Cracking of GaN on sapphire from induced non-uniformity in residual stress

Y. Lacroix, S.H. Chung and S. Sakai

Tokushima University Satellite Venture Business Laboratory

A simple model is given to explain the appearance of cracks along mesa structures formed in the processing of GaN device layers grown on sapphire substrates. Micro-Raman spectroscopy was used to measure the position dependent stress in the processed GaN layer. We show evidence that the stress at the interface with the substrate may be larger along the mesa structures than that of the as-grown layer. This increase in stress can be enough to induce cracking during processing.

Introduction

Some of the most challenging aspects of GaN based thin film technology, as compared with other device material systems such as Si or GaAs, stem from the fact that the substrate materials commonly used have very different material properties with respect to the device layer itself. In the case of GaN grown on (0001) sapphire substrates, an effective ~16% lattice mismatch induces dislocations soon after the start of growth to compensate for this strain. Much of the progress in the field has been achieved using "tricks" to reduce this dislocation density. However, even if sapphire were perfectly lattice-matched to GaN during growth, the difference in thermal expansion coefficients between the two materials would still induce strong bi-axial compressive stress in the GaN after cool down. This stress is the source of well-known effects such as the non-negligible piezoelectric field and a critical thickness for GaN layers beyond which cracking is induced from parting of the sapphire at the interface [1].

During our processing of GaN based lasers, such cracks were observed after performing standard selective-area dry etching for the formation of mesa structures. As shown in Fig. 1, cracking occurred along the mesas, independent of the sapphire or GaN crystalline directions.

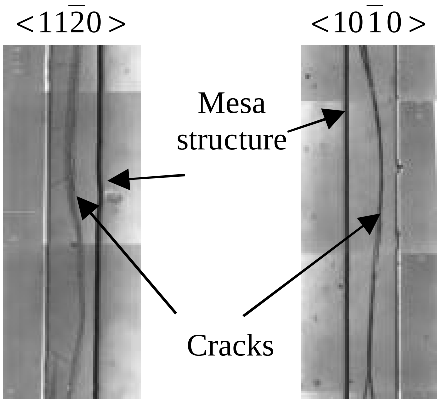

Fig. 1 Cracks along the mesa structure of two samples from the same wafer, showing that the cracking is independent of crystal directions.

We report results from experiments on thick GaN layers performed for the purpose of explaining such crack formation, and propose a model based on the non-uniformity of stress distribution induced by the mesa structures.

Sample preparation

In order to study the stress distribution before and after mesa formation, three samples were prepared from 7μ m thick GaN layers grown on sapphire substrates. There were no cracks in these samples even after processing so that the residual stress was not relaxed except via bending of the wafer (convex on the GaN side). Fig. 2 shows a diagram of the sample preparation. One sample (sample A) was left as-grown, uniformly 7 μ m thick. The other two were dry-etched (RIE, BCl_3 plasma) in order to remove 3 μ m, leaving a 4 μ m thickness of GaN on top of 330 μ m thick sapphire. One of these two samples was uniformly etched (sample B) whereas the other (sample C) was patterned by lithography with etch resist for mesa formation. Samples B and C were etched simultaneously. The mesa pattern can be described as arrays of un-etched stripes 50 μ m wide spaced 500 μ m

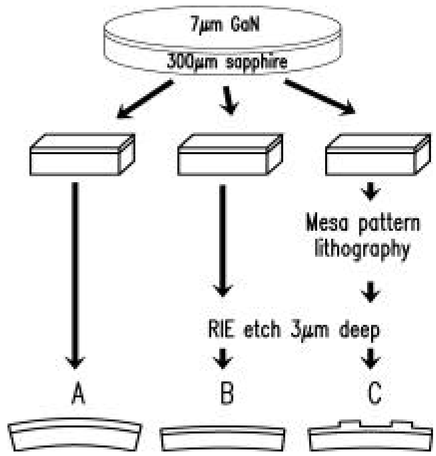

Fig. 2 Schematic description of the sample preparation. Samples A and B were uniformly 7 μ m and 4 μ m thick respectively, whereas sample C was patterned having regions of each thickness as described in the text.

apart. All the samples were 1cm x 1cm in dimension.

The curvature of the samples was measured using a surface profiler and the data are shown in Fig. 3. The linear dependence of the curvature as function of thickness is in agreement with Kozawa et al. who used the curvature to calculate the compressive stress [2].

Results and Discussion

The key point in understanding why cracks should occur beyond a critical thickness is that although the compressive stress decreases with thickness due to bending, in doing so the tensile stress on the sapphire substrate at the interface increases. If we assume that cracks initiate from the parting in sapphire near or at the interface, reduction of the stress in GaN by way of bending will enhance the probability of cracking.

Klose et al. showed that the bi-axial stress in GaN could be mapped linearly with respect to the Raman shift in the high energy E_2 mode [3], for which the electric and lattice displacements occur perpendicular to the [0001] axis. We used micro-Raman to measure this mode as a function of position in our samples. The results are shown in Fig. 4. The data from sample B showed a compressive shift from that of sample A since the GaN was made thinner. This shifted peak energy matched perfectly with measured Raman shift in the 4 μ m region of sample C. However, the peak measured at the center of the mesa had shifted toward a less compressive stress with respect to sample A. This would imply that the tensile stress on the sapphire at the interface just below the center of the mesa structure was larger than that of the uniform layer. In other words, the probability of cracks occurring at the sapphire interface just below the center of the mesa was larger than for the unprocessed sample.

It is evident that the tensile stress should be at a maximum at the mesa center, however that it should be larger than for a uniform layer of the same thickness has yet to be shown theoretically. In the affirmative case, a layer near the critical thickness for cracking can develop cracks during processing as just described. We propose that such an effect was responsible for the cracks observed in Fig. 1.

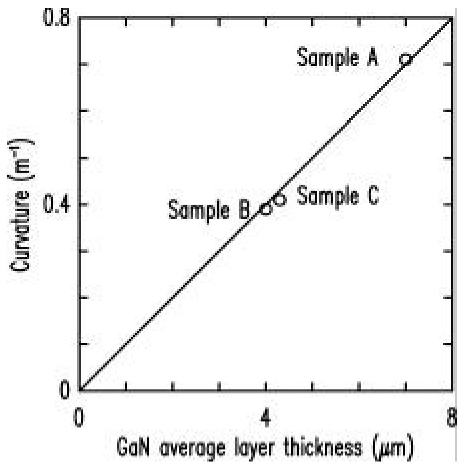

Fig. 3 The measured curvature of the prepared samples as a function of the average thickness of GaN.

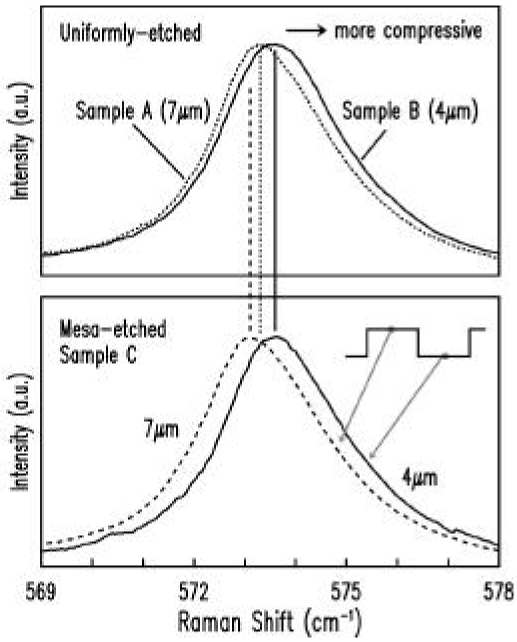

Fig. 4 The bi-axial stress sensitive E_2 mode measured by micro-Raman spectroscopy.

Conclusions

Following the observation of cracks along thicker regions of GaN-based material grown on sapphire, we prepared samples with similar physical structures in order to measure the stress distribution. From our results we conclude that these cracks were generated by a redistribution of the residual stress initially caused by the thermal expansion coefficient mismatch between GaN and the sapphire substrate. Supporting theoretical investigation is under way.

Acknowledgements

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References

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