Deep Level States in P-type GaN Grown by Ammonia-based Molecular Beam Epitaxy and Metal Organic Chemical Vapor Deposition

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Mg-doped p-type GaN is used for many device technologies including almost all optoelectronic devices (i.e. light emitting diodes, laser diodes, etc.) and several advanced electronic devices (such as heterojunction bipolar transistors and gate injection transistors etc). However, despite the wide spread use, the electrically active defects in p-GaN, which may act as compensating and/or recombination centers thus affect material properties and device performance, have been sparsely studied, mainly due the lack of suitable test structures and characterization techniques. To this end, we apply capacitance-based deep level transient/optical spectroscopies (DLTS/DLOS) to specially devised p+/p/n⁺ structures for fully characterizing defect states throughout the p-GaN bandgap. Trap spectra for p-GaN grown by ammonia-based molecular beam epitaxy (NH₃-MBE) and metal organic chemical vapor deposition (MOCVD) will be comparatively studied to evaluate the impact of growth method on deep level formation. This information will allow for further growth optimization, improved material quality, and enhanced device performance.

Both NH₃-MBE and MOCVD samples were grown on sapphire (with threading dislocation density of mid 10⁶ cm⁻²) at conditions optimized for each method. The two samples contained similar p+/p/n⁺ structures, which were designed to be sensitive to traps in the p'-GaN (1×10¹⁸ cm⁻³ Mg-doped layer) and provide low series resistance, enabling high-frequency (1 MHz) capacitance-based characterizations.

DLTS and DLOS revealed the presences of four traps at Eᵥ+0.74 eV, Eᵥ+1.50 eV, Eᵥ+2.42 eV, and Eᵥ+3.28 eV in both samples, with total trap concentrations of 4.2×10¹⁵ cm⁻³ and 2.2×10¹⁶ cm⁻³ for samples grown by NH₃-MBE and MOCVD, respectively. However, the impact of growth method is clearly different for individual traps. By changing from MOCVD to NH₃-MBE growth, the Eᵥ+2.42 eV trap reduces by 20× reduction in concentration, while the Eᵥ+0.74 eV and Eᵥ+3.28 eV states reduce by 2× and 3× respectively, and the deep level at Eᵥ+1.50 eV even increases by 2×. A direct consequence of such behaviors is the different dominances among traps between the two growth methods, i.e., the Eᵥ+2.42 eV trap is the most dominant state in MOCVD grown p-GaN, whereas the major traps in NH₃-MBE grown p-GaN become the ones at Eᵥ+1.50 eV and 3.28 eV. This may have consequences on the characteristics of devices grown by both methods depending on the device structure and application. And while ammonia-based MBE is significantly less mature than MOCVD, the overall lower trap concentration for ammonia-MBE p-GaN suggests that significant performance and/or functional advantages for devices grown by ammonia MBE that require p-GaN layers might be possible. Continued work focuses on the specifics of how each trap is influenced by growth parameters as well as by post-growth thermal processing is ongoing and will be discussed.