GaN-HEMT on 100mm Diameter Sapphire Substrate Grown by MOVPE

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Abstract

Possibility of using GaN-HEMT grown by MOVPE on 100mm sapphire substrates in the industry has been investigated. Bowing of 2μm thick GaN on 100mm substrate was 40 to 60 μm. Excellent uniformity of sheet carrier concentration of HEMT structure wafer across the wafer was obtained by optimizing the gas flow system and thermal circumstance to avoid pre-reaction between Ammonia and III group gases. FETs with 0.8μm gate were well fabricated in spite of the bowing and good pinch-off characteristics and high breakdown voltage over 100V was obtained. Standard deviation of Vth was 50mV across the wafer (average Vth=-2.6V), that of Idss and Gm-max were 11mA (average Idss=300mA/mm) and 5.3mS (average Gm-max=145mS /mm), respectively. This uniformity is good enough for mass production. These results are very encouraging as they show the high possibility to successfully achieve mass production of 100mm wafers.

INTRODUCTION

GaN-HEMT is a promising device for high power applications such as base stations for cellular phones. Currently, 50mm diameter wafers are mainly used. However, this small size has limitations, not only for mass volume production but also accuracy, variety and speed of device fabrication process on general development. This is because very few production lines can handle 50mm diameter wafers and most good process machines with high accuracy and controllability are those for manufacturing wafers of over 75mm in diameter, preferably 100mm. Thus, for practical purposes a large diameter wafer is very important for development of GaN-HEMT and, of course, for low cost manufacturing. In this paper, the properties and device performance of GaN-HEMT epi-wafers grown on 100mm sapphire substrate have been researched to explore the possibility of using 100mm wafers in the industry.

EPITAXIAL GROWTH AND DEVICE FABRICATION

A GaN single layer and HEMT structure (n+$Al_{0.25}$GaN /i-$Al_{0.25}$GaN/i-GaN) were grown on both a-face and c-face sapphire substrates of 100mm diameter by horizontal gas-flow type MOVPE. Each wafer had high resistive GaN buffer layers. The GaN buffer layer was grown under atmospheric pressure while other GaN layers and AlGaN layer were under low pressure of 100 torr over 1000C. Since ammonia is reactive to III group gases, especially to TMA, even at room temperature, it's important to avoid this pre-reaction in order to get stable growth of AlGaN with good uniformity across the wafer. Optimization of thermal condition, gas flow system not to mix the gas before its entering the heat chamber was useful to improve the stability of the growth and its uniformity across the wafer. Bowing of epi-wafer with GaN single layer was observed by light fringe, because the bowing of the wafer is one of the biggest obstacles for its practical use. Uniformity of AlGaN thickness, sheet resistivity, mobility of HEMT epi-wafer were also measured by XRD, Eddy current method and Hall measurement, respectively.

FETs were fabricated on the 100mm diameter HEMT structure epi-wafer. Ti/Al ohmic electrodes were metallized and Ni/Au were deposited as a gate electrode. The gate length is 0.8 μm. Detailed device fabrication method is the same as reported when using 50mm sapphire[1]. The wafer was able to be chucked firmly in spite of the bowing with enough flatness on the vacuum stage so that lithography process with enough accuracy had been done successively. Uniformity across the wafer of DC parameters, such as saturation current (Ids), threshold voltage and breakdown voltage were measured.

RESULTS AND DISCUSSIONS

Fig.1 showed the bowing of the epi-wafers with 2um thick GaN single layer on a-face and c-face substrate. The a-face wafer had anisotropic bowing with large value around 50μm. The c-face showed isotropics and a relatively small value. The bowing was calculated by the following equations.

$$h \approx -\frac{3}{4} \cdot \frac{E_{epi}}{E_{sub}} \cdot \frac{t_{epi}}{t_{sub}^2} \cdot \left(\alpha_{sub} - \alpha_{epi}\right) \cdot L^2 \cdot \Delta T \qquad \text{….. (1)}$$

where E, t, α, L and ΔT are coefficient of linear expansion, thickness, Young's modulus, wafer diameter and temperature dependence between growth temperature and room temperature, respectively.

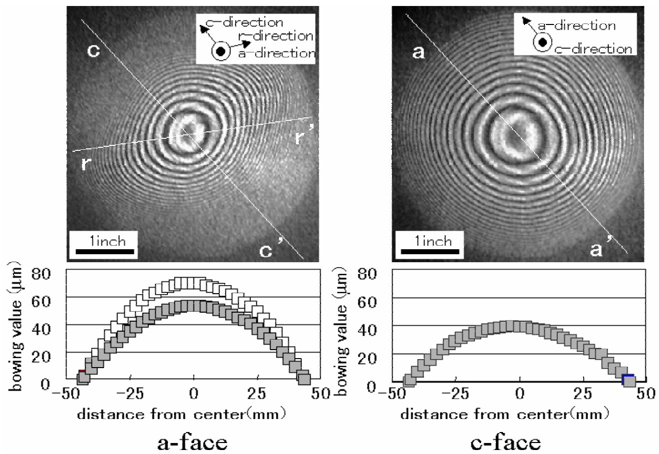

Fig.1 Bowing of 2um GaN on 100mm diameter Sapphire

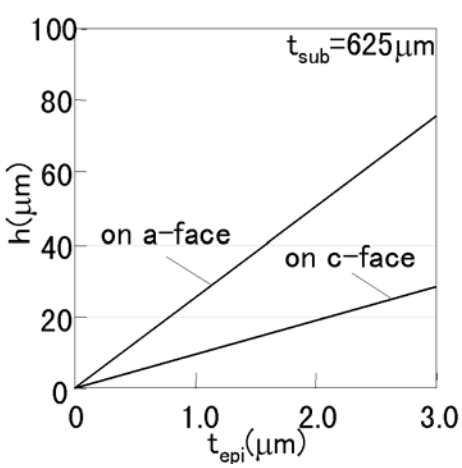

Fig.2 Calculated value of bowing

The calculation results are shown in Fig.2. Although the experimental value is relatively larger, this tendency well correlates with the calculated value. To improve the bowing, lowering the total thickness of the epi-layer (with good quality) is obviously most useful. The c-face substrate is better in this regard, but the a-face substrate has a much lower price than that of the c-face. The epi-wafer properties of the HEMT structure on the a-face and c-face of 50mm diameter wafer were investigated and no difference between the two was recognized as shown in Fig.3. Considering all these results, it was decided to use the less expensive a-face substrate for the next experiment (fabrication of FETs).

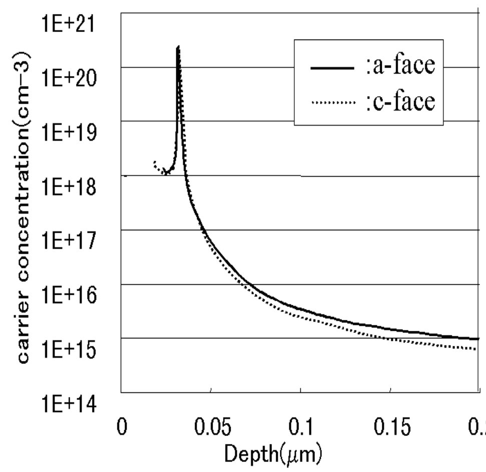

Fig.3 Comparison of C-V profile on a-face and c-face

Distribution of the sheet resistance on the a-face 100mm substrate was very uniform at +- 2.5% across the wafer as shown in Fig.4.

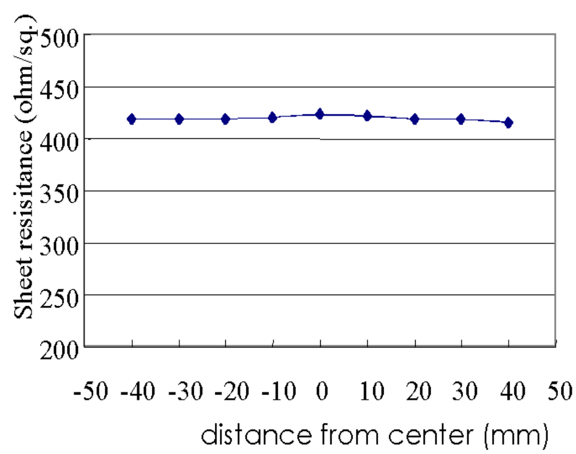

Fig.4 Uniformity of GaN-HEMT on 100mm substrate

Sheet carrier concentration and mobility was 1.2E13cm^{-2} and 1250cm^2/V.s, respectively. To obtain these excellent properties with good uniformity, many growth parameters such as temperature and pressure for each layer, mix ratio of carrier gas (N_2 and H_2) had to be carefully optimized, because the crystal quality is sensitive to all the parameters much more than conventional III-V materials like GaAs.

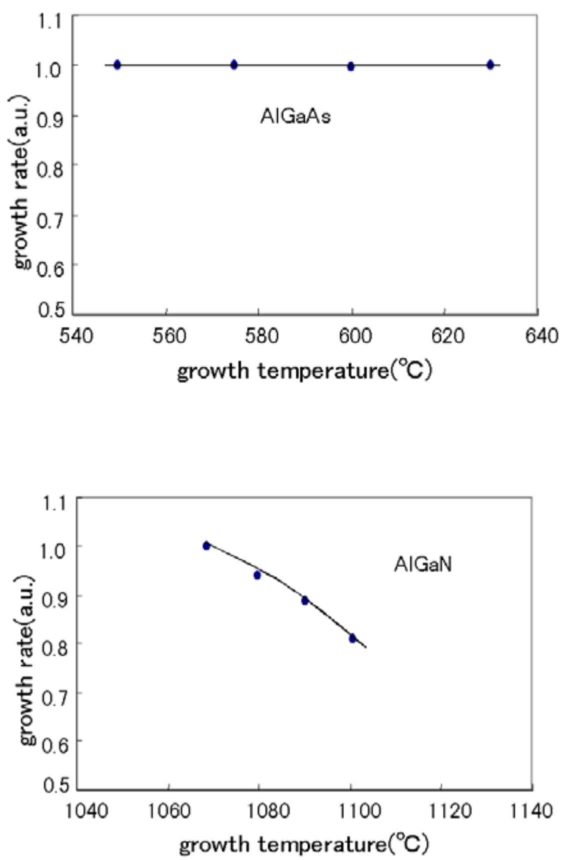

Fig.5 Dependence of growth ratio of AlGaAs and AlGaN on growth temperature

For example, Fig.5 shows the temperature dependence of growth rate of AlGaN in comparison with that of AlGaAs. Growth rate of AlGaAs is constant for the temperature region, (because the reaction growth is controlled to maintain at a condition of perfect mass transport limited growth), while, the growth rate of AlGaN changed greatly by changes in temperate. Furthermore, the growth temperature itself is much higher than that of AlGaAs. The growth mechanism needs more controllability for all of the parameters in order to go to real mass production with high yield.

The transistor performance is quite good as shown in Figures 6 and 7. Good pinch-off characteristics were observed without any kink phenomena. High breakdown voltage over 100V was obtained with high maximum drain current of 500mA/mm. This result indicates that the FETs were well fabricated in spite of the bowing, which could be acceptable for production.

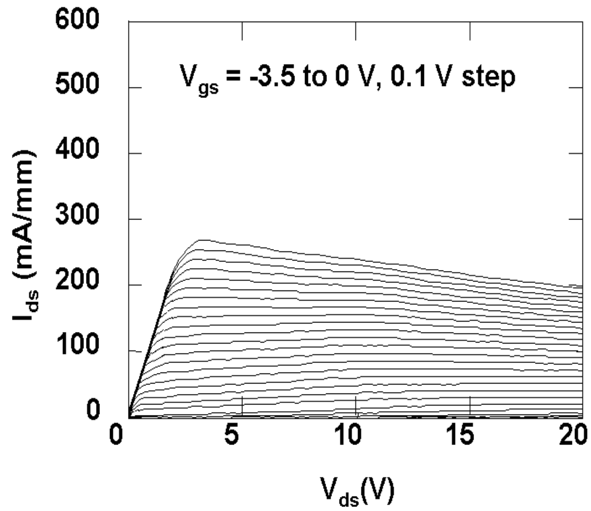

Fig.6 Ids-Vds Characteristics

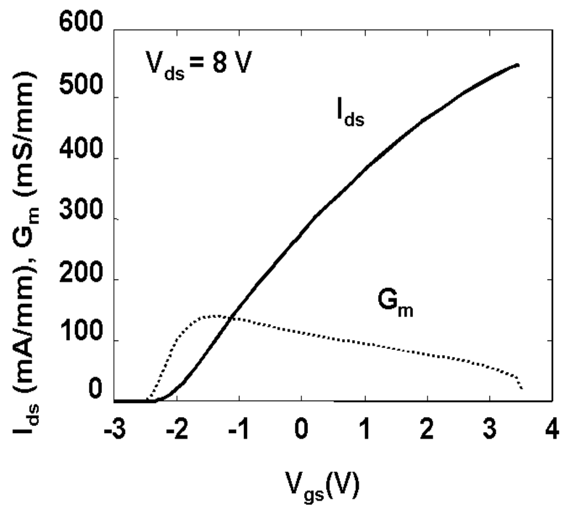

Fig.7 Ids-Vgs characteristics

The uniformity across the wafer is shown in Fig 8. Standard deviation of Vth was 50mV across the wafer (average Vth=-2.6V), that of Idss and Gm-max were 11mA (average Idss=300mA/mm) and 5.3mS (average Gm-max= 145mS/mm), respectively. This uniformity is good enough for mass production

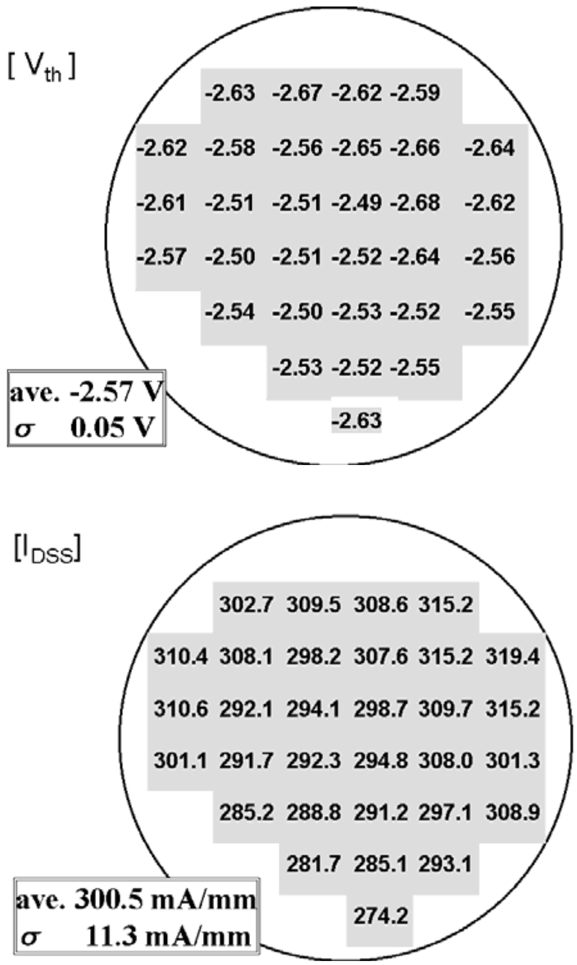

Fig.8 Uniformity of Ids at Vgs of 0V (Idss) and Vth across the wafer

Conclusion

GaN-HEMT structure epi-layers were successfully grown on 100mm diameter sapphire substrates. Although the wafer bowed by approximately 40µm, it showed good properties of epi-layers with excellent uniformity. Transistor performance also showed good uniformity across the wafer. These results are very encouraging as they show the high possibility to successfully achieve mass production of 100mm wafers.

Reference

[1] T.Kikkawa *et al*., 2001IEDM Tech. Digest (2001) 585

Acronyms

HEMT:High Electron Mobility Transistor
MOVPE: Metal Organic Vapor Phase Epitaxy
FET: Field Effect Transistor
TMA: Trimethyl Aluminum

