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 O_2 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 O_2 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 $Al_{0.2}Ga_{0.8}N$ 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 O_2 plasma treatment (100 W, 1 min). As reference, we also fabricated devices without O_2 plasma treatment. All devices were with a gate length of 3 μm while gate-to-drain spacing (L_{gd}) 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 (V_{ds}). The O_2 plasma-treated device exhibited *NDR* values about an order of magnitude lower compared to those of the device without O_2 plasma treatment, demonstrating the effectiveness of O_2 plasma treatment in suppressing current collapse. **Figure 3** shows the evolution of luminescence with increasing V_{ds} under pinched-off conditions (I_{dmax}<1 mA/mm) for O_2 plasma-treated HEMTs (L_{gd} = 25 μm). Weak red luminescence began to appear near the gate edge of the drain side when V_{ds} exceeded 1000 V and intensified with further increasing V_{ds}. The current abruptly increased at 1800～1900 V, leading to device breakdown. A similar behavior was observed for devices with L_{gd} = 25 μm without O_2 plasma treatment. On the other hand, for the O_2 plasma-treated device (L_{gd} = 25 μm), as shown in **Fig. 4**, a white luminescence began to appear near the edge of the drain contact at V_{ds} of around 1300 V. The luminescence intensity increased with increasing V_{ds} 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 O_2 plasma treatment can mitigate the effect of such negative surface charging. In other words, O_2 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 O_2 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 O_2 plasma treatment. The results suggested that the O_2 plasma treatment was effective in decreasing the surface electron trap density, resulting in the reduced net surface negative charge density between gate and drain.

[1] Y. Sakaida *et al., CS MANTECH* 2014, 197.
[2] M. Meneghini *et al., IEEE Electron Device Lett.*, vol. 33, pp. 375-377, Mar. 2012.
[3] Z. Tang *et al., IEEE Trans. Electron Devices*, vol. 61, pp. 2785-2792, Aug. 2014.
[4] R. Vetury *et al*., *IEEE Trans. Electron Devices*, vol. 48, pp. 560-566, Mar. 2001.

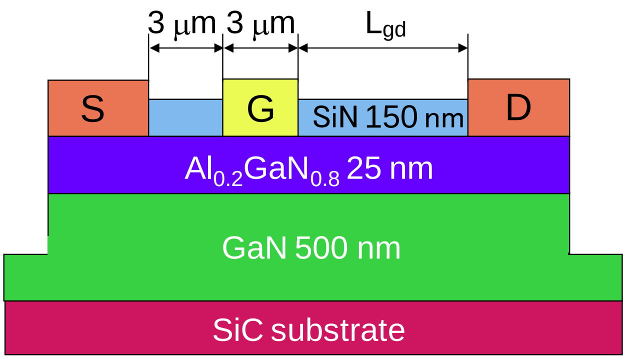

Fig. 1 Cross section of fabricated AlGaN/GaN HEMTs.

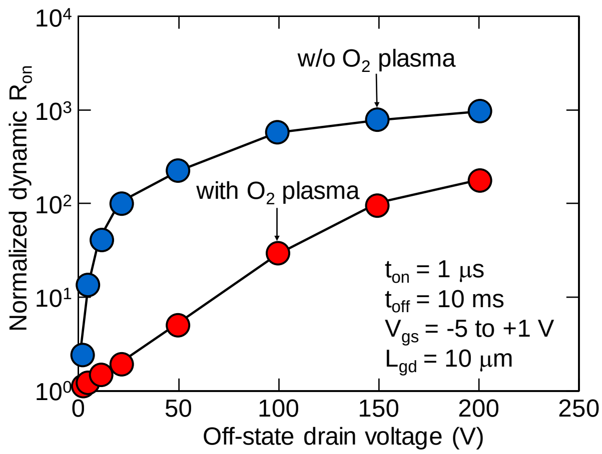

Fig. 2 Normalized dynamic R_{on} as a function of off-state drain voltage for devices with and without O_2 plasma treatment. On-state duration time is 1 μs.

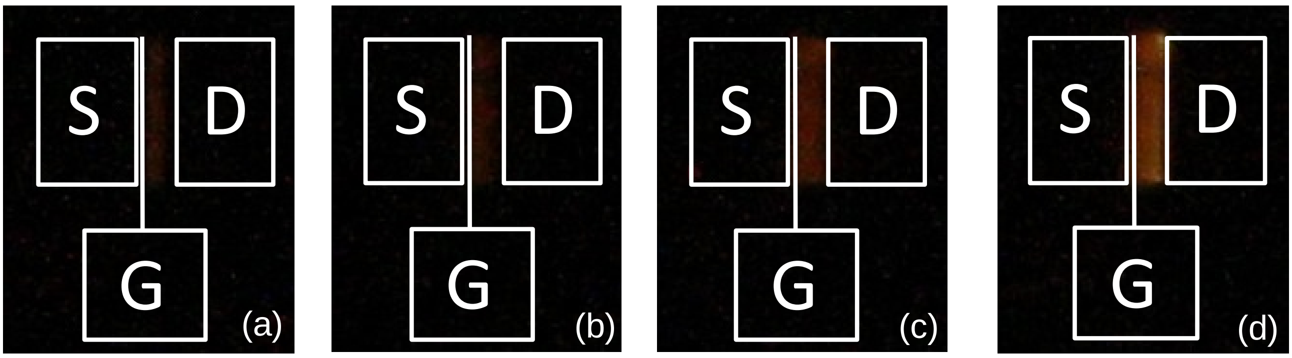

Fig. 3 Luminescence evolution of O_2 plasma-treated device (L_{gd} = 25 μm) with increasing V_{ds}: (a) V_{ds} = 800 V, (b) V_{ds} = 1200 V, (c) V_{ds} = 1500 V, (d) V_{ds} = 1800 V.

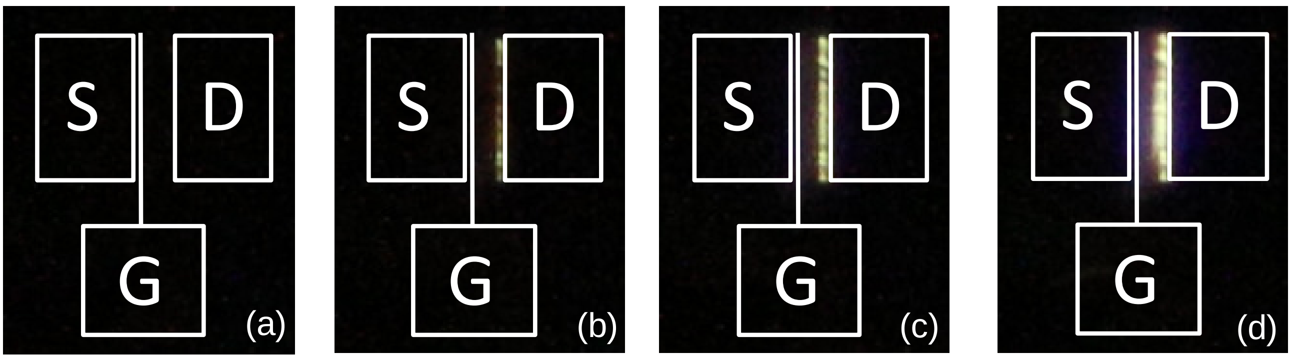

Fig. 4 Luminescence evolution of device (L_{gd} = 25 μm) without O_2 plasma treatment with increasing V_{ds}: (a) V_{ds} = 800 V, (b) V_{ds} = 1000 V, (c) V_{ds} = 1200 V, (d) V_{ds} = 1400 V.