Dielectric Engineering Using High-k $BaTiO_3$ and in-situ SiN for Breakdown Enhancement and Current Dispersion Suppression in AlN/GaN HEMTs

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AlN/GaN high electron mobility transistors (HEMTs) are promising for millimeter wave (mmW) range high-power amplification realm because of its better scalability due to the high gate aspect ratio and an extremely high 2DEG density and thus a high current drive capability than conventional AlGaN/GaN HEMTs[1]. However, the devices suffer from a low breakdown voltage due to the high electron density[2], and quite often high current dispersion[3]. In this work, we report a high-k $BaTiO_3$ (BTO)/Al_2O_3/in-situ SiN dielectric structure underneath the gate for passivation and field management for breakdown voltage enhancement and suppression of current dispersion.

The BTO film was deposited by RF sputtering. To characterize the dielectric constant and breakdown field, metal (Pt) / insulator (BTO) /metal (Pt) (MIM) capacitors were fabricated. Figure 2(a) shows the dielectric constant extracted from C-V as a function of electrical field. The dielectric constant is weakly dependent on the electrical field with a value of ~ 247 at 200 kV/cm. The deposited BTO film has a breakdown field of ~ 3.3 MV/cm from I-V measurements for the MIM structure as shown in Figure 2(b).

A schematic structure of the fabricated BTO/Al_2O_3/in-situ SiN/AlN/GaN HEMTs (BTO HEMTs) is shown in Figure 1(b). A stack of in-site SiN, ALD Al_2O_3, and BTO is used for passivation and field management. The devices have T-gates with L_g = 110 nm fabricated by electron beam lithography. Control devices, without BTO and Al_2O_3 gate dielectrics (SiN HEMTs), with the same device dimensions, were also fabricated for comparison. The output DC and pulsed IV characteristics of the fabricated BTO HEMTs are shown in Figure 3. Here the iso-trap condition has a maximum output current density I_{max} = 1.91 A/mm, which is higher than the DC condition and very close to isothermal condition, showing essentially no current dispersion. The device also shows no keen walk-out under pulse biases. At $V_{g\,(max)}$ = 2 V, the BTO HEMTs demonstrated I_{max} = 2.21 A/mm. Three terminal off-state breakdown characteristics were measured as shown in Figure 4. The BTO HEMTs exhibited a high breakdown voltage of 67.5 V in comparison with 24.6 V for the SiN HEMT, benefiting from the extremely high dielectric constant of BTO that results a more uniform distribution of electrical field.

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[1] Y. Tang, et al., *IEEE Electron Device Lett* 36 (6), 549 (2015).
[2] S. M. Han, et al., *IEEE J Electron Dev* 3 (3), 267 (2014).
[3] A. Hickman, et al., *IEEE Electron Device Lett* 40 (8), 1293 (2019).

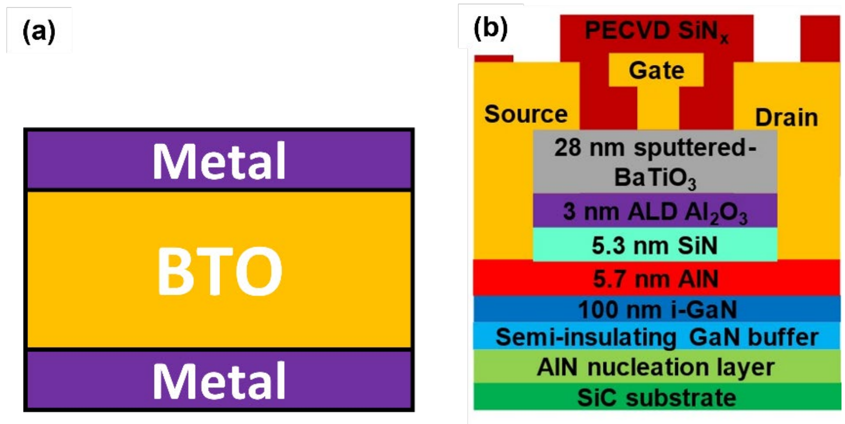

Figure 1: Schematic of (a) the fabricated MIM structure and (b) epitaxial stack of BTO /Al_2O_3/in-situ SiN/AlN/GaN HEMTs.

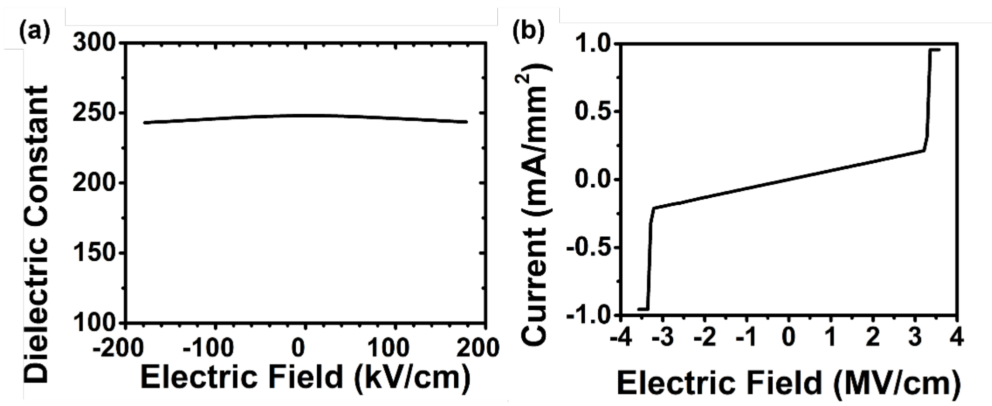

Figure 2: (a) Dielectric constant extracted from C-V as a function of electrical field . (b) Breakdown characteristics of the MIM structure from two terminal I-V measurements .

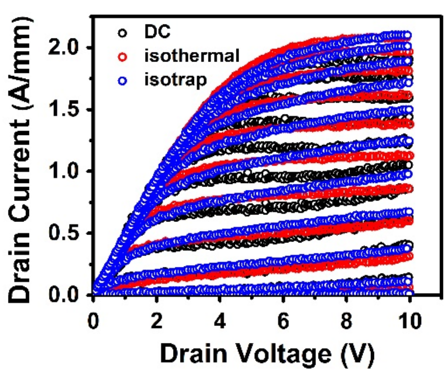

Figure 3: DC family I-Vs, off-state pulse I-Vs at quiescent bias conditions of $V_g = -11$ V, $V_d = 10$ V (iso-trap) and at quiescent bias conditions of $V_g = 0$ V, $V_d = 0$ V (isothermal). The gate is biased from 0 to − 11 V with a step of − 1 V.

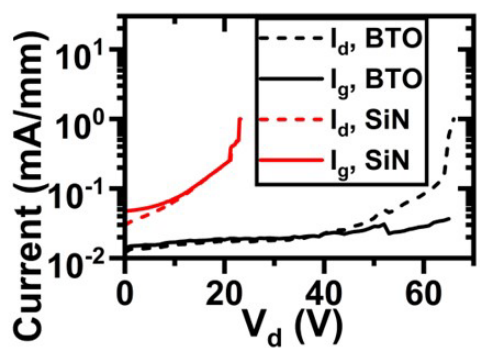

Figure 4: Representative device three terminal breakdown characteristics under $V_{g\ (BTO\ HEMTs)}$ = - 12V and $V_{g\ (SiN\ HEMTs)}$ = - 10 V for a gate-to-drain spacing L_{gd} = 0.6 μm.