Effect of Interaction of Deep Level Defects with Quantum Well States on Detrapping Transients in High-Voltage AlGaN/GaN HEMTs

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AlGaN/GaN High-Electron-Mobility Transistors (HEMTs) have traditionally been the device of choice in RF electronics. More recently, the ease of achieving a low on-state resistance due to high channel mobility (μ_{ch}) coupled with a wide bandgap (E_g = 3.4 eV) has led to significant advancements in developing the GaN HEMT as a device for the next generation of high voltage power electronics (1)-(2). Understanding the characteristics of defects in the AlGaN/GaN material system is a key factor in developing power devices with improved performance and reliability.

Most techniques for characterizing defects use a bias condition to fill the traps (like the filling pulse in Deep Level Transient Spectroscopy). Following this, optical or thermal excitation is used to study emission of the trapped carriers. However, either in an idealized material stack (like a Schottky diode) or in a device such as the HEMT under realistic operation conditions, trapped carriers are assumed to be thermally or optically emitted to the conduction band. Interaction of trapped carriers with the quantum well levels is usually not considered to influence the transient characteristics.

In this study, we demonstrate that following both ON-state (V_{gs} = 0, V_{ds} = 10V), and blocking voltage ($V_{gs} < V_{th}$, V_{ds} = 200V) stress, detrapping transients in AlGaN/GaN HEMTs exhibit strong dependence on stress time (Fig. 1). A temperature-independent component becomes progressively slower as the stress time is increased. This behavior is shown to be consistent with the capture of trapped carriers in the AlGaN barrier directly by quantum well states (Fig. 2). We show that the proximity of the quantum well can reduce the response time of a trap by several orders of magnitude below its bulk response time, and the effect is influenced strongly by the electric field normal to the AlGaN/GaN interface.

In switching applications, traps that are much slower than the switching time constants lead to parametric shifts such as threshold voltage (V_{th}) drift or increase in on-state

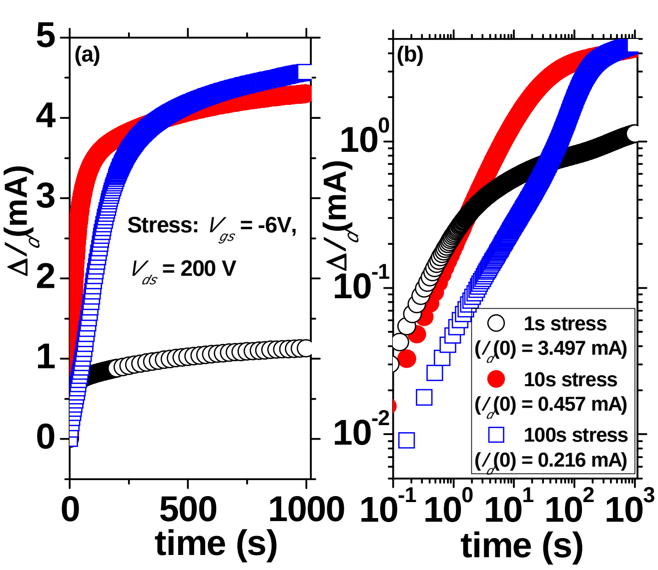

Figure 1. Detrapping transients (V_{ds} = 1V, V_{gs} = 0) in a passivated $Al_{0.15}Ga_{0.85}N$/GaN HEMT (L_g = 2μm, W_g = 100μm, L_{dg} = 10μm), following blocking voltage stress (V_{gs} = -6V, V_{ds} = 200V) for 1s, 10s and 100s respectively on (a) linear and (b) log scales.

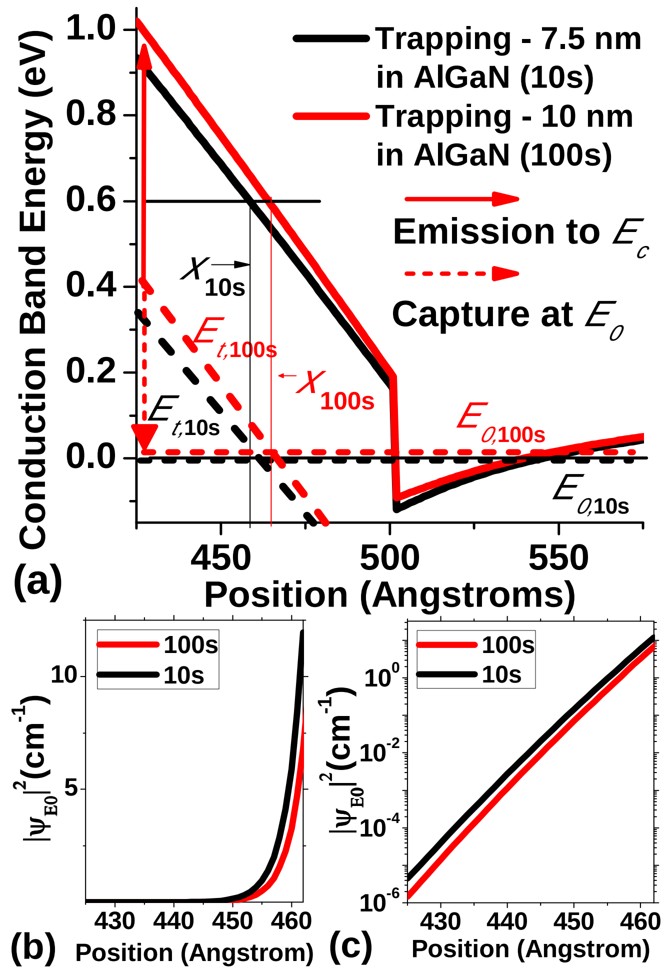

Figure 2. (a) Simulated conduction band profile, ground state energy E_0, and trap position $E_t \approx E_c - 0.6$ eV for trapping in AlGaN from heterointerface to 7.5 nm and 10 nm respectively, consistent with short and long duration stress times. Simulated wavefunction in the AlGaN barrier for the two cases is shown on a linear (b) and log (c) scales.

resistance (R_{ds}) over time. Faster traps (with time constants on the order of the switching time) lead to distortions in the switching waveform, affecting output power quality (3)-(4). Electric field management is generally understood to be important for breakdown voltage enhancement in power devices. However, the strong influence of electric field on the trap response time indicates that electric field management might have an equally important role in the switching performance of the AlGaN/GaN HEMT.

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