The Growth of Low Wafer Bow AlGaN/GaN Structure on 200mm Si(111)

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Abstract

In this study, we would like to find out the simplest way to achieve the lowest wafer bow in the GaN HEMT on 200mm Si wafer. The simplest refit that we found involved using 12 sapphire blocks distributed around the periphery of the flat susceptor. The final wafer bow can reach around 22um for the GaN HEMT on 1mm thick 200mm Si wafer. The sheet resistance of the sample with the sapphire blocks will measure 34% lower than the sample without the sapphire blocks.

INTRODUCTION

In recent years, GaN electronics attracts more and more attention. According to the different application, the user can choose a different substrate to achieve the target [1]. Especially, GaN on silicon substrates is getting more attention. The silicon substrate has the advantages of lower cost, better thermal conductivity, and it is easy to integrate with Si devices…etc. Therefore, there are many companies and research groups focusing on the GaN on Si devices. But, there were also some drawbacks for the GaN on Si substrate. For example, the huge thermal extension mismatch will induce larger wafer bow and residual stress, and the larger lattice mismatch will induce poor GaN quality. There are many researchers trying to develop a good buffer layer design that will release the stress in the epitaxy structure [2].

There are many requirements for integration of GaN and Si devices. The lower final wafer bow will be the most difficult to reach. Because of the lattice constant and thermal extension mismatch, the GaN wafer bow was a huge challenge. There are many research groups focusing on using complex transition layers to release the residual stress and lower the wafer bow. Some companies even use thicker silicon wafers to reduce the final wafer bow. But, the thicker silicon wafers will be an equipment issue to the Si industry. Therefore, the simplest way to reduce the wafer bow and release the residual stress was demonstrated in this study.

EXPERIMENTS

In this study, the wafers were grown by the CCS (Close Couple Showerhead) reactor, which was manufactured by AIXTRON. All the AlGaN/GaN structures were performed on 1mm thick, 200mm Si(111) wafers. The silicon wafers were manufactured by OKMETIC. The initial silicon wafer bow was lower than 30um. The complete epitaxy structure is shown in Figure 1. The buffer layer consisted of a LT-AlN nucleation layer, a higher growth temperature AlN buffer layer, and followed with three different composition AlGaN transition layers. Then, the 500nm un-doped GaN #1 was grown under lower growth pressure. And, the 1um thick un-doped GaN #2 channel layer was grown under higher growth pressure. After that, the 20nm un-doped $Al_{0.24}Ga_{0.76}N$ was stacked on the GaN layer for barrier. Finally, a 2nm GaN was grown on the top for the capping.

Figure1. The epitaxial structure for all samples.

In this study, the susceptor refit will be the key point to improve the final wafer bow. There are two samples. For one, the HEMT structure was grown on Si(111) with the original flat susceptor. Before the second sample growth, 12 sapphire blocks (1mm x 2mm) were distributed on the original flat susceptor. The distribution of the sapphire blocks is shown in the Figure 2. Figure 2b shows the sapphire blocks on the susceptor.

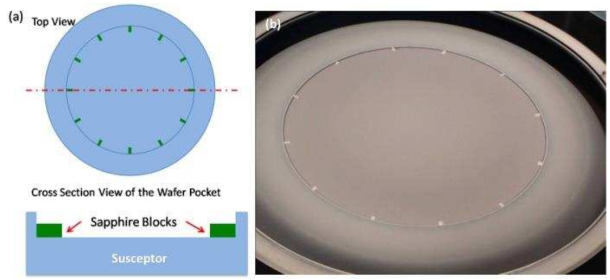

Figure 2. (a) Illustration of the sapphire blocks on susceptor; (b) Picture of the distribution of sapphire blocks on the susceptor.

RESULTS

The Figure 3 shows the curvature curve, which was extracted by the Laytec in-situ curvature monitor system. From the process beginning, the in-situ curvatures of the two samples are almost the same until the HT-AlN buffer layer. The sample with the sapphire blocks on the susceptor shows less concave strain during the HT-AlN buffer layer growth. Because the sapphire blocks are located on the edge of the pocket, the wafer center will not directly contact the susceptor. Since the wafer center temperature is not as hot as the periphery which is in contact with the susceptor, the wafer strain will not be so concave. Then, the strain will go more convex during the whole process. And, higher convex strain was exhibited during the GaN growth. After the epitaxial growth and temperature cooling down, the sample grown "with sapphire blocks" exhibited the curvature value close to zero. Therefore, smaller final wafer bow was expected. From the in-situ curvature result, the sample without sapphire blocks will show higher bow from the concave strain.

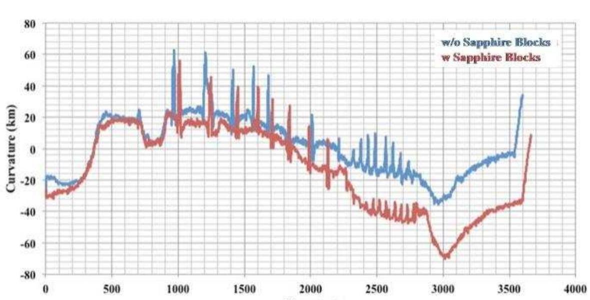

Figure 3. The in-situ curvature measurement for the samples growth with sapphire blocks and without sapphire blocks.

The final bow measurement, after growth, was done by TOHO stress measurement system. For the residual stress extraction, the initial wafer bow must be measured before the growth. The 3D bow measurement and the statistics data are shown in Figure 4. The final bow of the two samples shows the concave strain. The sample, grown with sapphire blocks, shows lower final bow of 21.27um and lower residual stress of 0.28GPa. The bow value was 77% lower than the sample grown without sapphire blocks. The multiple wafer bow measurements also presented the higher bow uniformity in the sample grown with sapphire blocks. The residual stress also exhibited huge improvement from 1GPa tensile stress down to 0.28GPa. The sapphire block refit can improve the residual stress around 72%.

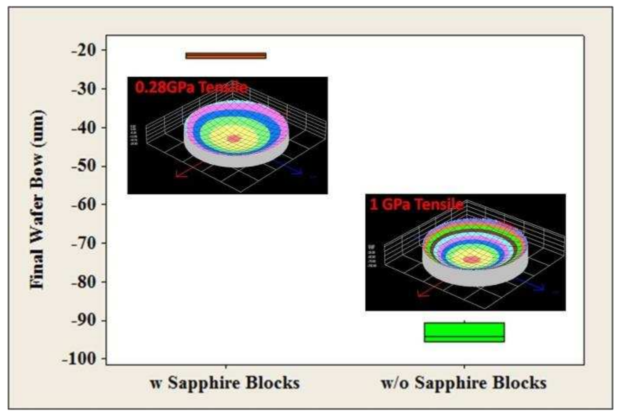

Figure 4. The stress measurement result exhibited for the samples grown with and without sapphire blocks.

The GaN quality characterization was done by HR-XRD. During the HR-XRD measurement, nine different locations measurement were necessary for the uniformity performance extraction. The GaN quality results are shown in the Figure 5. That is the statistics data from the FWHM of the GaN (002) OMEGA scan. The FWHM of the GaN(002) show lower value (599 arcsec) and better uniformity(0.22%) in the sample grown with sapphire blocks. The sample grown with sapphire blocks, exhibits 28% GaN quality improvement. Higher residual stress will induce material damage during the cooling step after the growth. The material damage will make poorer quality GaN. Therefore, the final wafer bow improvement and residual stress release will improve the GaN quality. The sapphire blocks raise the wafer up, and it also improved the wafer uniformity.

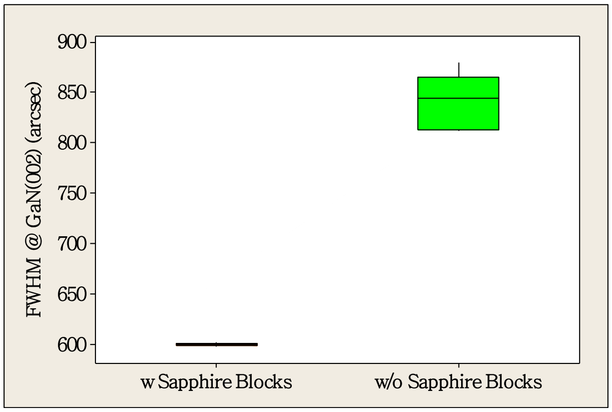

Figure 5. The FWHM @ GaN(002) statistics data for the samples grown with and without sapphire blocks.

The performance of the HEMT structure was determined by the sheet resistance of the 2DEG. Those data were extracted by the Lehighton system. The sheet resistance result is shown in the Figure 6. The sample grown with sapphire blocks shows lower sheet resistance of 369 ohm-mm and also shows higher sheet resistance uniformity in the 200mm wafer. The better quality of the GaN channel is the root cause of the improvement of the sheet resistance in the HEMT structure. Lower sheet resistance will induce higher drain current in the HEMT device. The uniformity of the 2DEG sheet resistance was also improved.

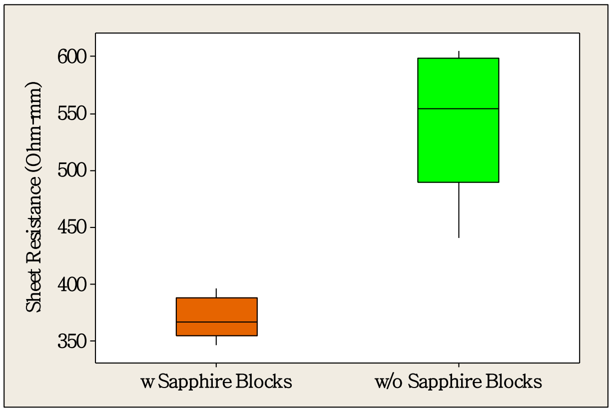

Figure 6. The sheet resistance for the samples grown with and without sapphire blocks.

CONCLUSIONS

After the simplest susceptor refit, the GaN HEMT structure exhibited huge improvement. The sapphire blocks raises the wafer and prevents the wafer center from contact with the susceptor directly. In the usual configuration in which the wafer center is in contact with the susceptor, it is quite hard to control the temperature in the wafer center. Even the zone setting adjustment, that still cannot control the temperature effectively. This situation is more extreme in thinner wafers. In the most extreme situation, the thinner wafer will become wavy. According to the measurement results, the sample grown with sapphire blocks can release the residual stress effectively. The sapphire block refit can release around 72% of the residual stress in the wafer. The final wafer bow will lower to 21.27um and become concave shape. The lower wafer bow and released residual stress also induce better GaN quality. From the XRD results, the sample grown with sapphire blocks can exhibit 28% improvement in the FWHM at GaN(002) omega scanning. The GaN quality improvement will decrease the 2DEG sheet resistance. The lower 2DEG sheet resistance will induce better GaN device performance.

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