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Study of the Leakage Current Mechanisms in Quasi-Vertical GaN-on-Silicon Schottky Diode Fabricated by Localized Epitaxy

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Abstract— in this work, temperature-dependent current-voltage characteristics was measured to investigate leakage conduction mechanisms in GaN-on-Si quasi-vertical Schottky barrier diode grown with localized epitaxy. At low reverse bias (-0V to -10V), thermionic emission and Frenkel-Poole are dominated, at a relatively high voltage range (-10V to -40V), the increased electric field promotes the electron hopping along the threading dislocation in the bulk GaN layers, and VRH becomes the main current mechanism at whole temperature range.

I. INTRODUCTION

Gallium Nitride (GaN) has become increasingly popular in the realm of power devices due to its remarkable properties such as wide bandgap, high electron mobility, and a strong breakdown field strength. A few research have been done on vertical GaN on Si power devices using localized growth [1], [2]. In this work we demonstrates quasi vertical GaN Schottky barrier diodes (SBDs) grown on Si Substrate using localized Epitaxy [3], as well as investigating electrical performance in forward and reverse. To understand the mechanisms responsible for leakage, temperature dependent reverse leakage characterization were performed and analyzed analytically [4].

II. DEVICE FABRICATION

Fig. 1 shows the schematic cross-section view of the fabricated quasi-vertical GaN SBD. The structure consists of $5\mu\text{m}$ n-GaN drift layer, three n+-GaN layers with 350 nm ($5 \times 10^{16}\text{ cm}^{-3}$, $5 \times 10^{17}\text{ cm}^{-3}$ and $5 \times 10^{18}\text{ cm}^{-3}$ from the bottom to the top) as current spreading layer, and 300 nm u-GaN and finally AlGaN/AlN buffer layer, grown on p-type 4-inch (111) Si substrate by MOVPE. The SEM image and Stylus profilometry are illustrated in Fig. 2.

III. RESULTS AND DISCUSSIONS

Fig. 3 depict the typical capacitance-voltage measurement of the diode, the extracted net doping concentration in n-drift region is $\sim 5 \times 10^{16}\text{ cm}^{-3}$. Fig. 4(a) showed the forward J-V characteristics in semi-log scale for quasi vertical Schottky diode, showing a low turn on voltage $\sim 0.6\text{ V}$ and a good ON/OFF current ratio of 10^8 . As shown in Fig. 4(b), the device achieve a high current density of 2.5 kA/cm^2 at 5 V and low R_{on} of $1.9\text{ m}\Omega\cdot\text{cm}$ at 5 V despite the current crowding effect on the edges. The extracted ideality factor and Schottky barrier height where close to 1.03 and 1.1 eV respectively. Fig. 5(a) and 5(b) show the temperature-dependent forward characteristics of the SBD. As shown in the inset of Fig. 5(a), as the temperature increases, the differential $R_{on,sp}$, increases from to the reduced

electron mobility mainly from thermal enhanced phonon scattering. In Fig. 5(c) the ideal factors η increases from 1 to ~ 2 with temperature indicating the impact of the surface traps on devices performances, which is well confirmed by the change in barrier with temperature. Which suggest the thermal instability of the Schottky contact in the SBD at high temperatures. The experimental Richardson's constant is $4.59\text{ A cm}^{-2}\text{ K}^{-2}$. This underestimation could be explained by the inhomogeneous barrier [5].

Fig. 6(a) shows reverse I-V characteristics of the GaN vertical SBD. The destructive BV of the SBD is $\sim 80\text{ V}$ probably due to the absence of Edge termination and the higher doping in drift layer. Fig. 6(b) shows the measured temperature-dependent reverse I-V characteristics of the SBD up to -40 V . The characteristics can be divided into three different voltage regions. Fig. 6(c) depicts the current density as a function of $1000/T$. Three regions with different characteristics are identified, which are marked as "A", "B" and "C". Region "A", is near zero bias with high temperature dependence which indicates the TE is the main mechanism in this region, while region "B" is from -0.5 to -10 V which is dominated by the Frenkel-Poole process. And region "C" from -10 to -40 V that can be attributed to the variable range hopping (VRH) [4]. It is worth pointing out that these mechanisms have been well confirmed with the extracted parameters.

IV. CONCLUSION

In conclusion, temperature-dependent reverse bias I-V characteristics in a range of $300\text{--}433\text{ K}$ was measured and the leakage current transport mechanisms were investigated for a GaN-on-Si quasi-vertical SBD grown by localized epitaxy. At low voltage (Region A & B: 0V to -10V), the current density (J) follows a linear relationship with $1/T$. This characteristic correspond to the TE and PFE leakages process [4]. While at high voltage (Region C: -10V to -40V), the leakage current becomes insensitive to the temperature which suggest the domination of VRH mechanism. Therefore, this work gives an in-depth insight for the leakage mechanisms and provides a useful guidance to improve GaN vertical power devices.

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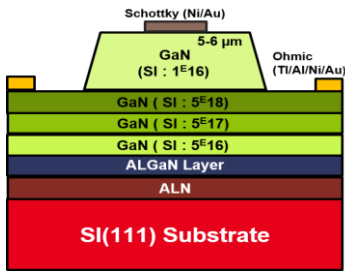


Figure 1. The schematic cross-section of quasi-vertical diode with localized growth.

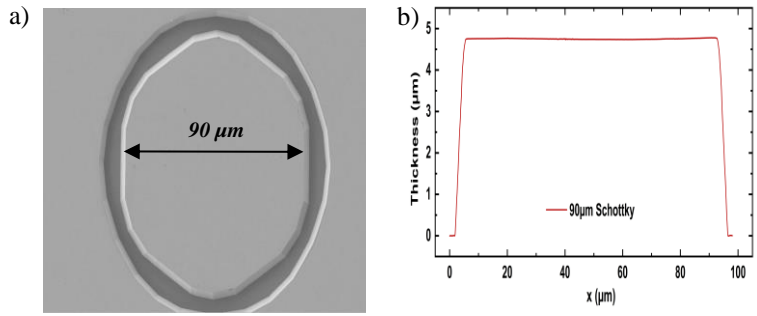


Figure 2.a) The SEM image and b) Stylus profilometry of the fabricated quasi-vertical GaN SBD.

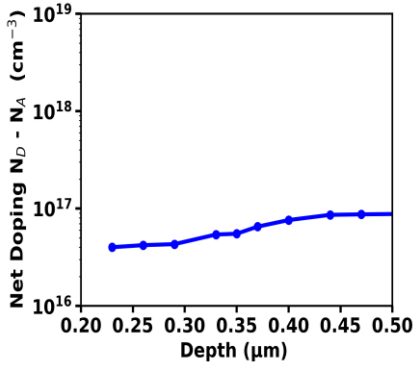


Figure 3. Extracted depth dependent net doping concentration in the n—GaN drift layer from the CV curve.

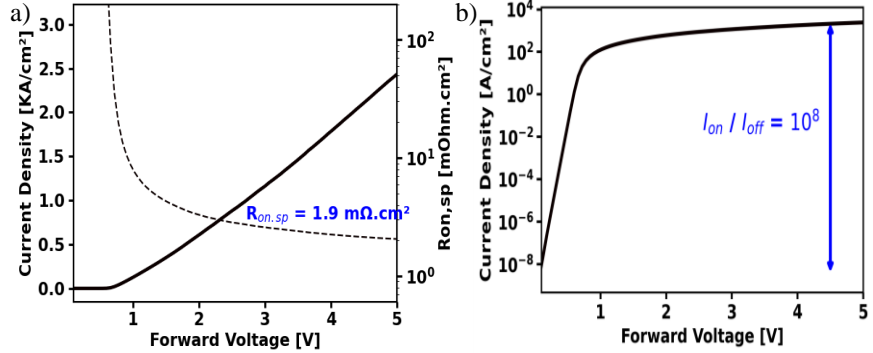


Figure 4. Forward I-V curves of SBD in a) linear scale and b) semi-log scale.

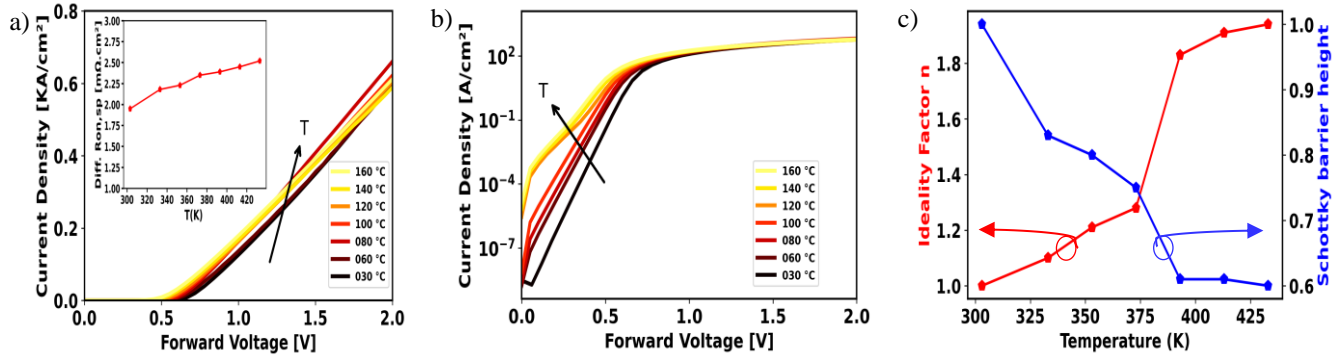


Figure 5(a) Temperature-dependent forward I-V characteristics on the linear scale. Inset: differential specific on-resistance $R_{on,sp}$ as a function of temperature T . (b) Temperature-dependent forward I-V characteristics on a semi-log scale..(c) Extracted ideality factor n and Schottky barrier height as a function of temperature for the Metal/n-GaN Schottky contacts.

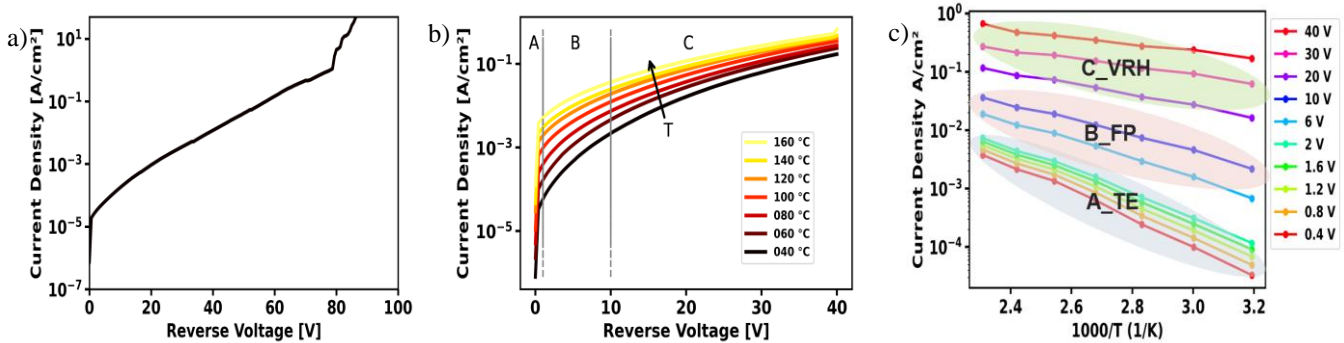


Figure 6(a) Breakdown characteristic of the fabricated quasi-vertical GaN (b) Temperature-dependent Reverse I-V characteristics on the log scale.(c). current density vs. temperature at different voltages (Region A : Thermionic Emission « TE », Region B : Frenkel-Poole « FP » and Region B : Variable Range Hopping « VRH »).