Ion Luminescence of Multi-Quantum Well Structures

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Motivation—A new microscopy technique, ion-photon emission microscopy (IPEM), is crucial for analyzing failure and pinpointing radiation sensitive elements in today's complex integrated circuits. The technique requires a thin (<5 μm) self-supporting luminescent layer, demonstrating sufficient quantum efficiency when excited by ions, as well as rapid decay. InGaN/GaN multiple quantum well (MQW) structures grown by MOCVD on sapphire substrates are being studied as possible candidates due to their potential for producing high light intensity with short lifetimes. These materials have demonstrated two significant ion-luminescence peaks: the blue near-band edge emission and the defect-induced yellow band. These characteristic emissions exhibit very fast (nanoseconds) and very slow (hundreds of microseconds) lifetimes, respectively. Various quantum well structures are being studied to optimize the blue emission and reduce/eliminate the slow yellow emission.

Accomplishment—A series of InGaN/GaN MQW structures were grown at Sandia, with various composition, layer thicknesses, and layer ordering (see Figure 1). Ions have been utilized to analyze these materials, allowing us to characterize their luminescence properties, such as emission peaks and lifetimes of the various emissions. In addition to providing insight into how the materials will behave on an IPEM, ionoluminescence experiments offer several benefits over the more common photoluminescence (PL) and cathodoluminescence (CL) techniques. The large penetration depth of a MeV ion beam over the relatively shallow penetration of keV electrons (from CL) is a significant advantage, especially when studying multi-layer structures. The ability to vary the beam energy and see into different layers allows us to pinpoint the main sources of the two emission bands, and engineer the structures to better optimize the light output. As seen in Figure 2a, when using a higher energy proton beam, the relative intensity of the yellow band increases dramatically, demonstrating that the majority of this light originates from the defective buffer layers. In addition, we concluded that n-type GaN barrier layers are undesirable, as they produce more yellow light than intrinsic GaN. In Figure 2b, the advantage of using quantum wells is demonstrated, highlighting the decrease in luminescence decay time. This is crucial to IPEM experiments to avoid overlapping of detected photons from sequential ions, which would result in inaccurate position determinations and poor spatial resolution.

Significance—The future of heavy ion radiation effects microscopy depends on developing scanned microbeams and/or emission microscopes that can easily be used on cyclotrons. IPEM provides a reasonable solution, and its continuing progress is promising. GaN seems to be an ideal ionluminescent material for IPEM, with InGaN/GaN MQWs providing advantageous and unique properties. These materials create copious quantities of photons and are demonstrating fair resolution on an IPEM system. We expect further improvement with additional materials engineering. IPEM will allow us to extend radiation effects microscopy to increasingly thick integrated circuit (IC) overlayers.

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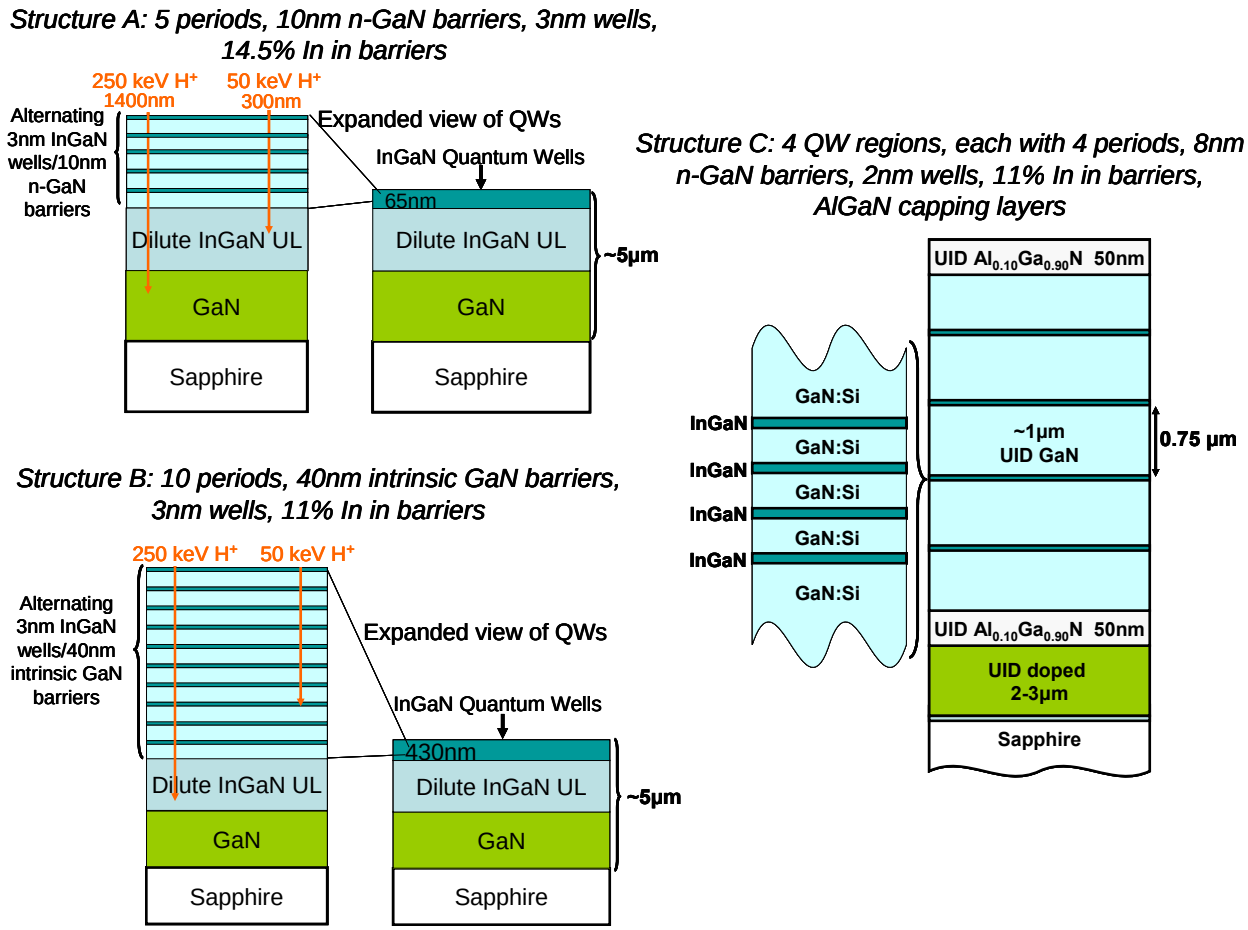

Figure 1. Various InGaN/GaN quantum well structures studied for their application in IPEM. Structure C is the most recent approach, utilizing AlGaN capping layers to limit the yellow emission.

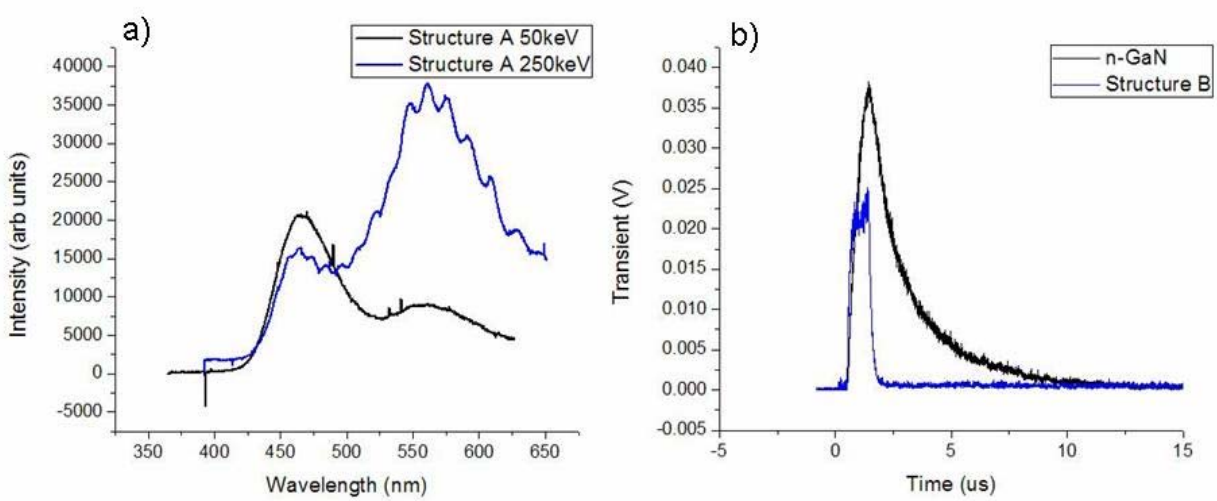

Figure 2. a) Ionoluminescence spectra of Structure A at different ion energies. b) Lifetime of ionoluminescence emission with a 1µs excitation pulse, demonstrating the advantage of using quantum wells over bulk n-type GaN. This shortened lifetime will improve the IPEM operation, limiting false coincidence signals, and thus allowing better resolution.