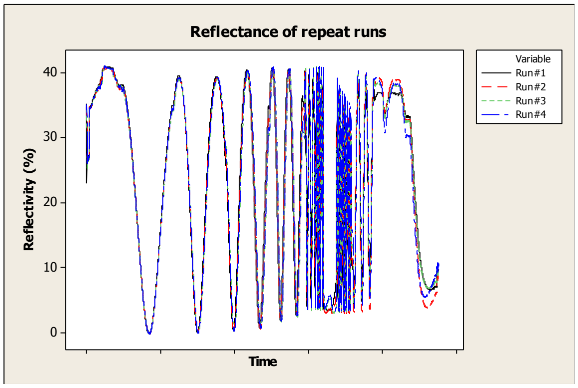

Fig. 4: Run-to-run repeatability of *in-situ* reflectance measured by DRT for AlGaN/GaN heterostructures

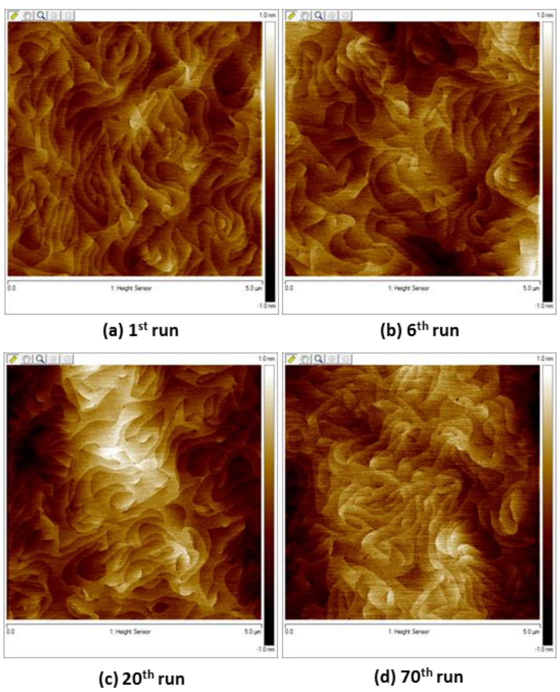

Fig. 5: 5µmx5µm AFM images of repeat runs of AlGaN heterostructures

The surface morphology of the AlGaN barrier without AlN spacer is shown in Fig. 5 (a)-(d) for the repeat runs (within 70 continuous runs without chamber opening). The AlGaN surface shows no micro-cracks and a step-flow feature comparable to the surface of the underlying GaN layer, indicating the pseudomorphic growth of AlGaN with less strain relaxation. The root-mean-square (RMS) roughness is around 0.2-0.4 nm in a 5µmx5µm scanned area.

Hall measurement is done on three points on the wafer from the center to the edge. The typical values of mobility, sheet carrier concentration, and sheet resistance across the wafer show variation of <10%, 1σ. Hall measurement for these AlGaN/GaN heterostructures without AlN spacer show comparable mobility, sheet carrier concentration, and sheet resistance, as show in Fig. 6 (a), (b), and (c).

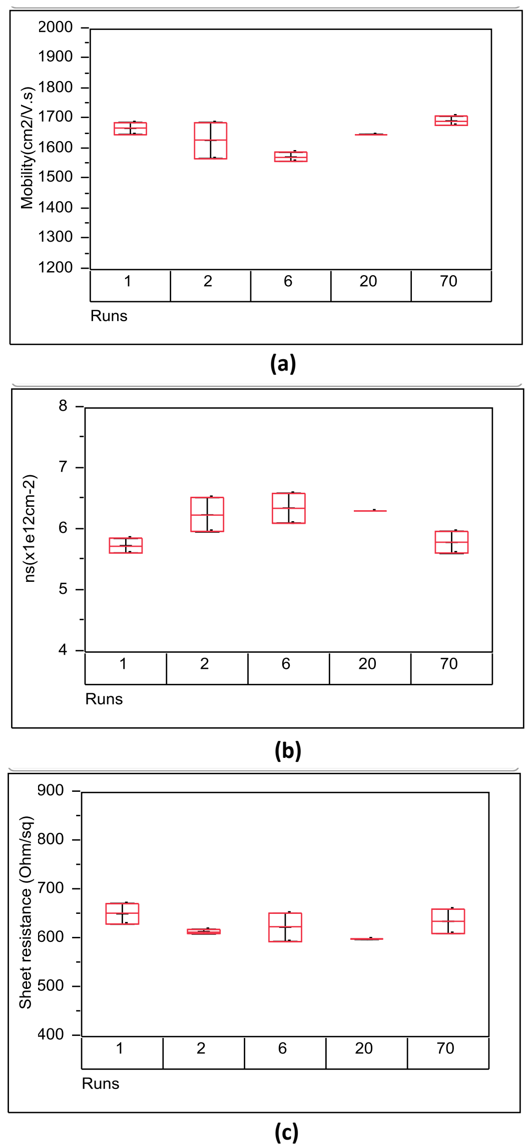

Fig. 6: 2DEG performance of repeat runs of AlGaN heterostructures without AlN spacer. (a) Mobility, (b) Sheet carrier concentration, (c) Sheet resistance

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CONCLUSIONS

In summary, we report here the MOCVD growth of crack-free AlGaN/GaN heterostructures on 150 mm silicon by MOCVD. The AlGaN/GaN heterostructures show high 2DEG mobility > 2000 cm^2/V.s, low sheet resistance < 400 Ohm/sq with a 1nm AlN spacer. Good run-to-run repeatability of AlGaN/GaN structural qualities, wafer bow, and 2DEG properties shows the possibility of using Si as platform for the manufacturing of AlGaN/GaN based HEMT devices.

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REFERENCES

[1] A. Dadgar, J. Blasing, A. Diez, A. Alam, M. Heuken, and A. Krost, Jpn. J. Appl. Phys. 39, L1183, 2000

[2] H. Marchand, L. Zhao, N. Zhang, B. Moran, R. Coffie, U. Mishra, J. Speck, S. DenBaars, and J. Freitas, J. Appl. Phys. 89, pp7846, 2001

[3] A. Able, W. Wegscheider, K. Engl, and J. Zweck, J. Crystal Growth, 276, pp415, 2005

[4] E. Feltin, B. Beaumont, M.Laugt, P. de Mierry, P. Vennegues, H. Lahreche, M. Leroux, and P. Gibart, Appl. Phys. Lett. 79, pp3239, 2001

[5] J. Komiyama, Y. Abe, S. Suzuki, and H. Nakanishi, J. Appl. Phys. 100, pp033519, 2006

[6] K.Cheng, M. Leys, S. Degroote, M. Germain, and G. Borghs, Appl. Phys. Lett. 92, pp192111, 2008

[7] S. Tan, T. Suzue, S. Selvaraj, and T. Egawa, Jpn. J. Appl. Phys. 48, pp111002, 2009

ACRONYMS

MOCVD: Metal-Organic Chemical Vapor Deposition
HEMT: High Electron Mobility Transistors
2DEG: Two-Dimensional Electron Gas
AFM: Atomic Force Microscope
HRXRD: High Resolution X-Ray Diffraction
PL: Photoluminescence
FWHM: Full Width at Half Maximum
RMS: Root-Mean-Square
RtR: Run-To-Run