

Effects of AlGaN/GaN HEMT structure on RF reliability

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A comparison of RF reliability at 10 GHz on four different undoped AlGaN/GaN HEMT structures with AlGaN barrier thickness variation is presented. The output power degradation characteristics during RF stress for each structure are shown, and the results indicate a strong dependence of reliability on AlGaN thickness. A device from the structure with the thinnest AlGaN in the study, with initial output power of 8.8 W/mm at 40 V, showed only a change of 0.55 dB in output power after 185 h of RF stress at 40 V. The results demonstrate excellent RF reliability of high-power devices and the potential of stable high-power operation of undoped AlGaN/GaN HEMTs on SiC.

Introduction: In recent years, the AlGaN/GaN HEMT has positioned itself as a strong candidate for future high-power amplifiers. However, to fulfil its promise, the reliability must be improved. There have been a very limited number of published studies on the device reliability under RF stress. AlGaN/GaN devices grown on SiC substrates have typically shown rapid degradation in output power and drain current within a short time at low drain bias [1–4]. One recent study recorded a 1 dB drop in output power at a drain bias of 10 V after 116 h of RF stress [1]; however, the best result so far is reported in [5] where a doped AlGaN/GaN HEMT showed almost no change in output power measured at a drain bias of 60 V for 1000 h. All results indicate that further improvements in reliability are needed.

In this Letter, we present a comparison of RF reliability at 10 GHz on four different undoped AlGaN/GaN HEMT structures grown on 6H SiC. The thickness of the AlGaN barrier layer was varied from 260 to 138 Å. The output power degradation trends from each structure are discussed. Our reliability study showed that the structure with the thinnest barrier of 138 Å was more reliable than others in this study and demonstrated significantly better RF reliability at high drain bias (40 V) and high power density (>8 W/mm) over typically published data on AlGaN/GaN devices on SiC.

Device structure and fabrication: The epitaxial layers were grown by MOCVD on 6H SiC. For the study, the undoped $\text{Al}_{0.32}\text{Ga}_{0.68}\text{N}$ layer was grown on $\sim 1.5 \mu\text{m}$ of GaN buffer to form the heterostructure with an AlN sub-barrier inserted in between to improve mobility. For each of the four structures, $\text{Al}_{0.32}\text{Ga}_{0.68}\text{N}$ barrier thickness was 260, 208, 180 and 138 Å, which will be referred to as structures A, B, C and D, respectively. In addition, structure D has a very thin GaN layer to cap off the $\text{Al}_{0.32}\text{Ga}_{0.68}\text{N}$ barrier. The devices were fabricated with TriQuint's field-plate process for GaN HEMTs as described in [6]. The $0.25 \mu\text{m}$ gates were formed by etching a window in the Si_3N_4 layer using RIE etching. Then the gate metal was evaporated and lifted-off after patterning the field-plate on top of the nitride.

Results: RF stress tests were performed on $200 \mu\text{m}$ devices on each wafer after performing continuous wave load-pull measurements at 10 GHz. For each device under test (DUT), the load and source impedances were fixed at the states where maximum output power (P_{out}) at peak PAE was achieved at the given V_{DS} and V_{GS} . The gate bias was adjusted for each DUT to achieve 300 mA/mm of quiescent current. The devices were stressed at the input power where the gain compression is about 3 dB. The change in the RF power characteristics were recorded every 15 min. No active cooling was performed for the entire stress duration.

Initially, one device on each wafer was tuned at a drain bias of 30 V and RF stressed for a minimum of 65 h. The device fabricated from structure A had excellent initial power performance of 7.9 W/mm with 50% PAE at $V_{ds} = 30$ V. Devices on structures B and C showed similar initial P_{out} of 6.5 W/mm with respective PAEs of 43 and 37%. The device on structure D had comparable initial condition of 7 W/mm with 43% PAE at 30 V of drain bias.

Fig. 1 shows the output power degradation characteristics for the DUTs from each epitaxial structure. ΔP_{out} for all devices from each structure seems to degrade at a faster rate within the first several hours then the degradation rate decreases. Interestingly, the representative

from each structure exhibited distinct degradation trends. For structure A, with 260 Å of AlGaN barrier, P_{out} degraded by 1.73 dB after 66 h of stress with an initial drop of 0.66 dB in P_{out} after the first 10 h. The power drop observed on this wafer is comparable with typically published reliability data on AlGaN/GaN HEMTs [1–4]. Next, the second best degradation characteristic was observed from structure C, which had a thinner barrier of 180 Å. P_{out} decreased most considerably after the initial 10 h (0.73 dB), then posting a much smaller degradation of 0.36 dB for the remaining 56 h of stress time. A significantly better reliability performance was observed on devices from structure D. After 100 h of RF stress, P_{out} degraded by only 0.42 dB with a drop of 0.22 dB in the last 90 h. In view of the excellent RF power stability at 30 V, another device from structure D was subjected to RF stress at V_{ds} of 40 V with an initial P_{out} of 8.8 W/mm and 39% PAE for an extended duration of 185 h. The degradation trend does not appear to depend on the bias voltage for both devices tested at 30 and 40 V from structure D as shown in Fig. 1. During the first 10 h, P_{out} degraded by 0.2 and 0.22 dB at 30 and 40 V, respectively. For the next 90 h, the device stressed at 40 V degraded by an additional 0.2 dB, which closely followed the trend at 30 V. At the end of the 185 h stress at 40 V, the accumulated changes in P_{out} and PAE were, respectively, 0.55 dB and 2.1% points, demonstrating a significant improvement in reliability and stable operation of devices with >8 W/mm of power density. The DUT from structure B degraded most severely of all the devices. Excluding the degradation from the first 10 h, P_{out} still dropped by 2.94 dB for the remaining 55 h.

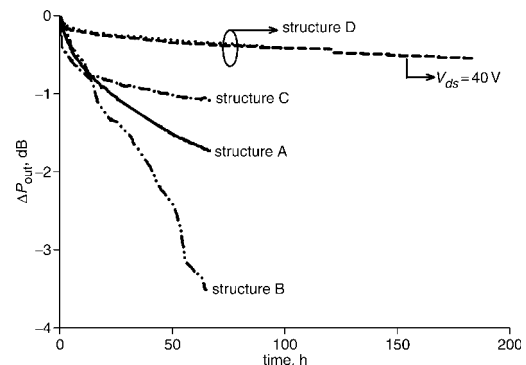


Fig. 1 Degradation characteristics of output power under RF stress of AlGaN/GaN HEMTs grown on four different epitaxial structures $V_{ds} = 30$ V, except when specifically noted

The results from structures A, B, C and D suggest a strong correlation of device reliability to AlGaN barrier thickness. Gotthold *et al.* studied the time-dependent decay of the sheet resistance of AlGaN/GaN material (with no device fabricated) with different AlGaN barrier thickness while fixing the Al composition [7]. They found that structure with thinnest AlGaN barrier in their study (220 Å) showed the slowest degradation compared with thicker structures. They attributed the dependence to the reduction in strain by lowering barrier thickness and Al composition [7]. We expect that the degradation rate that is inherent to AlGaN/GaN heterostructure may be accelerated when devices are fabricated and subjected to electrical stress. Therefore, structure D, with the thinnest barrier, produced the best RF reliability performance while device performance from structure A, B and C, with thicker barrier, degraded significantly after RF stress of 65 h. We are currently investigating the effect of the thin GaN cap layer on reliability, which may have also contributed to the improvement. The worst reliability performance from the randomly selected device from structure B can be explained by the unpredictable variation in the rate of degradation from an unstable structure, where the phenomenon was also observed on unstable AlGaN/GaN material in [7].

An additional device from each structure was subjected to short-term RF stress for a minimum of 20 h, and the results are shown in Fig. 2. There are two DUTs from structures A, B and C, while five devices were randomly selected from structure D for RF stress. All stress conditions were set in the same manner as the initial devices at $V_{ds} = 30$ V described above. The smallest variation in reliability was observed on structure D. The spread in ΔP_{out} among five DUTs across the wafer was only 0.13 dB after 20 h, which was a significantly smaller

spread compared with the structures with thicker AlGa_N. The minimum change in P_{out} was 0.13 dB while the maximum change was only 0.27 dB after 20 h. For structure A, one device degraded by 1.69 dB while the other device showed ΔP_{out} of 0.93 dB. A range of 0.76 dB of degradation was observed after a short-term of 20 h on the same wafer. For structure B, after 20 h, the second stressed device yielded much better reliability performance than the first device shown in Fig. 1. Similar to structure A, a difference of 0.86 dB of ΔP_{out} was measured between the two DUTs on structure B. The variation reduced to only 0.44 dB for structure C as the AlGa_N thickness was reduced to 180 Å. Even though more data points are required from each structure to draw any statistical conclusions, the preliminary results indicate that the more stable material structure with thinner AlGa_N barrier yields more reliable devices whereas the less stable structures with thicker AlGa_N barrier produce less reliable devices with a wide spread in degradation across the wafer.

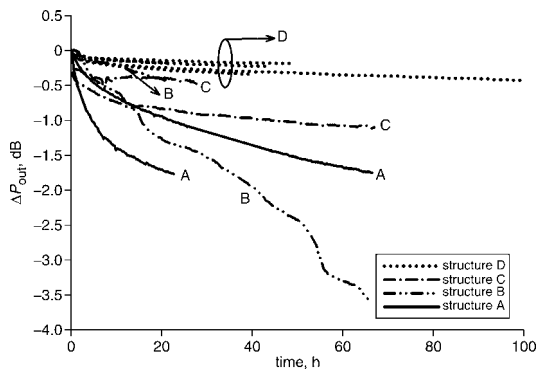


Fig. 2 Degradation characteristics of output power under RF stress of AlGa_N/Ga_N HEMTs grown on four different epitaxial structures
Minimum of two DUTs per structure shown with $V_{\text{ds}} = 30$ V for all tests

Conclusions: We have presented the RF reliability results at 10 GHz on four different undoped AlGa_N/Ga_N HEMT structures grown on 6H SiC substrates. The results indicate that reducing the AlGa_N barrier thickness improves the reliability. We also have demonstrated a significant improvement in RF reliability with a change of only 0.55 dB in output power and 2.1% points in PAE after 185 h of stress at drain bias of 40 V and with initial P_{out} of 8.8 W/mm and PAE of 39%. These results suggest that further improvements in a stable

AlGa_N/Ga_N device on SiC are achievable through further epitaxial optimisation.

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