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Epi-design optimization in AlN/GaN HEMTs for superior drain bias operation and reduced trapping effects

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In this work, AlN/GaN HEMT structures grown on SiC substrate with various buffer architectures have been compared by means of trapping effects and related RF power performance at 40 GHz. The reference device is based on a high concentration carbon-doped buffer with a 150 nm undoped GaN channel (Fig. 1 a) enabling an excellent electron confinement but at the expense of trapping effects [1]. The second structure is similar but with a low C-doped buffer while inserting an Al_{0.25}Ga_{0.75}N back-barrier (BB) thin layer (Fig. 1 d). The thin BB is expected to maintain the electron confinement under high electric field with no thermal penalty and reduced trapping effects owing to the lower carbon concentration. Indeed, both HEMT structures deliver a low DIBL of less than 60 mV/V up to V_{DS} = 25 V. TCAD simulations show a negligible current punch-through in both cases (Fig. 2 and 3), which is not the case when using lower C-doping or lower Al-content into the BB. Moreover, the electron trapping is investigated through Drain Current Transient (DCT) measurements using a large trap filling period of 100 s, which confirms the significant reduction of current collapse when inserting the BB and using a lower carbon concentration (Fig. 1 b). This reflects the presence of traps due to point defects and nitrogen vacancies with high carbon concentration. Furthermore, DCT measurements enabled to extract the trap time constant (Fig. 1 c) and related activation energy. CW (pulsed) large signal measurements at 40 GHz revealed a PAE of 60% (70%) under a P_{OUT} > 3 W/mm at V_{DS} = 20V for the structure with high C-doped. It can be pointed out that the large CW / pulsed PAE gap is attributed to the trapping effects. On the other hand, the structure with low C-doped buffer + AlGa_N BB demonstrates state-of-the-art CW (pulsed) PAE of 67% (70%) under a P_{OUT} > 3 W/mm at V_{DS} = 20 V owing to the reduced trapping effects.

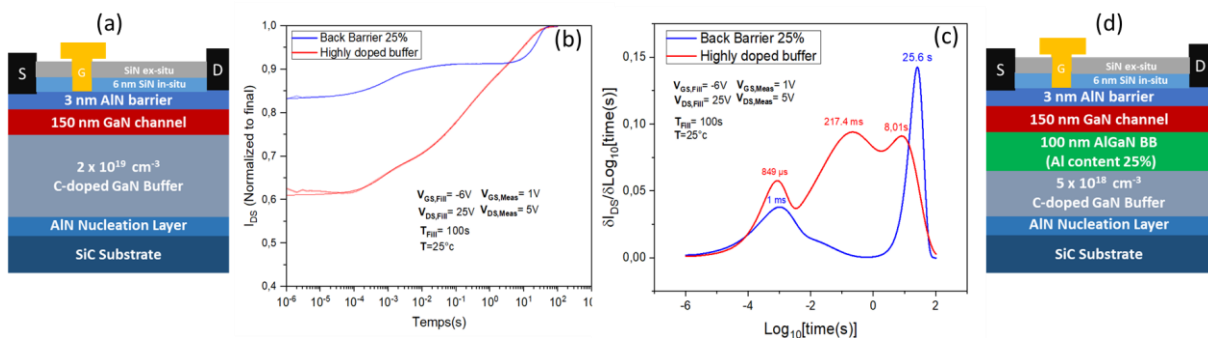


Fig. 1. DCT monitoring subsequent to 100 s filling pulse and corresponding time constants spectrum for AlN/GaN HEMTs with high C-doped GaN buffer and AlGa_N back-barrier with low C-doped buffer [1] K. Harrouche *et al.*, *Appl. Phys. Express* 2022, 15, 116504.

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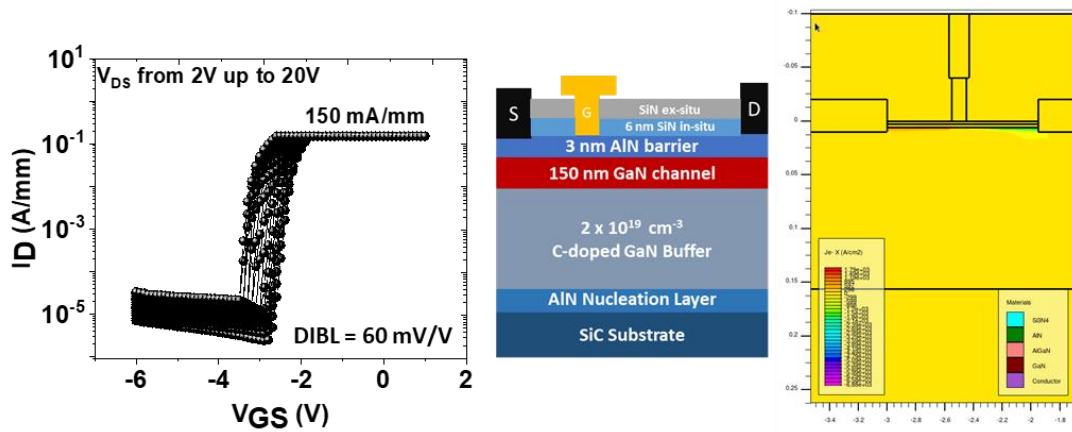


Fig. 2. Transfer characteristics from $V_{DS} = 2V$ up to $20V$ (left) and TCAD spatial current distribution plot in off-state (right) for the highly C-doped buffer structure

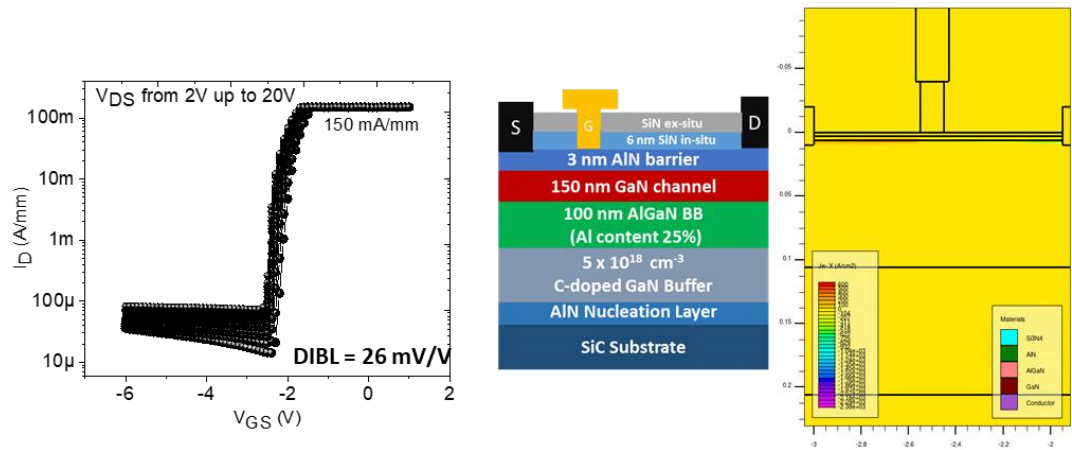


Fig. 3. Transfer characteristics from $V_{DS} = 2V$ up to $20V$ (left) and TCAD spatial current distribution plot in off-state (right) for the low C-doped buffer and AlGaIn BB structure

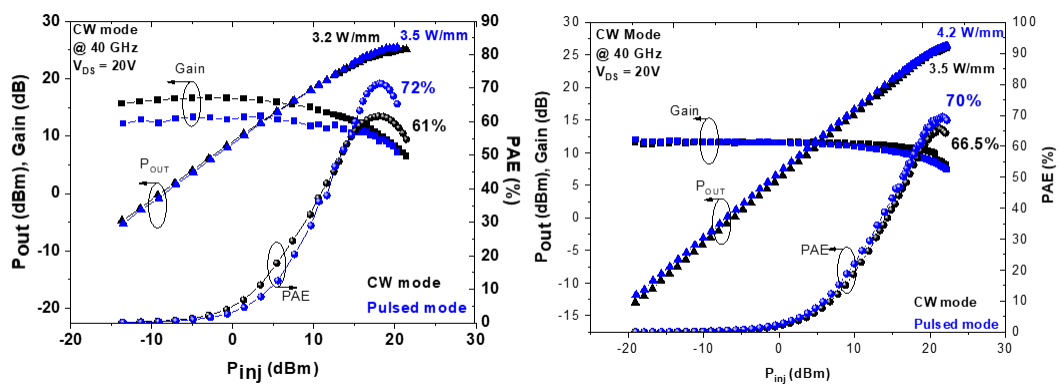


Fig. 4. CW and pulsed large signal performances at 40 GHz for the highly C-doped buffer structure (left) and low C-doped buffer and AlGaIn BB structure (right)