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Vishwajeet Maurya, Daniel Alquier, Hala El Rammouz, Pedro Fernandes Paes Pinto Rocha, Eugénie Martinez, et al.. Low leakage and high breakdown voltage GaN-on-GaN Schottky diode by TMAH surface treatment.. GaN Marathon 2024, Jun 2024, Verona, Italy. 2024. cea-04667618

HAL Id: cea-04667618

<https://cea.hal.science/cea-04667618v1>

Submitted on 5 Aug 2024

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Low leakage and high breakdown voltage GaN-on-GaN Schottky diode by TMAH surface treatment.

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Abstract—In this study, the impact of surface treatment by TMAH and HF on the electrical characteristics of GaN-on-GaN Schottky diode is explored by I-V and C-V characterisation. TMAH surface treatment leads to an improvement in the forward and reverse characteristics of the device and improvement in breakdown voltage (BV) by almost 200V compared to just HF treated sample. Additional XPS characterisations reveals reduction in both O and C concentration due to TMAH treatment.

Index Terms— Vertical GaN, Schottky, surface treatment

I. INTRODUCTION

GaN is an interesting material for power device fabrication due to its exceptional properties like high bandgap, high carrier mobility, critical electric field, etc. This is advantageous for fabricating devices which can withstand higher voltages and offers lower resistance compared to its Si counterpart. In this study, we discuss the impact of surface treatment (by HF and TMAH) on the electrical properties of GaN-on-GaN Schottky diodes. Due to TMAH anisotropic nature, it has been widely used in GaN to smoothen sidewall and remove damage post plasma etching. We have utilised TMAH not just to remove plasma related damage but also to remove surface contaminations.

II. DEVICE FABRICATION

7 μm Si doped epitaxial layer was grown by MOVPE in Axitron closed coupled showerhead reactor on GaN substrate provided by Sumitomo. The studied samples are presented in Fig. 1 and the process flow and device structures are shown in Fig. 2. Two of the cleaved pieces were used for device fabrication. Before ohmic contact deposition, one piece was treated with 25% TMAH for 20 min at 85°C. Both the samples were treated with 1% HF treatment for 1 min which was followed by immediate deposition of Pt/Au Schottky contact by liftoff. The Schottky contacts were not annealed post deposition and no passivation or edge termination was employed on the samples. Three other pieces were utilised for XPS characterisation, an as-grown sample, second with HF 1% for 1 min and third with 25% TMAH at 85°C for 20 min.

III. RESULTS AND DISCUSSIONS

The forward and reverse I-V characteristics are presented in Fig. 3 and 4 respectively. The extracted ideality factor was close to 2 on both the samples as shown in Fig. 5 whereas the barrier height improved by ~ 0.2 eV for TMAH treated sample (Fig. 6). Fig. 7 shows almost 2 order reduction in leakage current density extracted at -100V for TMAH treated sample (Sample B) compared to only HF treated sample (Sample A). TMAH

treatment also leads to an improvement in BV reaching higher than 300 V as shown in Fig. 8. The interface state density (N_{ss}) was extracted using the method presented in [1] using the forward I-V is represented in Fig. 9. By using an interface thickness of 3 nm [2] for the calculation, a broad peak with peak density close to $1 \times 10^{13} \text{ eV}^{-1} \text{ cm}^{-2}$ was extracted for HF treated sample whereas TMAH treatment leads to 3 times increase in the interface states density. C-V measurements performed at 1 MHz is presented in Fig. 10 and the distribution of barrier height calculated from x-axis intercept of A^2/C^2 plot is represented in Fig. 11. The median barrier height increases by 1 eV for sample B treated sample compared to sample A. From the Poisson's equation [3], the increase in barrier height can be written as $\Delta\phi_B = -\frac{q \times \rho \times \delta^2}{2\epsilon}$, where $\Delta\phi_B = \phi_{B, \text{Sample C}} - \phi_{B, \text{Sample A}}$, ρ and δ are the interface charge density and thickness respectively. The calculated ρ was equal to $1.2 \times 10^{20} \text{ cm}^{-3}$ for $\delta = 3 \text{ nm}$, and $\Delta\phi_B = 1 \text{ eV}$. This gives an increase in surface charge by $3.6 \times 10^{13} \text{ cm}^{-2}$ which is close to the N_{ss} value extracted from the forward I-V.

XPS characterization revealed reduction in C and O concentration (Table. 1). A higher reduction in C and O concentration was observed for sample treated with TMAH.

The proposed model in Fig. 12 considers removal of native oxide and other contaminations by TMAH which leaves behind N terminated GaN with three negatively charged dangling bonds [4]. These negatively charged dangling bonds could be responsible for the observed increase in the barrier height extracted from the C-V measurements. TCAD simulations performed using the structure in Fig. 13 confirm the upward bending of band by 1eV as shown in Fig. 14.

IV. CONCLUSION

In conclusion, TMAH treatment on Si-doped epitaxial layers resulted in improved Schottky barrier characteristics, reduced leakage current, and enhanced breakdown voltage. XPS analysis suggested a reduction in C and O concentrations, supporting the proposed model of N-terminated GaN with negatively charged dangling bonds contributing to the barrier height enhancement. TCAD simulations validated the observed 1eV band bending, highlighting the efficacy of TMAH in optimising semiconductor device performance.

REFERENCES

- [1] Card, H. C., et al., (1971).
- [2] Al-Ahmadi, N. A., et al. (2020).
- [3] Sze, Simon M., et al. (2006)
- [4] He, Junlei, et al. (2018)

This work is part of the VertiGaN project supported by the Labex GANEXT (ANR-11-LABX-0014).

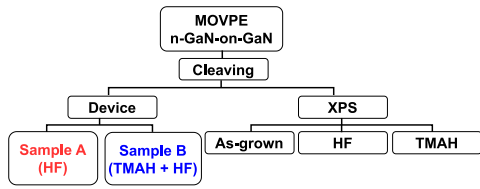


Figure 1. Studied samples.

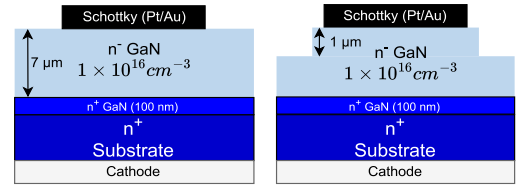
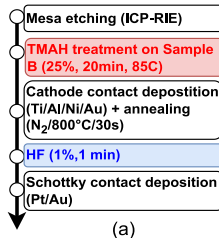


Figure 2. (a) Process flow (b) Planar structure (c) Mesa structure. No passivation or edge termination were employed on these structures.

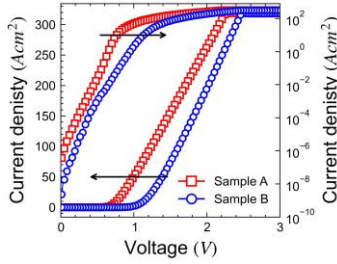


Figure 3. Representative forward I-V in both semi-log and linear scale

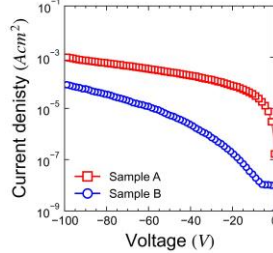


Figure 4. Representative reverse I-V characteristic.

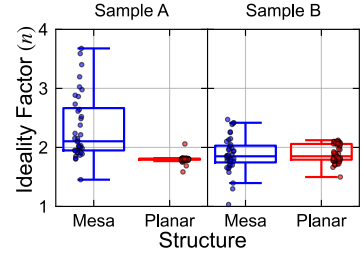


Figure 5. Ideality factor extracted from linear region of I-V plot in semi-log scale.

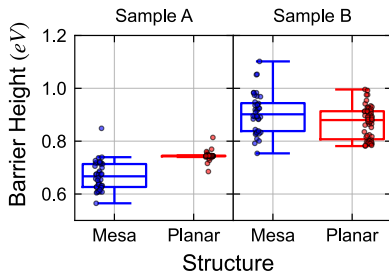


Figure 6. Barrier height extracted from forward I-V using thermionic emission model.

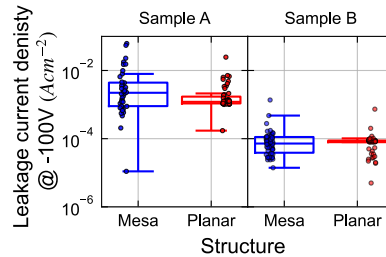


Figure 7. Leakage current density @ -100V.

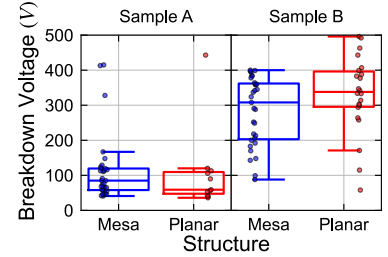


Figure 8. Almost 200V enhancement in the destructive BV by TMAH surface treatment.

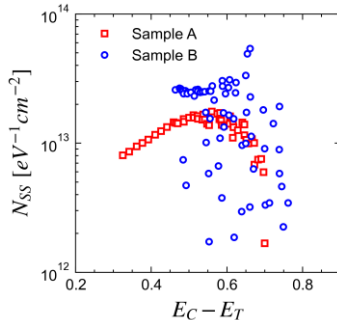


Figure 9. Interface state density (N_{ss}) extracted from the forward I-V characteristic.

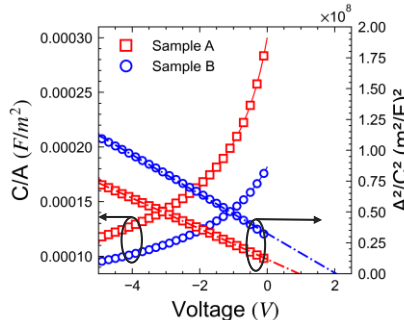


Figure 10. C-V characteristics at 1Mhz. The x-axis intercept of A^2/C^2 plot represents the built-in potential.

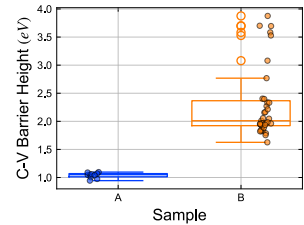


Figure 11. Barrier height calculated from x-axis intercept of A^2/C^2 plot.

at. %	N 1s	O 1s	Ga 3d		C 1s
			Ga-N	O-Ga	
Ref.	29.3	12.4	31.6	6.4	20.3
HF	32.2	7.9	32.2	9.1	18.6
TMAH	33.4	6.0	37.7	6.8	16.1

Table 2. XPS data for as-grown, HF and TMAH treated samples.

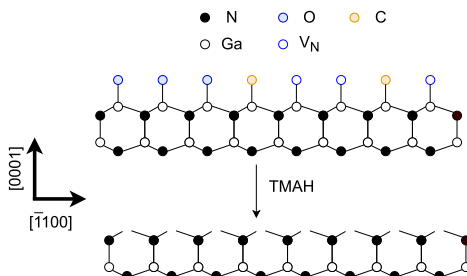


Figure 12. Etching mechanism of TMAH on as grown c-plane GaN. Native oxide and other contaminations like C are removed by TMAH as confirmed by XPS. This leaves behind N-terminated GaN with three negatively charged dangling bonds.

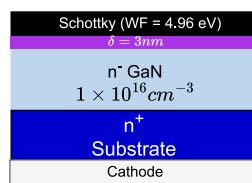


Figure 13. Structure simulated in TCAD with 3nm interface with $1.2 \times 10^{20} \text{ cm}^{-3}$ negative fixed charges. The WF of the Schottky contact was adjusted to match the barrier height of Sample A then the interface layer was introduced for Sample B.

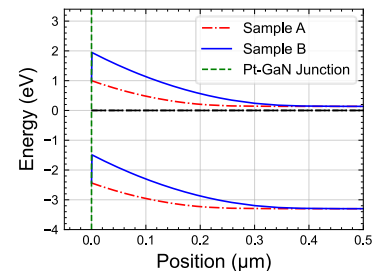


Figure 14. Band diagram obtained for Sample A (in red dash-dotted line) and sample B (in blue line) with negative charges at the interface.