Exploring GaN Trench CAVET Performance from Cryogenic to Elevated Temperatures

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Introduction

Growing demand for compact and high-performance power electronics drives the pursuit of higher power density and efficiency. With its 3.4 eV bandgap, GaN supports high critical electric fields and elevated-temperature operation, while polarization effects in its heterostructures form a two-dimensional electron gas (2DEG) with high carrier density and mobility [1]. Among GaN vertical power transistors, the current-aperture vertical electron transistor (CAVET) uniquely integrates a vertical p–n junction for sustaining off-state voltages with a lateral 2DEG channel for low on-state channel resistance. Polarization-induced 2DEG formation is not subject to the freeze-out seen with impurity doping. These attributes make CAVETs well suited for extreme-temperature environments, where devices must remain functional under high-temperature degradation while offering enhanced performance at cryogenic conditions.

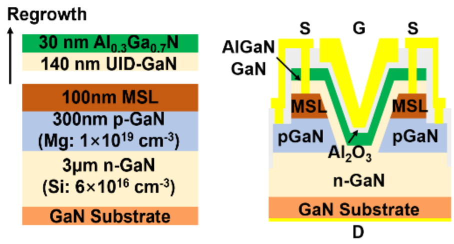

Fig. 1: Schematic of GaN trench CAVET fabricated on a GaN substrate.

Experimental Procedure

The trench CAVET (Fig. 1) was grown by an all-MOCVD process. The epitaxial p-n structure comprised a 3 µm drift layer (Si: 6×10^{16} cm^{-3}) and a 300 nm p-GaN layer (Mg: 1×10^{19} cm^{-3}). A 100 nm GaN layer was grown at low temperature to prevent Mg out-diffusion [2]. The p-GaN was etched to form the aperture, followed by TMAH wet etching. After UV Ozone+HF surface treatments, MOCVD regrowth formed a 140 nm UID-GaN and a 30 nm $Al_{0.3}Ga_{0.7}N$ layer. After isolation etching, the buried p-GaN was activated by RTA at 900 °C for 10 min. Ti/Al/Ni/Au source ohmic contact was deposited with post-annealing at 800 °C for 45 sec. Ni/Au p-GaN contact was deposited on the exposed p-GaN surface. A 15 nm ALD-Al_2O_3 was deposited as the gate dielectric. A Ni/Au gate electrode was formed on top. A Ti/Au drain contact was deposited at the backside.

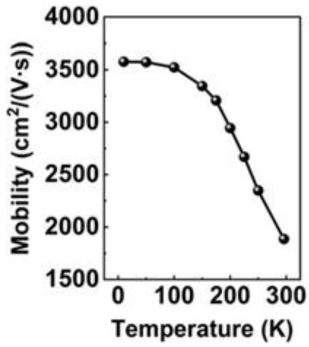

Fig. 2: Field effect mobility measured in lateral trench channel structure with identical epitaxial layers to CAVET.

Results and Discussion

Electrical characterization at a range of temperatures from cryogenic (10 K) to room temperature (296 K), and after high temperature thermal shock testing serves as a preliminary assessment for GaN CAVETs in extreme temperature applications. Threshold voltage (V_{th}) and 2DEG density remained stable throughout the 10 K to 296 K range. V_{th} had an average value of -7.45 V with standard deviation 0.069 V. 2DEG density was found with 1 MHz CV measurements to be 7.36×10^{12} cm^{-2} at 296 K and 6.83×10^{12} cm^{-2} at 10 K. Performance enhancements were observed over temperature reduction from 296 K to 10 K. Subthreshold slope (SS) decreased from 98.32 mV/dec to 51.31 mV/dec. I_{on}/I_{off} ratio increased from 3×10^9 to 9×10^{10} . Peak field effect mobility increased from 1886 cm^2 /(V·s), to 3577 cm^2 /(V·s). $R_{on,sp}$ reduced from 1.02 mΩ·cm^2 to 0.586 mΩ·cm^2.

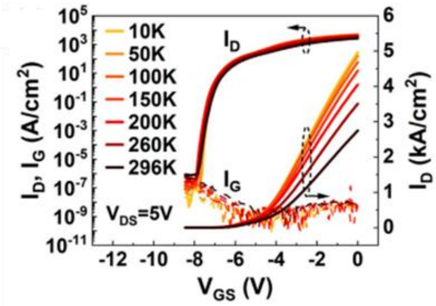

Fig. 3: I_D-V_{GS} transfer curve for trench CAVET from 296 K to 10 K.

As an initial assessment of high temperature survivability, two trench CAVETs were subjected to RTA in a nitrogen ambient for one minute at 773 K and 1073 K, respectively. The device retained qualitative transistor behavior after three 773 K thermal shock tests, with performance reductions. Off-state gate leakage current increased gradually from 10^{-5} A/cm^2 to 10^{-3} A/cm^2 . $R_{on,sp}$ increased sharply to 1.58 mΩ·cm^2 after the first test, then remained mostly stable. One 1073 K test increased gate leakage to the point (~10 A/cm^2) that the drain current could not be pinched off with gate control. $R_{on,sp}$ jumped to 24.2 mΩ·cm^2, with an according reduction in output current. Visible metal degradation and peel-off were observed.

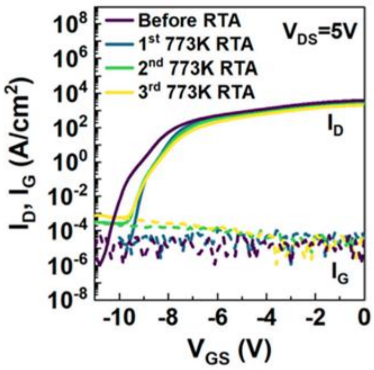

Fig. 4: I_D-V_{GS} transfer curve for trench CAVET after repeated thermal shock tests.

Acknowledgements

This work is funded by KYOCERA Corporation, Japan.

References

[1] S. Chowdhury et al., IEEE TED, vol. 60, no. 10, pp. 3060-3066, 2013.
[2] X. Wen, et al., Crystals, vol. 13, no. 4, p. 709, 2023.