Warp of 4” Free-standing GaN Wafers

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Abstract

Free-standing GaN wafers were produced by hydride vapor phase epitaxy (HVPE). The growth process resulted in internal tensile stress which caused a concave bow of the lattice planes and the wafer, which is typical of HVPE grown GaN wafers. The wafer warp is a significant concern for the yield of the wafers during production and also for the application of GaN wafers for homoepitaxial device growth. The warp of the wafer can be reduced by optimization of the HVPE process. The polishing process also has a large effect on the warp.

INTRODUCTION

There are four main types of GaN-based semiconductor devices; LEDs, laser diodes, power electronics, and RF devices. Each of these devices have developed to favor a unique substrate; LEDs use GaN on sapphire, laser diodes use GaN on GaN, power electronics uses GaN on Si, and RF devices use GaN on SiC. Although GaN wafers may seem like an ideal choice of substrate, their use in GaN-based devices is limited by the size, price, availability, and quality such as pit defects, dislocation density, and warp. The improvement in GaN wafer manufacturing methods and the properties of GaN wafers will enable homoepitaxial GaN devices with superior performance metrics. Promising potential markets for GaN on GaN devices are vertical GaN power devices and lateral HEMTs as RF devices.

EXPERIMENTAL PROCEDURE

Free-standing GaN wafers were grown on 5” sapphire substrates by HVPE. The GaN wafers were separated from the substrate by a novel interlayer separation process and were free-standing when they were removed from the HVPE, pictured in Fig. 1. The as-grown GaN wafers were then cut into 4” wafers. Then the wafers were polished via multiple steps of grinding, lapping, and CMP.

The curvature of the wafers was measured by different methods and at different states in the processing of the wafer. The wafers were measured in the as-grown state, the final polished state, and during different stages in the polishing process. The curvature of the c-plane lattice was measurement by XRD, and calculated based on the displacement of the 002 omega peak position at different x-y positions on the wafer [1]. The lattice curvature is given as the radius of curvature in meters.

The curvature of the physical wafer was measured by Microsense back pressure method [2]. This method uses physical probes but it measures the air pressure from the probes as they approach the wafer surface. It is non-contact; independent of optical properties, electrical properties, and roughness of the wafer; and has an accuracy of 1 μm. The front surface and back surface are simultaneously measured and the wafer is held by the edges in an unclamped state. The measurement included three different parameters which describe the shape of the wafer; warp, bow, and back sori. Warp is the total variation in height of the median plane of the wafer, where the median plane is the imaginary plane that is an average of the front and back surface. The bow is the change in height of the wafer center point relative to a best fit reference plane. The bow will be positive or negative to indicate concavity. The back sori is the total variation in height of the back surface plane of the wafer. The back sori was used for as-grown wafers because the large TTV of as-grown wafers renders the median plane meaningless to the shape of the wafer. The warp and back sori are approximately the same for polished wafers with small TTV. The warp and back sori are always positive and do not indicate concavity.

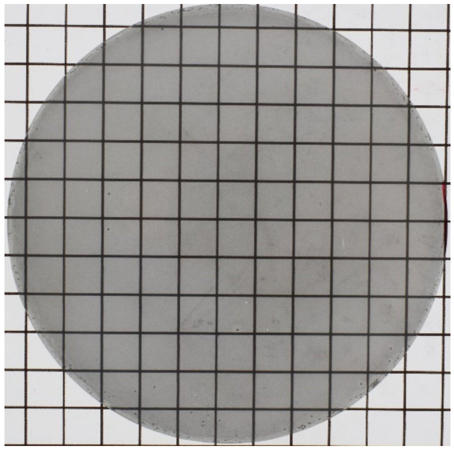

Fig. 1. As-grown free-standing GaN wafer with 116 mm diameter.

RESULTS

XRD rocking curves of the GaN 002 and 102 peaks were measured to determine the crystal quality, and how that affected the curvature of the wafer. Typical XRD rocking curve FWHMs for both 002 and 102 for as-grown wafers were between 40 to 80 arcsec. It was observed that lower XRD rocking curve FWHMs corresponded to improvement in the lattice curvature and warp. The 102 rocking curve FHWM had a stronger correlation than the 002 rocking curve. Figures 2 and 3 show how the radius and back sori correlate to the average 102 rocking curve FWHM for as-grown GaN wafers. Typical as-grown wafers had radius of 20 to 30 m and back sori of 40 to 80 μm, measured at 100 mm diameter. The factors that affected the crystal quality were the design of the interlayer for separation, the nucleation of the GaN growth, and the HVPE recipe.

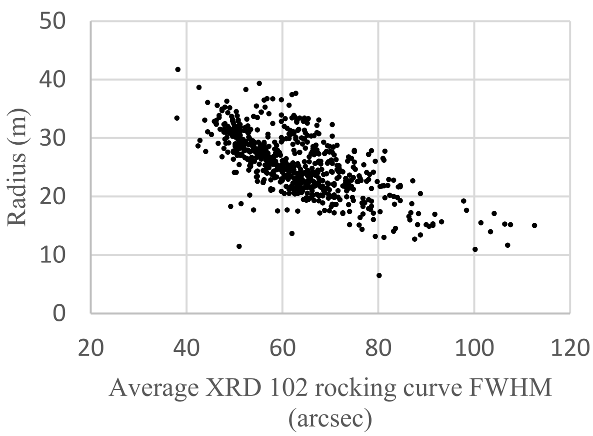

Fig. 2. The radius improved with lower average XRD 102 rocking curve FWHM for as-grown GaN wafers.

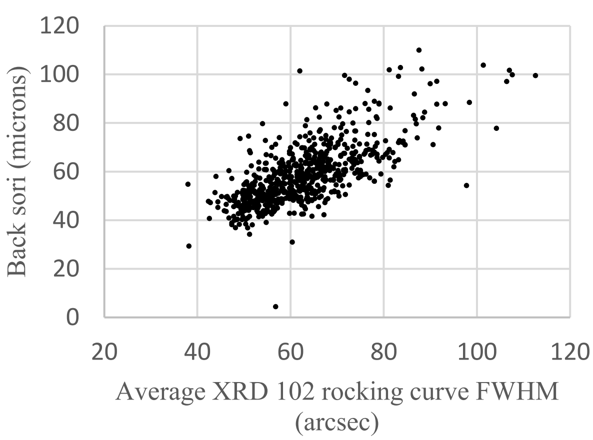

Fig. 3. The back sori is lower with lower average XRD 102 rocking curve FWHM for as-grown GaN wafers.

The polishing process consisted of grinding, lapping, and CMP of both faces of the GaN wafer. Each of these steps resulted in significant change to the bow and warp of the wafer. The initial grinding of the as-grown wafer surfaces would cause the wafer to increase positive bow for front grinding and increase negative bow for back grinding. Subsequently, lapping and CMP would cause the wafer to bow in the opposite direction. Front lapping and CMP causes the wafer to increase negative bow, and back lapping and CMP causes the wafer to increase positive bow. Therefore, grinding of the surface introduced a compressive stress state on the lattice damaged surface. Then lapping and CMP steps removed the lattice damaged surface layer and reduced the introduced surface state stress.

The order of the steps is important to the yield of the process because the wafers change bow and concavity throughout the process. It is preferrable to alternate the surface that is being worked on to prevent a maximum of the bow in either direction because that can cause the wafer to crack during the process. If the front side is polished without removing the back side surface damage layer, then the warp can reach 200 um with a negative concavity.

In the final state of the wafer, all of the surface damage must be removed from the wafer in order to minimize the warp. It is obvious that the surface damage should be removed from the front side, usually the Ga-face, for the purposes of epitaxy. But the back side surface damage must also be removed to obtain the lowest possible warp. The back side surface damage can be removed by either CMP or etching, and both methods achieved nominally the same warp. The final radius and warp of the polished GaN wafers showed a small improvement compared to the radius and back sori of the wafers in the as-grown state. Polished wafers always had a negative concavity with a typical radius of 20 to 50 m and warp of 30 to 60 μm, measured at 90 mm diameter.

CONCLUSION

The warp of free-standing GaN wafers is an important parameter for their application in homoepitaxial growth. The HVPE growth conditions are the determinate factor for the final warp of the wafer. The polishing process also affects the warp as it is being processes, but does not play a role in determining the final warp. It is important that all surface damage from the polishing process is removed from the wafer, including the back side by either polishing or etching.

ACKNOWLEDGEMENTS

References

[1] H. Foronda, et al., *Curvature and bow of bulk GaN substrates,* J. Applied Physics **120**, 035104 (2016).

[2] http://www.microsense.net/UltraMap-APBP.htm

Acronyms

HVPE: hydride vapor phase epitaxy
XRD: X-ray diffraction
FWHM: Full width half maximum