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# Suppression of the regrowth interface leakage current in AlGaN/GaN HEMTs by Fe doped GaN substrate

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In the process of homoepitaxy AlGaN/GaN heterojunction by metal-organic chemical vapor deposition (MOCVD) on free-standing substrates, Si impurities from the air and reaction chamber accumulate at the regrowth interface [1], forming a leakage path in the AlGaN/GaN high electron mobility transistor (HEMT) [2]. In this study, we quantified the leakage current at the regrowth interface, compensated the interfacial n-type leakage channel by Fe impurities, and subsequently introduced a Fe-stopper to inhibit Fe diffusion to improve the device output current.

*Experiments.* The device fabrication process utilizes a standard normally-off HEMT process. The device geometry of GaN-HEMT consists of a finger-type gate ($W_g$ of 300 μm and $L_g$ of 6 μm) $L_{\rm gs}$ of 3 μm, and $L_{\rm gd}$ of 9 μm. The device structure is shown in Figure 1(a). Sample A refers to the device on the GaN/sapphire template, while the Fe-doped SI substrate device is defined as Sample B and Sample C is the device with Fe-stopper for clarity in subsequent discussions.

*Results and discussions.* We first studied the IV characteristics ($I_{\rm DS}$-$V_{\rm DS}$) of Sample A at $V_{\rm GS} = -8$, 2 V, as shown in Figure 1(b). The device shows an unusually large leakage current of 160 mA/mm, and the output characteristics indicate an abnormal trend of forward on-state current in the saturation region, which is comparable in magnitude to the leakage current. In the absence of intentionally doping Si, secondary ion mass spectrometry (SIMS) measurement revealed a significant Si pileup layer with a density as high as 2E18/cm$^3$ at the regrowth interface at 600 nm, as shown in Figure 1(c). To evaluate the leakage current induced by Si pileup layer and considering the actual Si impurity concentration according to SIMS result, we simulated the leakage current of the device at $V_{\rm GS} = -8$ V by Silvaco. Cross-

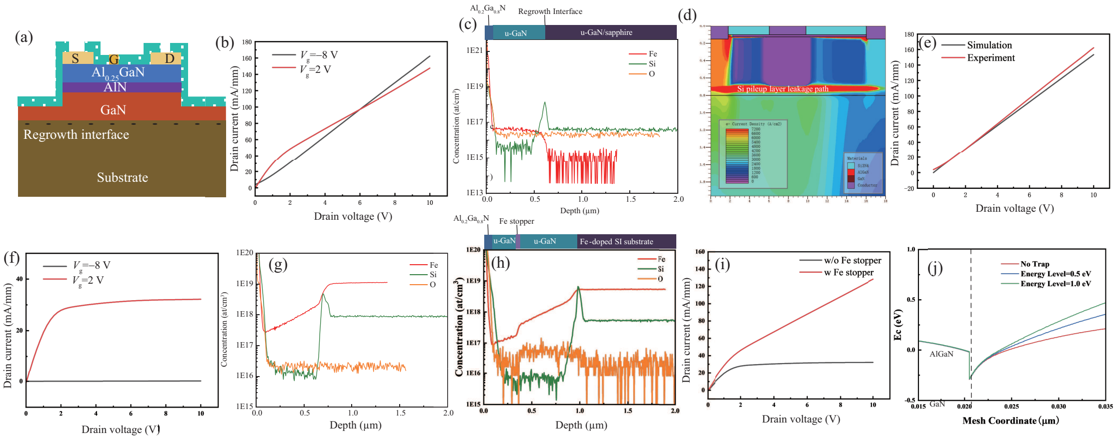

**Figure 1** (Color online) (a) Cross-sectional view of the device; (b) output characteristics and (c) SIMS profiles of Sample A; (d) distribution of current density on a device cross section; (e) simulation of off-state leakage current at $V_{\rm GS} = -8$ V; (f) output characteristics of Sample B at $V_{\rm GS} = -8$, 2 V; (g) SIMS profiles of Sample B; (h) SIMS profiles of Sample C with Fe diffusion stopper layer; (i) output characteristics of HEMTs w or w/o Fe stopper layer at $V_{\rm GS} = 2$ V; (j) AlGaN/GaN conduction band structures with different energy levels of the acceptor traps at $V_{\rm GS} = 0$ V.

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section of Sample A in Figure 1(d) indicates a significant leakage current at the regrowth interface. Figure 1(e) shows the reliability of this simulation analysis for regrowth interface leakage current and further emphasizes that this leakage current primarily originated from the high-density Si impurities.

As shown in Figure 1(f), the IV characteristics of Sample B ($V_{\rm GS} = -8$, 2 V) are presented. Compared to Sample A, the leakage current of Sample B ($V_{\rm GS} = -8$ V) is reduced to 0.16 mA/mm, and the device output curve in the saturation region also exhibits a more stable saturation current, The SIMS results of Sample B in Figure 1(g) shows that the memory effect of Fe compensated for charge carriers and reducing leakage current, meanwhile.

In order to suppress the further diffusion of Fe into the two-dimensional channel, we prepared Sample C with Fe diffusion stopper layer [3]. Figure 1(h) shows that the concentration of Fe impurity in the Fe diffusion stopper layer drops sharply. The concentration of Fe impurity in the two-dimensional channel layer of Sample C decreases from 2E17/cm$^3$ in Sample B to 8E16/cm$^3$, and the output current of the device increases from 36 to 140 mA/mm. As shown in Figure 1(i). As shown in Figure 1(j), the presence of electron traps in the GaN buffer layer enhances the conduction band of the GaN buffer layer, leading to a lower two-dimensional electron gas (2DEG) density.

*Conclusion.* The Fe impurity concentration in the 2DEG channel is effectively reduced by introducing the Fe diffusion stopper layer. This study focuses on understanding how Si pileup layer affects the electrical characteristics of HEMT, quantifying the contribution of interface Si pileup layer to leakage current, and explaining how Fe influences the electrical performance of AlGaN/GaN HEMTs with regrowth interface.

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