Stability and Temperature Dependence of Dynamic $R_{ON}$ in AlN-Passivated AlGaN/GaN HEMT on Si Substrate

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Abstract

We carried out detailed characterization and evaluation of dynamic performance of high-voltage AlGaN/GaN high electron mobility transistors (HEMTs) with AlN/Si$_N$ passivation by means of pulsed I-V measurements. Transient OFF-to-ON switching testing verifies the effectiveness of surface passivation by PE-ALD-grown AlN epitaxial layer. The dynamic ON-resistance ($R_{ON}$) measured 350 ns after the switching event (500 ns) remains as low as only 1.08 times the static $R_{ON}$ with an OFF-state drain bias of 60 V. Less than 10% degradation in dynamic $R_{ON}$ is achieved under 40-V switching at various frequencies of 1-133 kHz within a wide temperature range of 50-200 °C. The stability of dynamic $R_{ON}$ is also confirmed with a simple approach by monitoring the pulsed current at a drain bias of ~1 V for 100 consecutive switching cycles.

INTRODUCTION

Power switches built on III-nitride (e.g., AlGaN/GaN) HEMT structures have shown great promise as key elements for achieving an energy-efficient power conversion system in recent years [1]. The unique and outstanding material properties (e.g., high critical breakdown electric field) of gallium nitride and the availability of high-quality heterojunctions (high 2DEG density and mobility) enable AlGaN/GaN high-voltage power HEMTs to deliver enhanced device performance that could break the limit of silicon power MOSFETs [2]. In reality, however, the intrinsic capability of GaN lateral power devices still remains out of reach due to several challenging technical issues, one of which is the higher dynamic ON-resistance ($R_{ON}$), or reduced transient ON-state drain current obtained during high-voltage drain bias switching [3].

Aimed at addressing the surface-state-relevant issue, we have recently developed an effective and robust surface passivation technology employing epitaxial AlN thin film grown in a PE-ALD system as the passivation dielectric [4-6]. Owing to the strong polarization effect in the AlN passivation layer, a large amount (~3×10$^{13}$ cm$^{-2}$) of positive polarization charges are introduced, compensating any slow-response surface/interface traps that would cause current collapse. The effectiveness of surface passivation has been verified by high-voltage OFF-to-ON switching measurements [4, 6]. However, only slow trapping effects have been investigated because the switching intervals are relatively long in the range of 0.1-1 s. In addition, it is crucial to evaluate current collapse at elevated temperatures because a power switching transistor usually operates at a high junction temperature. To date, however, only a few works on this important topic have been reported, with more severe degradation in dynamic $R_{ON}$ observed at higher temperatures [7, 8].

In this work, we carried out detailed pulsed I-V characterization in a wide temperature range (~50-200 °C) to evaluate the PE-ALD AlN passivation technique for high-voltage AlGaN/GaN HEMTs.

PULSED I-V METHOD AND DYNAMIC $R_{ON}$ EXTRACTION

The AlN-passivated HEMTs used in this study were fabricated on an Al$_{0.25}$Ga$_{0.75}$N/GaN-on-Si sample described in our previous work [6]. The device features a gate-source distance of 1 µm, a gate length of 1.5 µm, a gate width of 2 × 50 µm, and a gate-drain distance of 5 µm. In order to evaluate current collapse quantitatively, on-wafer transient switching characterization of the device is performed with an AMCAD pulsed I-V system. As shown in Fig. 1, the applied pulse width and period are 500 ns and 7.5 µs, respectively. The device is switched from OFF state to ON.
The time intervals for the ON state and the OFF-to-ON switching are both 500 ns. In Fig. 3(a), the dynamic ON-resistance of GaN HEMTs have been investigated in a wide temperature range of 50 °C to 200 °C. By measuring dynamic $R_{ON}$ during 100 consecutive 133-kHz switching cycles, its variation is shown to be less than 2.5%. The pulsed $I_D-V_{DS}$ characteristics of the pulsed output curve at a gate bias of 1 V. The testing sample is placed on the thermal chuck, for which the temperature varies from −50 °C to 200 °C.

RESULTS AND DISCUSSION

The pulsed $I_D-V_{DS}$ characteristics are plotted in Fig. 2. Low current collapse at room temperature (RT) can be implied from the subtle difference observed in the pulsed $I_D-V_{DS}$ curves measured from two quiescent bias conditions of (0 V, 0 V) and (−5 V, 60 V) in the linear regime. The larger saturation current after stress is due to the field-assisted electron de-trapping from the traps at the drain-side gate edge.

Continuous switching test for 100 consecutive cycles at a switching frequency of 133 kHz at RT is conducted with various OFF-state drain biases of 20 ~ 60 V to assess the stability of dynamic $R_{ON}$, based on a simple pulsed I-V measurement setup (Fig. 3(a)). In the ON state, $V_{GS}$ is kept at 1 V while $V_{DS}$ is swept from 0.95 V to 1.05 V with 1 mV steps. The time intervals for the ON state and the OFF-to-ON switching are both 500 ns. In Fig. 3(b), the dynamic $R_{ON}$ increases slightly with higher OFF-state drain bias due to enhanced electron trapping at AlN/GaN (passivation/cap) interface.

interface, and yet remains low (8.3% increase) and stable (2.5% variation) under 60-V drain bias switching.

Dynamic $R_{ON}$ under 40-V switching operation at various temperatures is measured at different switching frequencies of 1-133 kHz, as illustrated in Fig. 4. The dynamic $R_{ON}$ exhibits an increase of less than 10% in the wide temperature range of −50 ~ 200 °C, which differs from previous results reported in [7] and [8]. In addition, almost no frequency dispersion of dynamic $R_{ON}$ is noticed, which indicates that the electron capture process is very fast and highly suppressed.

CONCLUSIONS

Temperature dependence and stability of dynamic ON-resistance of GaN HEMTs have been investigated in detail with pulsed I-V measurements. The PE-ALD AlN passivation technique enables effectively suppressed current collapse, resulting in less than 10% dynamic $R_{ON}$ increase in a wide temperature range of −50 ~ 200 °C. By measuring dynamic $R_{ON}$ during 100 consecutive 133-kHz switching cycles, its variation is shown to be less than 2.5%.

REFERENCES


ACRONYMS

HEMT: High Electron Mobility Transistor
2DEG: Two-Dimensional Electron Gas
PE-ALD: Plasma-Enhanced Atomic Layer Deposition