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AlGaN etching-induced electron traps in GaN channel of Schottky barrier diodes

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Abstract

Deep traps in AlGaN/GaN Schottky barrier diodes (SBD) have been investigated using deep level transient spectroscopy (DLTS). It has been found that ion-assisted gate recess process leads to the formation of electron traps. The defects related to these traps are located in the two dimensional electron gas (2DEG) channel below the Schottky contact. The activation energies of the electron traps, extracted from the data, range between 0.28 eV and 0.41 eV. We believe that these centers are linked with nitrogen vacancies which may be in extended defects.

1. Introduction

Many high power field effect transistors use a recessed gate geometry in which the gate metals are placed on an etched surface to position the gate slightly below the surface. Compared to wet chemical etching, ion-assisted etch processes offer the possibility of better control over the depth and profile of the recess. However, these processes introduce the possibility of damage to the transistor channel [1]. Inductively coupled plasma (ICP) etching of GaN has been shown to severely degrade the Schottky contact, decreasing the Schottky barrier height and increasing the reverse leakage current by several orders of magnitudes [2]. In this work, we studied by DLTS the AlGaN etching-induced electron traps in GaN channel of AlGaN/GaN Schottky barrier diodes.

2. Results and discussion

The AlGaN/GaN bilayer was grown by metalorganic chemical vapor deposition (MOCVD) on 200 mm diameter silicon substrate, oriented (111). The epitaxy consists of an AlN nucleation layer, followed by 1.6 µm of AlGaN buffer layers, then 1.6 µm thick semi-insulating carbon doped GaN buffer layer, a 100 nm unintentionally doped GaN layer acting as the channel, a 1 nm unintentionally doped AlN layer and a 24 nm unintentionally doped $Al_{0.21}Ga_{0.79}N$ layer. Interdigitated comb-like diodes with twenty six 15 x 1000 µm fingers are then formed using TiN/W as Schottky electrodes and Ti/Al annealed for 30 seconds at 875°C as Ohmic contacts. Recessed Schottky electrodes are achieved by etching 10 nm of the AlGaN layer using inductively coupled plasma reactive ion etching (ICP-RIE), with BCl_3/Ar-He gas chemistry and 100 V dc bias. The Schottky/Ohmic spacing is 15 µm and is passivated with Si_3N_4. Data were acquired with a DLTS system using a Boonton 7200 capacitance meter with a 100 mV test signal at 1 MHz.

SBDs without AlGaN etching step don't exhibit a DLTS signal in the temperature range 100 K – 250 K. However, an asymmetrical peak around 150 K (labeled E1) appears on

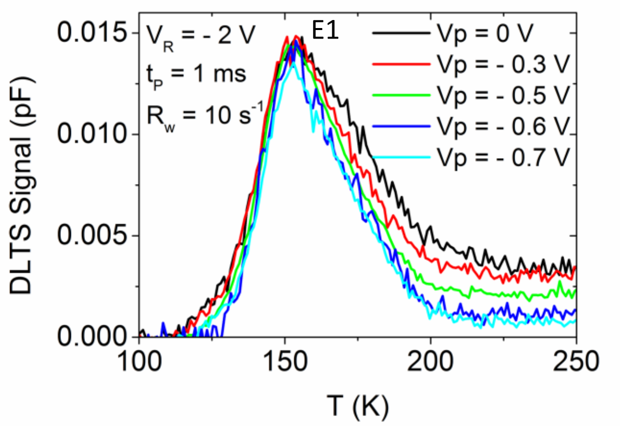

Figure 1 : DLTS spectra for V_P varying from 0 V to - 0.7 V. The amplitude of the peak is constant when the filling pulse height is reduced.

DLTS spectra of a SBD which has undergone the gate recess process. In Figure 1, we see the modification of this peak as a function of the filling pulse height V_P. The pinch-off of the SBD, determined by capacitance voltage measurement, is – 0.85 V at 100 K and – 1.1 V at 300 K. Consequently, by changing V_P between 0 V and – 0.7 V, the filling pulse height stays in a region where the channel remains open. For V_P = 0 V, the probe zone is close to the GaN surface and moves towards the bulk when V_P is decreased. In Figure 1,

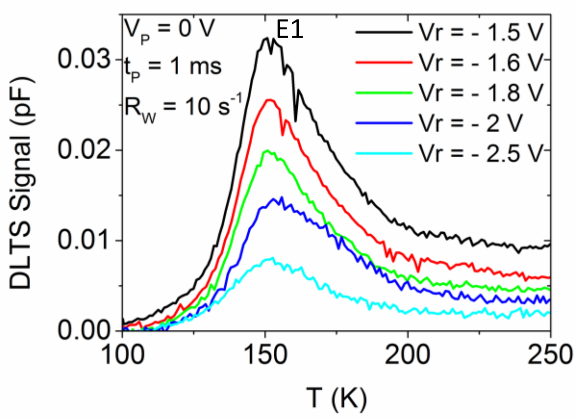

Figure 2 : DLTS spectra for V_R varying from - 1.5 V to - 2.5 V. The reduction of the peak amplitude indicates a decrease in defects concentration.

we see that the amplitude of the DLTS signal is not dependent on the filling pulse height. This behavior indicates first that the defect concentration is constant inside the channel and secondly that it is not an interface defect.

In Figure 2, we fix the filling pulse height at $V_P = 0$ V and we change the reverse bias from $V_R = -1.5$ V to $V_R = -2.5$ V. When the reverse bias goes to more negative values, the probe region is deeper in the GaN bulk. The quenching of the DLTS signal allows us to conclude that the defect linked with trap E1 is mainly located in the upper part of the GaN layer.

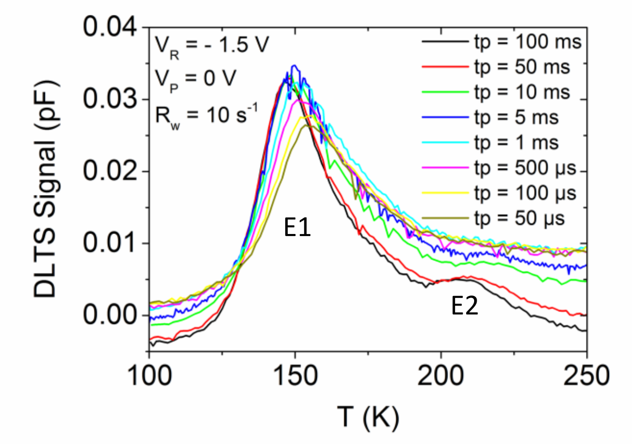

Figure 3 : Evolution of the DLTS signal as a function of the filling pulse duration. Whereas only one peak is clearly visible near 150 K for small t_P, a second peak near 218 K appears for t_P larger than 5 ms.

In Figure 3, we follow the shape evolution of the signal as a function of the filling pulse duration t_P. A new peak (labeled E2) emerges at 218 K for t_P larger than 5 ms and the maximum of the dominating peak E1 moves to lower temperature when t_P increases. Using several rate windows R_W between 5 s^{-1} and 2000 s^{-1}, we extracted from Arrhenius plots the activation energy E_a and the apparent capture cross-section σ_{na} of traps E1 and E2. For trap E1, we found $E_a = 0.33$ eV and $\sigma_{na} = 3.5\text{x}10^{-14}$ cm^2 with $t_P = 50$ µs and $E_a = 0.28$ eV and $\sigma_{na} = 3.2\text{x}10^{-15}$ cm^2 with $t_P = 10$ ms. For trap E2, we found $E_a = 0.41$ eV and $\sigma_{na} = 1.3\text{x}10^{-15}$ cm^2 with $t_P = 5$ ms. We believe that trap E1 is composed of traps ES2 and ES3 found by Auret et al. [3] in their study of sputter deposition-induced electron traps formation in GaN. Trap ES3 can be observed as a high-temperature shoulder on E1. Increasing t_P, ES2 dominates and the activation energy of E1 decreases, becoming closer to the activation energy of trap ES2. Both traps ES2 and ES3 have been assigned to defects related to nitrogen vacancies as a complex [4] and are associated with RIE-induced surface damage [5]. They are point defects which can be aligned along dislocations [5]. Trap ES2 has a bulk nature but its concentration is enhanced in surface by the etching process and trap ES3 has a near-surface nature [6]. Trap E2 is close to trap ES4 observed by Auret et al. [3] which has been assigned to complexes related to surface defects induced by ion penetration and has a band-like energy distribution.

3. Conclusions

The effect of an ion-assisted gate recess process in AlGaN/GaN SBD has been investigated using DLTS measurements. Three traps have been found in the energy range 0.28 eV – 0.41 eV under the minimum GaN conduction band. These traps are mainly located in the 2DEG channel, i.e. in the upper part of the GaN layer. They are related to nitrogen vacancies as a complex and can behave as extended defects. We demonstrated that an ion-assisted gate recess process leads to the formation of deep states in the GaN bandgap which may impact the diodes performance due to trapping effects.

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