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Short-term reliability assessment of sub-micron thick AlN/GaN-on-Silicon HEMTs grown by MBE for RF applications

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In this work, a submicron thick AlN/GaN-on-Silicon HEMT structure for high frequency power RF applications is reported. Using molecular beam epitaxy, an ultrathin step-graded buffer with a total stack thickness of 450 nm enables to combine an excellent electron confinement as reflected by a low drain-induced barrier lowering (DIBL) < 50 mV/V, a low leakage current around $10 \mu\text{A}/\text{mm}$ and low trapping effects up to a drain bias $V_{\text{DS}} = 30$ V while using a 100 nm gate length and a gate-to-drain distance of 500 nm. Furthermore, drain current transient (DCT) measurements using a trap filling time ranging from 100 μs to 100 s at $V_{\text{DS,Fill}} = 20$ V reveals less than 8 % current collapse below 1 s filling time, which is in agreement with the standard DC pulsed assessment. Even with a filling time as high as 100 s the current collapse is around 10 % confirming the low trapping effects despite the thin total buffer thickness grown on silicon substrate. The reduced trapping is attributed to the low impurity concentration into the epi-stack such as carbon and oxygen as observed from SIMS measurements and the high processing quality including a proper surface passivation. As a result, excellent class AB bias operation (up to $V_{\text{DS}} = 30$ V) at 40 GHz for 100 nm gate lengths GaN-on-Si HEMTs is demonstrated. The proposed AlN/GaN-on-Si HEMT structure delivers output power density of 1.1 W/mm / 2.2 W/mm together with state-of-the-art PAE of 45.6% / 35.1% at $V_{\text{DS}} = 10$ V / 30 V at 40 GHz, respectively¹ without any specific thermal management such as substrate thinning and subsequent use of heat sink. Short-term high temperature lifetime operation (HTOL) at high junction temperature during 8-hours RF stress were carried out at a chuck temperature of 150°C, $V_{\text{DS}} = 20$ V and $I_{\text{D}} = 230$ mA/mm. Under such a severe stress test, an extremely low drop of output power and PAE are observed with no failure. Despite the proximity of the dislocation density at the substrate interface, no increase of the current collapse is observed after the RF stress. The results demonstrate promising RF reliability and potentially stable ultrathin AlN/GaN-on-Si HEMTs under high-power operation.

¹ Carneiro, E. et al., *Electronics* 2023, 12, 2974. <https://doi.org/10.3390/electronics12132974>

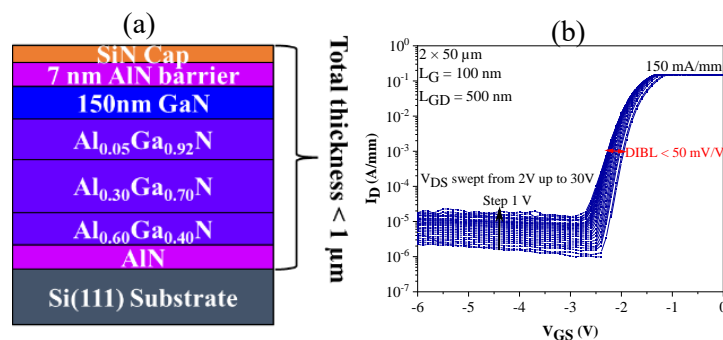


Fig. 1: (a) Schematic cross-section of the ultrathin AlN/GaN-on-Si HEMTs. (b) Transfer characteristics up to $V_{\text{DS}} = 30$ V with $L_{\text{G}} = 100$ nm and $L_{\text{GD}} = 500$ nm.

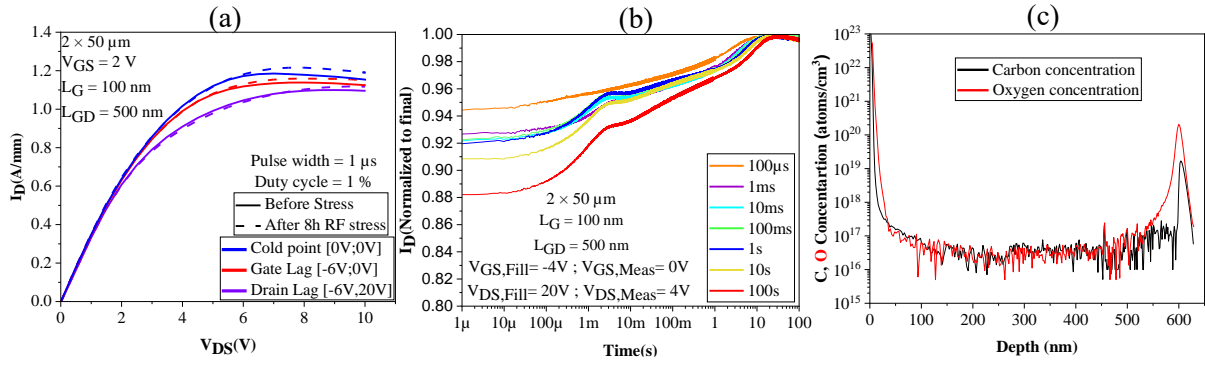


Fig. 2: (a) Open channel pulsed I_D - V_{DS} output characteristics before and after 8 hours RF stress and (b) drain current transient characteristics for various filling time. (c) Unintentional carbon and oxygen doping measured by secondary-ion mass spectrometry in the epi-stack.

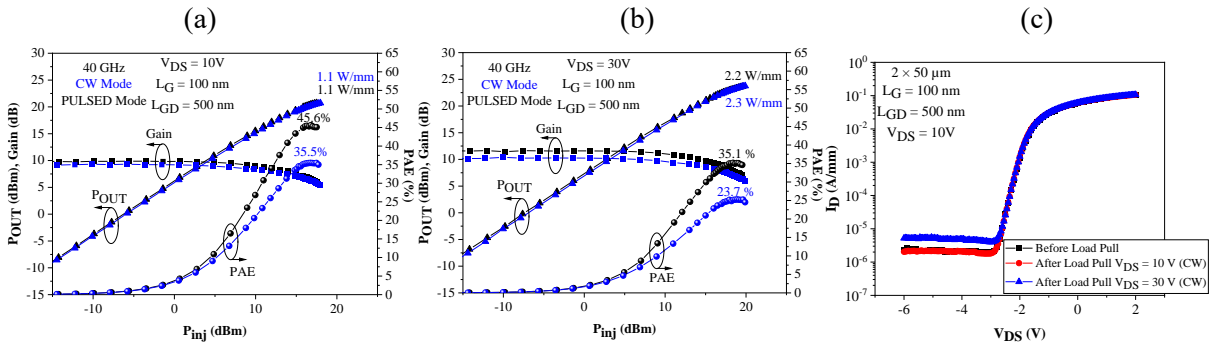


Fig. 3: Typical CW and pulsed large signal performances at 40 GHz at (a) $V_{DS} = 10\text{ V}$ and (b) $V_{DS} = 30\text{ V}$. (c) Transfer characteristics after more than 40 CW Load Pull sweeps in deep class AB under high compression up to $V_{DS} = 30\text{ V}$.

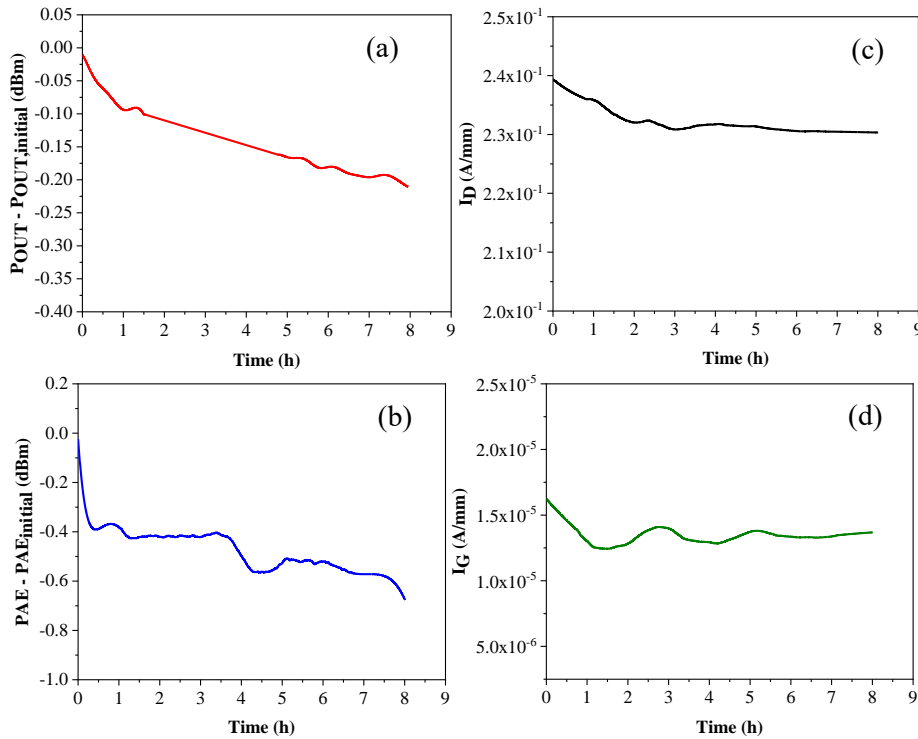


Fig. 4: Changes in (a) output power P_{OUT} , (b) PAE, (c) drain current and (d) gate leakage current during the 8 hours RF stress at $V_{DS} = 20\text{ V}$ and chuck temperature 150°C of $2 \times 50 \mu\text{m}$ ultrathin AlN/GaN-on-Si HEMT with $L_G = 100\text{ nm}$ and $L_{GD} = 500\text{ nm}$.