Epitaxial ScAlN/GaN ferroelectric transistors with a subthreshold sway of <50 mV/dec from 0.0017 to 38 mA/mm for both V_{GS} scan directions

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Ever since the first demonstration of ferroelectric switching in ScAlN,[1] the III-nitride research community has devoted tremendous efforts into the development of ScAlN/GaN ferroelectric high mobility electron transistors (HEMTs). Two generally pursued research targets are: 1) reduction of subthreshold sway (SS) in transfer characteristics by taking advantage of the negative capacitance effect during ferroelectric flipping, and 2) reconfigurable Enhance-/Depletion-mode HEMTs enabled by the large residual polarization charge density. J. Casamento et al. reported SS=28.1mV/dec for I_{DS} changing from 0.1 to 0.001 mA/mm during backward scan of V_{GS}, while a very high SS was observed during forward scan.[2] Similar phenomenon was demonstrated by P. Wang et al., with a SS<50 mV/dec for I_{DS} changing from 0.004 to 1×10^{-5}mA/mm during backward scan and a SS>100 mV during forward scan.[3] To date, ferroelectric reduction of SS was widely observed in "OFF" state, *i.e.*, for I_{DS} in the μA/mm range. Herein, we demonstrate a ScAlN/GaN ferroelectric transistor with a SS<30 mV/dec for backward scan and a SS<50 mV/dec for forward scan. The ON/OFF state I_{DS} is 38/0.0017 mA/mm, respectively, and the ON/OFF transition occurs within 0.1V, promising drastic reduction of power consumption during HEMT ON/OFF switching.

Figures 1(a) and (c) show the schematics of two ScAlN samples grown by molecular beam epitaxy. Sample 241015B is 100-nm ScAlN sandwiched by 5-nm AlN layers and capped by 5-nm GaN surface protection layer grown on a 4μm-GaN-on-Sapphire template. The sample was fabricated in a capacitor for ferroelectric Polarization-Electrical field characterization (P-E). Sample 241218A is a ScAlN/GaN heterostructure with 10 nm ScAlN barrier layers for the fabrication of ferroelectric HEMT. XRD characterization of Sample 241018A exhibit sharp (002) and (102) peaks, evidencing single-crystalline ScAlN epilayer with (002)/(102) ω rocking curves of 986/267 arcsec. Hall effect measurements of as-grown sample 241218A at 300K/77K demonstrates a two-dimensional electron gas (2DEG) density of $\sim2.5\times10^{13}$cm^{-2}, shown in Table I. In Fig. 2(a), unambiguous ferroelectric switching current peaks were observed at applied voltage of ±9.7V, corresponding to a coercive field of 0.97 MV/cm. P-E curves in Figs. 2(b) and (c) demonstrate a clear wake-up process in the first 20 scans, and afterwards, the residual polarization (P_r) stabilized at 54μC/cm^2. Several groups have reported different values of P_r,[1-5] which could be related to ScAlN deposition method, defects and even interaction between ferroelectric flipping with the underlying 2DEG as unintentionally doped GaN buffer was grown in this case. Further investigation on the discrepancy in P_r is ongoing. The transfer characteristics of HEMT in Fig. 2(d) demonstrates hysteresis curves, with sharp turn off gate voltage (V_{GS}) at -11.6 V and sharp turn on V_{GS} at -5.2V while V_{DS} is 10V. We found that the threshold voltage turning range shrinks as V_{DS} decreases. At V_{DS}=0.5V, almost no hysteresis was observed. This work paves path towards 'digital' GaN HEMTs without a subthreshold zone.

Reference

[1] S. Fichtner et al. J. Appl. Phys. 125, 114103 (2019). [2] J. Casamento et al. arXiv:2302.14209v, (2023). [3] P. Wang et al. Appl. Phys. Lett. 122, 090601 (2023). [4] J. Yang et al. IEEE Electron Dev. 44, 1260 (2023). [5] Z. Zhao et al. Appl. Phys. Express, 16, 031002 (2023).

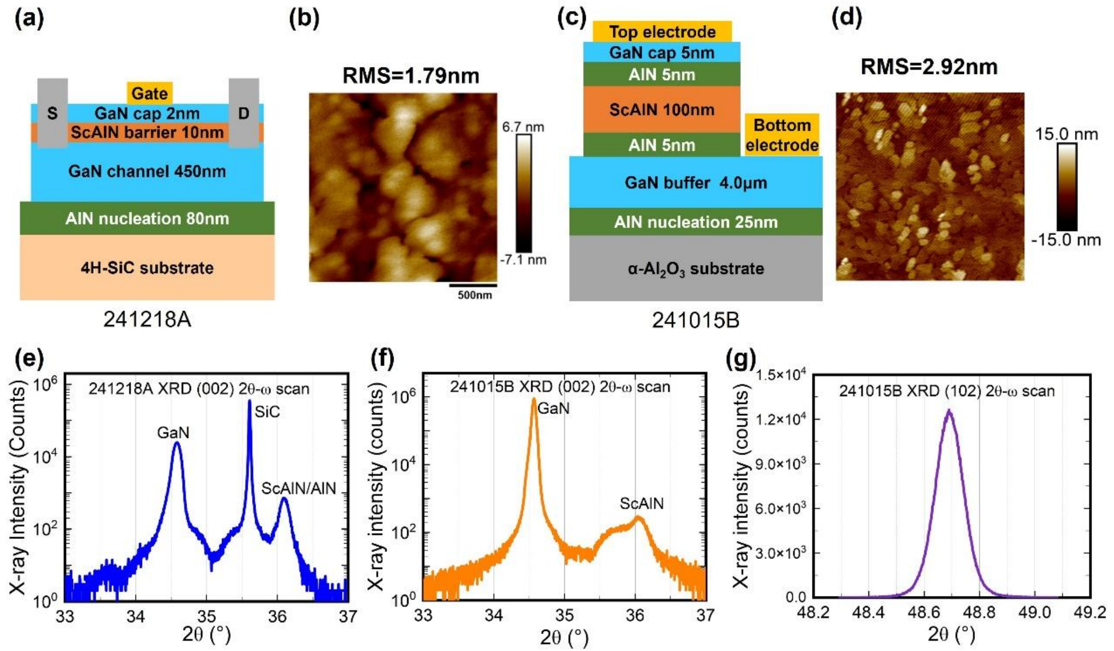

Figure 1. Structural schematics and AFM images of Sample 241218A [(a) and (b)] and Sample 241015B [(c) and (d)]. (e) XRD (002) 2θ-ω scan of 241218A. (f) and (g) XRD (002) and (102) 2θ-ω scans of 241015B.

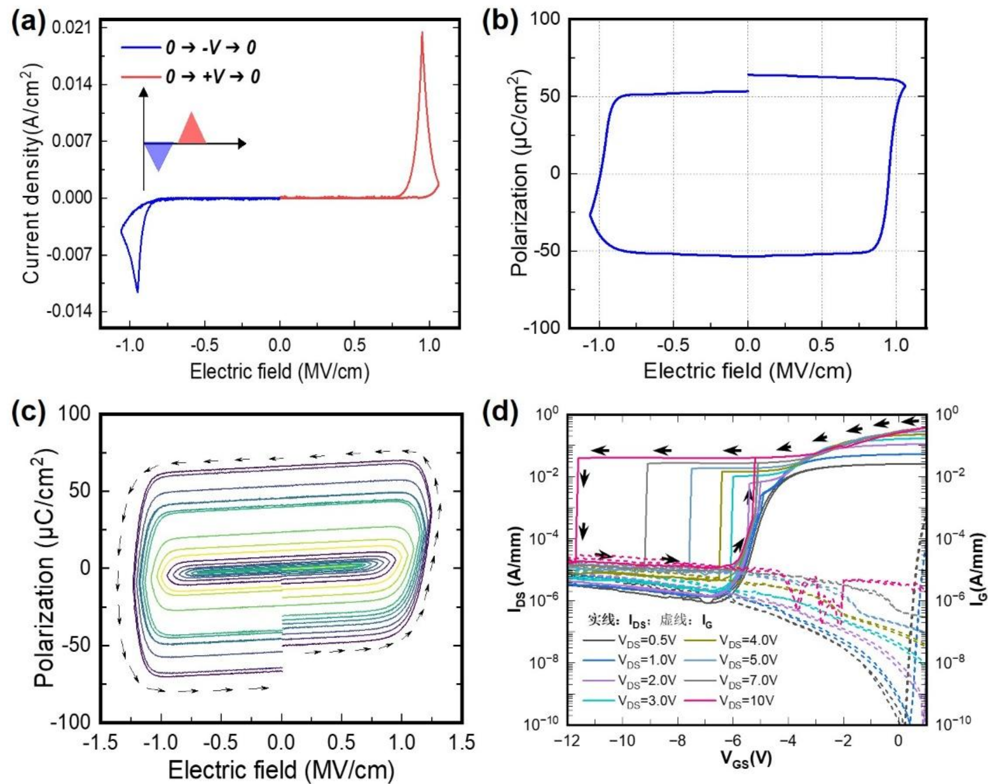

Figure 2. (a) I-V, (b) and (c) P-E curves of Sample 241015B. (d) Transfer characteristics of Sample 241218A.

Table I. Hall effect measurement on Sample 241218A.

Temperature	R_{Sheet} (Ω/□)	Mobility (cm^2/V·s)	2DEG(/cm^2)
300K	293	860	2.47×10^{13}
77K	157	1600	2.49×10^{13}