Correlation between Luminescence and Current Collapse in AlGaN/GaN HEMTs

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Introduction

AlGaN/GaN HEMTs are one of the most promising candidates for realizing ultra-low loss power switching devices. However, the performance of these devices is still limited by current collapse. In our previous study [1], we have found that O₂ plasma treatment for the AlGaN surface prior to SiN passivation resulted in reduced current collapse. Meanwhile, there have been reports that AlGaN/GaN HEMTs emit luminescence signal when operated at high drain voltages. Meneghini et al. observed luminescence at the drain edge from unpassivated GaN-based Gate Injection Transistors [2], whereas Tang et al. reported luminescence at the gate edge of the drain side in AlN-passivated AlGaN/GaN HEMTs [3]. In this paper, we present a clear correlation between luminescence and current collapse in AlGaN/GaN HEMTs subjected to O₂ plasma treatment prior to SiN passivation.

Experiments

Figure 1 shows the cross-sectional schematic illustration of AlGaN/GaN HEMTs fabricated on an SiC substrate used in this study. The epitaxial structure consists of a 500 nm GaN channel layer and a 25-nm Al₀.₂Ga₀.₈N barrier layer. For ohmic and gate electrodes, we used Ti/Al/Mo/Au and Ni/Au stacks, respectively. Prior to SiN passivation, the AlGaN surface was subjected to O₂ plasma treatment (100 W, 1 min). As reference, we also fabricated devices without O₂ plasma treatment. All devices were with a gate length of 3 µm while gate-to-drain spacing (Lgd) was either 10 or 25 µm.

Results

For evaluation of current collapse, we have measured normalized dynamic R_on (NDR), which is defined as the ratio of dynamic to static on-resistances. Detailed description on the evaluation method is found in [1]. Figure 2 shows the measured NDR as a function of off-state drain voltage (Vds). The O₂ plasma-treated device exhibited NDR values about an order of magnitude lower compared to those of the device without O₂ plasma treatment, demonstrating the effectiveness of O₂ plasma treatment in suppressing current collapse. Figure 3 shows the evolution of luminescence with increasing Vds under pinched-off conditions (I_dmax<1 mA/mm) for O₂ plasma-treated HEMTs (Lgd = 25 µm). Weak red luminescence began to appear near the gate edge of the drain side when Vds exceeded 1000 V and intensified with further increasing Vds. The current abruptly increased at 1800~1900 V, leading to device breakdown. A similar behavior was observed for devices with Lgd = 25 µm without O₂ plasma treatment. On the other hand, for the O₂ plasma-treated device (Lgd = 25 µm), as shown in Fig. 4, a white luminescence began to appear near the edge of the drain contact at Vds of around 1300 V. The luminescence intensity increased with increasing Vds until reaching breakdown at around 1700 V.

It is widely believed that electric field concentration near the gate edge is varied by surface charging [4]. Our present results suggest that O₂ plasma treatment can mitigate the effect of such negative surface charging. In other words, O₂ plasma treatment can reduce the electron trap density at the surface, presumably leading to a more uniform electric field distribution along the gate-to-drain access region.

Summary

We have investigated luminescence characteristics for O₂ plasma-treated AlGaN/GaN HEMTs prior to SiN passivation. With gradually increasing the drain bias voltage while keeping the device at off-state, we observed uniformly distributed red emission along the gate-to-drain region. Meanwhile, white emission with relatively higher intensity was observed near the drain contact edge when similar measurements were made for the device without O₂ plasma treatment. The results suggested that the O₂ plasma treatment was effective in decreasing the surface electron trap density, resulting in the reduced net surface negative charge density between gate and drain.

Fig. 1 Cross section of fabricated AlGaN/GaN HEMTs.

Fig. 2 Normalized dynamic $R_{on}$ as a function of off-state drain voltage for devices with and without O$_2$ plasma treatment. On-state duration time is 1 $\mu$s.

Fig. 3 Luminescence evolution of O$_2$ plasma-treated device ($L_{gd} = 25$ $\mu$m) with increasing $V_{ds}$: (a) $V_{ds} = 800$ V, (b) $V_{ds} = 1200$ V, (c) $V_{ds} = 1500$ V, (d) $V_{ds} = 1800$ V.

Fig. 4 Luminescence evolution of device ($L_{gd} = 25$ $\mu$m) without O$_2$ plasma treatment with increasing $V_{ds}$: (a) $V_{ds} = 800$ V, (b) $V_{ds} = 1000$ V, (c) $V_{ds} = 1200$ V, (d) $V_{ds} = 1400$ V.