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Micro-Raman characterization of vertical GaN Schottky and PN diodes

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Abstract

In this work, measurements from Cathodo-Luminescence (CL), micro-Raman spectroscopy and Breakdown Voltage (BV) have been coupled to assess the effects of physical parameters such as threading dislocations and effective doping level homogeneity on the electrical performances of vertical GaN Schottky and PN diodes. Two different substrates from Saint Gobain Lumilog and Sumitomo Electric with different threading dislocation densities have been compared.

Introduction

GaN-based power devices have been gaining popularity in recent years thanks to GaN properties such as wide bandgap, high electron mobility, and high breakdown field strength, allowing low R_{on} , and high-frequency operation. Lateral GaN devices, which are grown on a foreign substrate like Si and sapphire have already been commercialized and have been able to achieve much better performance compared to their silicon counterparts. However, these devices are unable to achieve sufficiently high breakdown voltage ($BV > 1kV$). One alternative to boost the breakdown voltage and lower R_{on} is to have vertical devices grown on a native GaN substrate [1]. However, some physical parameters such as those due to structural defects (like threading dislocations (TDs)) and doping inhomogeneity in the drift layer may influence electrical performance by degrading the device breakdown voltage (BV) and leakage current. Cathodoluminescence (CL) measurements can be used to highlight the presence of dislocation clusters [2], and 2D Raman mapping can be performed to observe the structural defects such as dislocations [3], the stress distribution [4] and n-doping concentration distribution [5,6]. In this work, the E_2^H peak shift and width have been used to probe the defect and stress distribution, while the $A_1(LO)$ peak shift has been employed to analyse the n carrier distribution in the epitaxial layers of P-N and Schottky vertical structures. In addition, BV measurements were performed to examine the effect of stress, defects and carrier concentration distribution on the electrical performance of the diodes.

Experimental

The epitaxial layers were grown by Metal Organic Vapor Phase Epitaxy (MOVPE) at $T=1020^\circ C$ on freestanding GaN substrates from Saint-Gobain Lumilog and Sumitomo. The Schottky structure consists of a 10 μm thick film doped by silicon with a net doping concentration of around $1.4 \times 10^{16} cm^{-3}$ grown on top of a 2 inch n^+ freestanding GaN substrate (see Fig.1). The P-N structure consists of a 20 nm layer of p^{++} GaN and a 300 nm p GaN layer doped at $4.6 \times 10^{18} cm^{-3}$ on top of the Schottky structure (see Fig. 1). The front Schottky contact (or ohmic contacts for PN-samples) is made of a Ni/Au (50nm/150nm) stack while the backside ohmic contact is a Ti/Al/Ni/Au stack. Mesa structures were fabricated by Cl_2 ICP/RIE and fluorine implantation was used to reduce peak fields at the contact edges. In addition, field plates are made of a SiN/SiO₂ stack covered with TiAl/Ni/Au-Ti/Pt. Micro-Raman

spectroscopy measurements were carried out at room temperature using a confocal spectrometer (Renishaw Invia model) in back scattering geometry with an excitation laser source at 532 nm.

			20 nm p^{++} GaN
			300 nm p-GaN
			$4.6 \times 10^{18} cm^{-3}$
10 μm GaN n- $1.4 \times 10^{16} cm^{-3}$	10 μm GaN n- $1 \times 10^{16} cm^{-3}$	10 μm GaN n- $1.4 \times 10^{16} cm^{-3}$	
FS GaN (Lumilog)	FS GaN (Sumitomo)	FS GaN (Lumilog)	
(a)	(b)	(c)	

Fig. 1. Schematic structure of the Schottky diode grown on a Lumilog substrate (sample a), on a Sumitomo substrate (sample b), and of the P-N diode grown on a Lumilog substrate (sample c).

Results and Discussion

The mean value of the E_2^H and $A_1(LO)$ peak position for samples a, b and c are summarized in Table 1. The two Schottky structures (sample a and b) have the same mean value for the E_2^H Raman peak positions, which seems to indicate a similar stress distribution. The mean position of the $A_1(LO)$ peaks is also the same, found at $733.4 cm^{-1}$. Moreover, it has been reported that the shift in the $A_1(LO)$ position reflects changes in the electron plasma frequency due to a Plasmon phonon coupling mode called LOPC and can therefore be used to investigate changes in carrier density [5,6]. In addition, with the linear calibration equation ($A_1(LO)$ position versus n carrier concentration) from ref. [7] for $n < 10^{17} cm^{-3}$, the $A_1(LO)$ position mean value gives a net carrier concentration of ($1 \times 10^{16} cm^{-3}$) which is close to the values found with capacitance-voltage (C-V) measurements. For sample c (PN structure), the two Raman peak positions are shifted to lower wavenumbers. The decrease of the E_2^H peak position can be attributed to a more tensile stress, and the decrease of the $A_1(LO)$ peak position can be attributed to both a decrease of the stress and the presence of the p layer at the surface of the PN diode.

Fig. 2, 3 show the comparison between the CL mapping and the E_2^H and $A_1(LO)$ Raman mapping of Schottky diode grown on a Lumilog substrate (Fig. 2) or on a Sumitomo substrate (Fig. 3). In Fig 2., a correlation can be established between the dislocation clusters highlighted by the CL map and both the E_2^H and the $A_1(LO)$ peak position shift to lower frequencies. Interestingly, the $A_1(LO)$ position show "patches" with higher peak position (in red on Fig.2), which may be attributed to local increase of the n-doping probably caused by incorporation of impurities (such as carbon) during the MOVPE growth process. The comparison between the CL mapping of Fig.2 and 3 show that there are far fewer dislocation clusters in the Schottky diode grown on the Sumitomo substrate. The comparison between Raman maps of Fig.2 and 3 shows a more homogenous structure, stress and doping concentration for the diode grown on the Sumitomo substrate than for the diode grown on the Lumilog substrate, likely due to the absence of these clusters. Fig. 4 shows the E_2^H and $A_1(LO)$ position mapping of a PN diode. No CL measurements are shown for the

PN diode, and so it was not possible to image the dislocations by CL for this structure. However, thanks to the Raman mapping, the local variation of the E_2^H and $A_1(LO)$ peak positions can be attributed, as for sample (a), to the presence of dislocation clusters. BV measurements performed on Schottky diodes grown on the Lumilog substrate show that these diodes can withstand a maximum of 370V (Fig.5.). The low value of this BV could be

explained by the presence of the structural and electrical defects highlighted by Raman spectroscopy and CL. On the other hand, PN diodes grown on Lumilog substrate can withstand a maximum of 1200V (Fig.5.), as expected for such PN structures. The I-V measurements on Schottky diodes grown on Sumitomo substrate will be done soon.

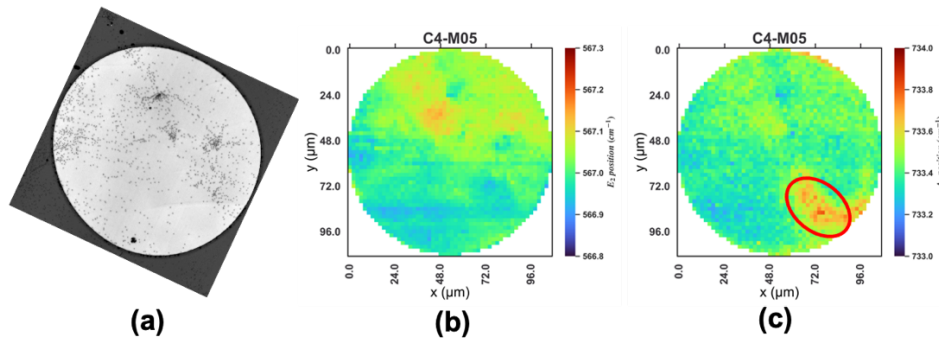


Fig. 2 . Comparison between the CL mapping (a) and the Raman mapping of the E_2^H (b) and the $A_1(LO)$ (c) position of a Schottky diode grown on a Lumilog substrate (sample a).

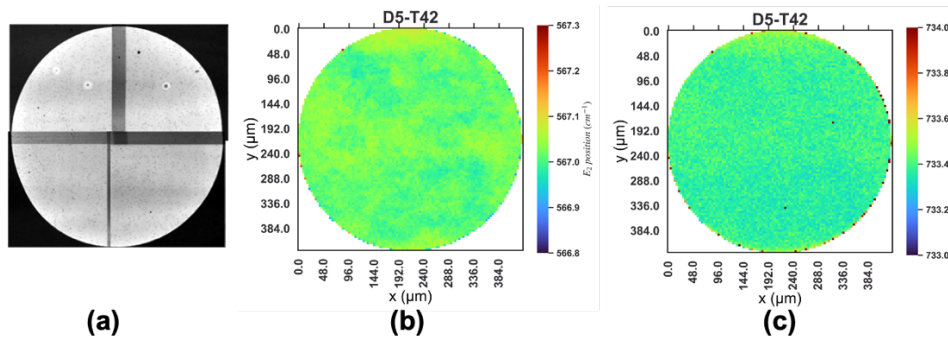


Fig. 3 . Comparison between the CL mapping (a) and the Raman mapping of the E_2^H (b) and the $A_1(LO)$ (c) position of a Schottky diode grown on a Lumilog substrate (sample a).

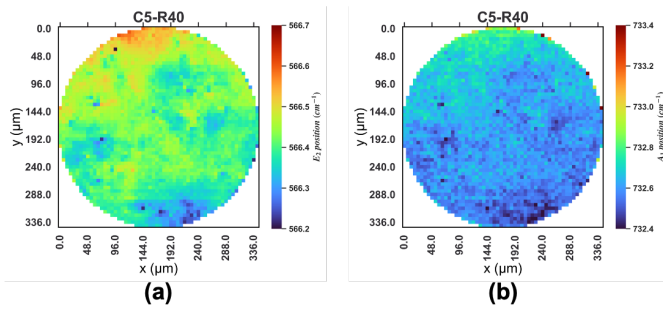


Fig. 4 . Raman mapping of the E_2^H (a) and the $A_1(LO)$ position (b) of a PN diode grown on a Lumilog substrate (sample c).

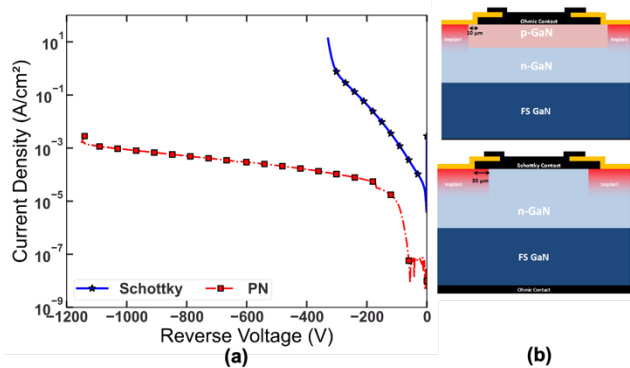


Fig. 5 . (a) Schottky diode (Lumilog substrate) and PN diode (Lumilog substrate) I-V reverse measurements and (b) devices structure description.

Conclusions

In this study, micro-Raman spectroscopy coupled with CL-SEM measurements has been used to physically characterize vertical GaN Schottky and PN diodes. Local variations of the doping, of the stress and presence of dislocations clusters have been highlighted and these seem to be highly dependent on the GaN substrate initial quality. Complementary analysis such as DLTS and BV will be performed to confirm the nature of the defects and their influence on the electrical properties of the diodes.

Acknowledgments

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