Using X-rays nanoprobes to investigate local carrier confinement in multi-quantum wells-based nanostructures

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The performance of optoelectronic devices based on quantum confined systems is strongly influenced by the dynamics of local charge carriers. Carrier relaxation processes are particularly sensitive to the presence of localized states and electric fields, which can be caused by defects, impurities and other atomic-scale perturbations. These phenomena were investigated in this study using multi-quantum wells (MQWs) of InGaN/GaN embedded in GaN nanowires (NWs) grown by metalorganic vapor phase epitaxy. A multimodal synchrotron approach utilizing a hard X-ray nanoprobe was employed to investigate the composition and optical emission properties of these MQWs, with a special focus on the nature of carrier dynamics and their localization. Experiments were conducted at the beamline ID16B of the European synchrotron (ESRF), which offers unique capabilities for study complex solid-state systems by coupling multiple techniques. The beamline's hard X-ray nanoprobe, featuring a spatial resolution of 50 x 50 nm^2 and a high photon flux up to 10^{12} ph/s, enabled advanced characterization. Two-dimensional (2D) mapping using X-ray fluorescence and X-ray excited optical luminescence (XEOL) was combined with time-resolved XEOL (TR-XEOL) measurements to analyze the structure.

The MQWs investigated consisted of polar and non-polar facets deposited on GaN c-plane (polar) and m-planes (non-polar) surfaces, respectively [1]. XRF mapping revealed a uniform distribution of chemical elements across the facets, ruling out significant alloy fluctuations that could impact optical emission. XEOL measurements identified two distinct emissions: one at approximately 3.05 eV localized at the interface between the polar and non-polar facets, and another around 2.75 eV in the m-planes. The 3.05 eV emission exhibited primarily single-exponential decay behavior, attributed to excitonic relaxation in a varying electronic potential, potentially arising from semi-polar facets. In contrast, the 2.75 eV emission showed a double-exponential decay, linked to localized states caused by nanoscale variations in indium concentration and well thickness—both below the spatial resolution of the XRF mapping.

This study highlights the critical role of advanced sychrotron techniques in nanoscale analysis of composition and optical emission in quantum confined systems. The combination of multimodal characterization methods using an X-ray nanoprobe provided unique insights into the origins of optical emission and its dependence on local atomic environment.

References

[1] J. S. Ruiz, D. Salomon, A. Rogalev, et al. Nano Lett., 21, (2021) 9494–9501.