Step-stress Reliability Studies on AlGaN/GaN HEMTs on Silicon with Buffer Thickness Dependence

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1. Introduction

Though many substrates are reported suitable for the growth of AlGaN/GaN heterostructure, undoubtedly silicon is the promising choice of substrate for its low cost and large size availability [1]. In spite of extra ordinary performance, AlGaN/GaN HEMTs (GaN HEMTs) still needs investigation for reliability. Improvement in reliability requires a better understanding of failure mechanisms of GaN HEMTs which is essential [2]. GaN HEMTs with epi-layer total thickness ($T_{tot}$) of 3.5 μm and 5 μm were step-stressed under increasing voltage.

2. Experiment

100 nm-thick SiO₂ passivated GaN HEMTs on silicon with $T_{tot}$ of 3.5 μm and 5 μm (Fig. 1) were studied. The super lattice structured (SLS) buffer comprising multiple pairs of GaN/AlN (20/5 nm). The aluminum composition 26% and thickness 25 nm are same for Al-GaN barrier layer in both the HEMT structures with $L_{g}/L_{gd}/W_{g}$ of 1.5/4.0/200 μm.

Typical DC characteristics of both devices are listed in Table I. The fabricated devices showed good $I_D$-$V_D$ characteristics with excellent pinch off.

![Device Structure](image)

Table I. Device characteristics of AlGaN/GaN HEMTs on silicon.

<table>
<thead>
<tr>
<th>SLS Pair</th>
<th>$T_{tot}$ [μm]</th>
<th>$W_{g}$ [μm]</th>
<th>$I_{D_{max}}$ [mA/mm]</th>
<th>$g_{max}$ [mS/mm]</th>
<th>$V_B$ [V]</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>3.5</td>
<td>200</td>
<td>165</td>
<td>58</td>
<td>-1.66</td>
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<tr>
<td>160 (4.0 μm) or 100 (2.5 μm)</td>
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<tr>
<td>1-AlGaN 40 nm</td>
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<tr>
<td>1-AlN 100 nm</td>
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<tr>
<td>4&quot; p-Si substrate</td>
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</table>

In step-stress measurement the gate bias was maintained at a $V_g = -10$V, a bias well below the threshold voltage. At this gate bias, $V_D$ was varied from 20 V to higher bias until breakdown. Under these conditions, the device was stressed for 10 mins and $I_D$-$V_D$ characteristics were measured every time before and after the step-stress.

3. Results and Discussion

For GaN HEMTs on $T_{tot} = 3.5$ μm, during 600 sec step-stress, no sudden increase in drain leakage was observed until 120 V $V_D$ stress. However, during $V_D$ stress at 140 V, a sudden increase (= 2 orders) in the leakage current was observed as shown in Fig. 2.

![Step-Stress Measurement](image)
After 140 $V_D$ stress, the $I_D$-$V_D$ measurement showed a normal pinch off. This sudden increase in the leakage currents $I_D$, $I_G$ followed by good pinch-off $I_D$-$V_D$ characteristics by the same device is what we mean as step-stress failure mode (SSFM). For GaN HEMTs on $T_{\text{tot}} = 5.0 \ \mu m$ no sudden increase in the $I_D$ was observed. At a higher $V_D$ stress total device breakdown was observed at 230 V without showing a SSFM as shown in Fig. 3.

At every increase in $V_D$ stress the drain leakage is plotted as initial and final as shown in Fig. 4. The result shows and confirms the SSFM observed in Fig. 4(a) and the gradual increase in drain leak without SSFM is observed in Fig. 4(b).

![Fig. 3. Step-stress measurement on $T_{\text{tot}} = 5.0 \ \mu m$ at $V_G = -10V$, $V_D = 230V$ stressed for 600 sec. Here the breakdown occurs without observing SSFM.](image)

![Fig. 4. For every increase in $V_D$-stress, the initial and final point is plotted. SSFM observed for (a) $T_{\text{tot}} = 3.5 \ \mu m$, however SSFM not observed for (b) $5.0 \ \mu m$.](image)

![Fig. 5. The change in the drain leakage for $\Delta I_D = (I_{\text{final}} - I_{\text{initial}}) / I_{\text{initial}}$ for $T_{\text{tot}} = 5.0 \ \mu m$ shows a stable ID leak but in $T_{\text{tot}} = 3.5 \ \mu m$ there is a sudden increase observed which is the SSFM.](image)

Even though the drain leakage for $T_{\text{tot}} = 5.0 \ \mu m$ increases (Fig. 4(b)), the ratio in drain leakage is calculated (i.e., $\Delta I_D = (I_{\text{final}} - I_{\text{initial}}) / I_{\text{initial}}$) demonstrate a stable drain leak, indicating no SSFM. On the contrary $T_{\text{tot}} = 3.5 \ \mu m$ shows the sudden increase as shown in Fig. 5, which is SSFM.

4. Conclusion

We observed two types of failure mode under biasing stress conditions using GaN HEMTs grown on silicon of total thickness ($T_{\text{tot}}$) 3.5 µm and 5 µm. For GaN HEMTs on $T_{\text{tot}} = 3.5 \mu m$, continuous biasing at 140 V caused a SSFM. On the contrary in the case of GaN HEMTs on $T_{\text{tot}} = 5.0 \ \mu m$ no trace of SSFM identified even beyond 140V $V_D$ stress but it ends in a permanent failure of device.

References