

Supplementary Materials

Mitigation of Substrate Bias Effect by Front-Side Local Si Removal in GaN-on-Si HEMTs

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S1. The gate and substrate leakage characteristics of different devices.

The same measurement methods were used to characterize the gate and substrate leakage currents of all three device structures. For the gate leakage current measurements, the substrate, drain, and source voltages were maintained at 0 V ($V_{\text{sub}} = 0$ V, $V_d = 0$ V, $V_s = 0$ V), while the gate voltage (V_g) was swept from -15 to 15 V and the corresponding gate leakage current was recorded. For the substrate leakage current measurements, the gate, drain, and source voltages were maintained at 0 V ($V_g = 0$ V, $V_d = 0$ V, $V_s = 0$ V), while the substrate voltage (V_{sub}) was swept from 0 to 500 V and the corresponding substrate leakage current was recorded.

The gate and substrate leakage currents remain within comparable ranges across the three device structures. These results indicate that, under the measurement conditions shown in Fig. S1, neither the deep etching employed in the FSR device nor the combination of deep etching and photoresist filling used in the Filled device causes an abnormal increase in gate or substrate leakage current.

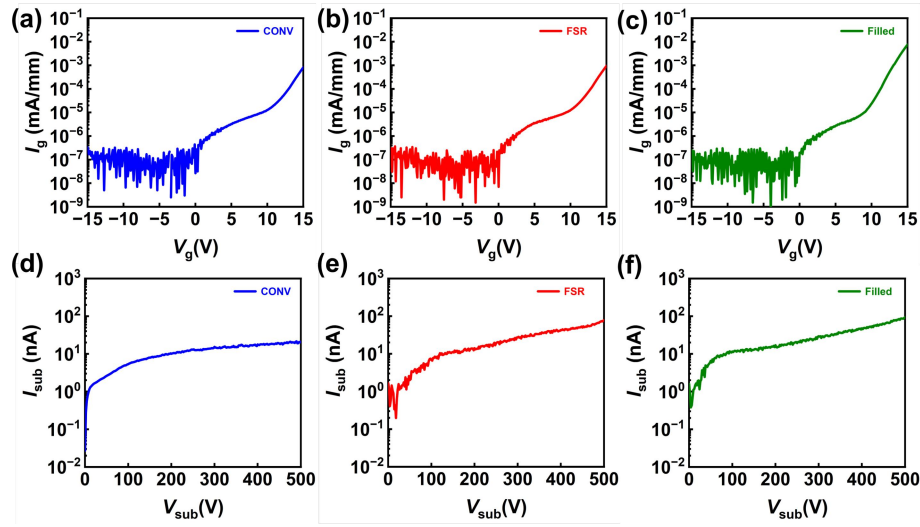


Fig. S1. Leakage characteristics of different devices. (a–c) Gate leakage-current density and (d–f) substrate leakage current for the (a, d) CONV, (b, e) FSR, and (c, f) Filled devices.

S2. The temperature-dependent transfer characteristics of different devices.

The same temperature-dependent transfer-characteristic measurement method was applied to all three device structures. During the measurements, the drain and substrate voltages were fixed at $V_d = 10$ V and $V_{sub} = 0$ V, respectively, while the gate voltage was swept from -15 to 5 V to obtain the transfer characteristics at different temperatures. At each temperature (50 , 75 , and 100 °C), the devices were first heated to the specified temperature. After thermal stabilization was achieved, the temperature was maintained for an additional 10 min before the electrical measurements were performed.

As shown in Fig. S2, all three device structures exhibit similar temperature-dependent trends, including a negative shift in the threshold voltage and an increase in the off-state leakage current with increasing temperature. Within the investigated temperature range, no clear evidence of enhanced temperature sensitivity is observed for the FSR or Filled device compared with the CONV device.

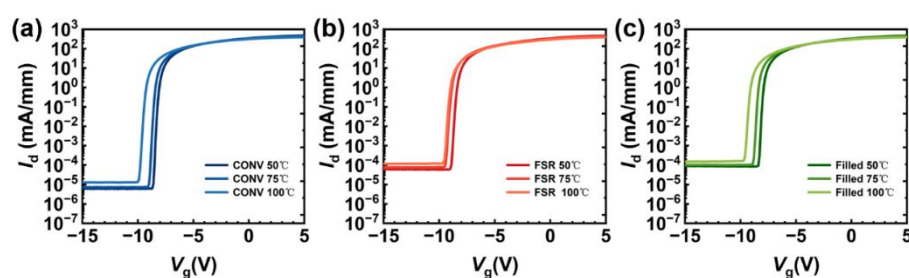


Fig. S2. Temperature-dependent transfer characteristics of the (a) CONV, (b) FSR, and (c) Filled devices measured at 50 , 75 , and 100 °C.

S3. The time-dependent normalized drain current of CONV and Filled devices at various temperatures.

The same temperature-dependent transient drain-current measurement protocol was applied to the CONV and Filled devices. During the measurements, the drain and gate voltages were maintained at $V_d = 10$ V and $V_g = 0$ V, respectively. At each target temperature (25, 50, 100, and 150 °C), the devices were thermally stabilized and maintained at the specified temperature for an additional 10 min. The transient measurement was then initiated by stepping the substrate voltage from 0 to -200 V. The moment at which $V_{\text{sub}} = -200$ V was applied was defined as $t = 0$.

The normalized drain current was calculated as $\text{Normalized } I_d = I_{d(t)}/I_{d,\text{max}}$, where $I_{d,\text{max}}$ represents the maximum drain current recorded during the corresponding transient measurement. As shown in Fig. S3, the normalized drain current of the CONV device under $V_{\text{sub}} = -200$ V exhibits a pronounced temperature dependence. In contrast, the corresponding normalized drain current of the Filled device remains nearly unchanged over the investigated temperature range. These results suggest that the Filled structure effectively suppresses electrical coupling between the substrate and the active region, thereby reducing the influence of substrate bias on the device characteristics.

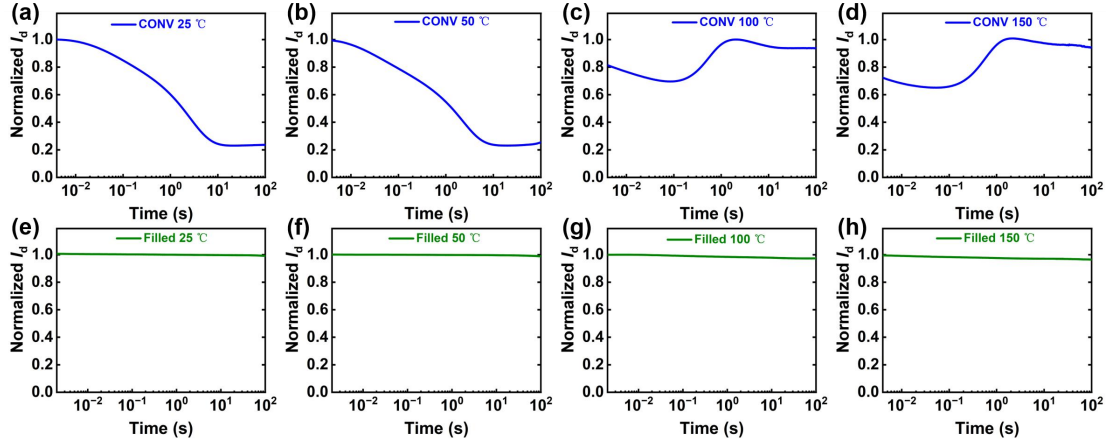


Fig. S3. Time-dependent normalized drain current of the (a–d) CONV and (e–h) Filled devices under a substrate bias of $V_{\text{sub}} = -200$ V and a drain bias of $V_d = 10$ V at temperatures of (a, e) 25 °C, (b, f) 50 °C, (c, g) 100 °C, and (d, h) 150 °C.

S4. The maximum transconductance as a function of substrate bias voltage of different devices.

The maximum transconductance ($g_{m,max}$) values were extracted from the transfer characteristics of the three devices measured at different substrate biases with $V_d = 10$ V. As shown in Fig. S4, $g_{m,max}$ of the CONV device decreases substantially with increasingly negative substrate bias, decreasing from approximately 92.50 mS/mm at $V_{sub} = 0$ V to approximately 35.46 mS/mm at $V_{sub} = -200$ V. In contrast, the FSR and Filled devices exhibit small variations in $g_{m,max}$ over the same substrate bias range. These results further support that removing the Si substrate beneath the active region effectively suppresses the modulation of device characteristics by the substrate bias.

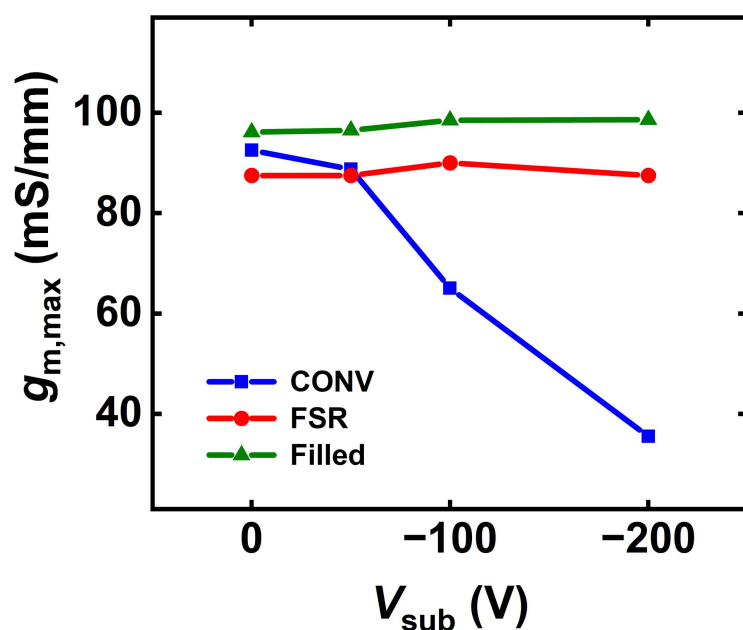


Fig. S4. Maximum transconductance as a function of substrate bias voltage for the CONV (blue), FSR (red), and Filled devices (green).