Revisiting the determination of the carrier diffusion length in GaN from cathodoluminescence spectroscopy

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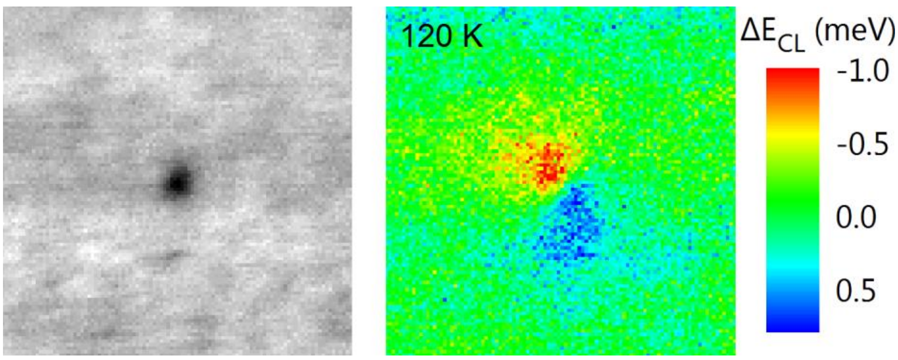
A crucial parameter for the design of any bipolar semiconductor device is the carrier diffusion length. For GaN, a popular way to determine this quantity uses the cathodoluminescence (CL) intensity profiles across the intersection of threading dislocations with the sample surface. However, at least for the dominant edge or mixed dislocations, this approach fails as it ignores that the strain relaxation at the surface induces both, variations of the band gap energy [1] and a piezoelectric field [2]. The latter is sufficient to fully explain the reduced CL emission intensity at dislocations [3]. This background motivates us to take a fresh look on how to determine the carrier diffusion length in GaN using CL spectroscopy.

First, to experimentally identify the precise lateral extent of the CL generation volume as a prerequisite to a detailed treatment of carrier diffusion, we measure monochromatic CL intensity profiles across an (In,Ga)N quantum well (QW) sandwiched between (Al,Ga)N barriers and embedded within thick GaN layers [4]. The obtained width of the generation profiles is wider than predicted using the commonly employed software CASINO. Moreover, the profiles broaden at lower sample temperatures T. This previously unreported T-dependence is explained by the necessity for the excited hot carriers to cool down to the band edges prior to radiative recombination, a process governed by carrier-phonon scattering. Second, to determine the diffusion length, we employ a QW without additional barriers as the carrier collector and record CL profiles across the QW [5]. A classical diffusion model accounts for the profiles acquired between 120 and 300 K, while a quantum capture process has to be added for $T < 120$ K. From the determined diffusion lengths and the effective carrier lifetimes measured by time-resolved photoluminescence spectroscopy, we determine the carrier diffusivity as a function of T. Comparing these data to the calculated ambipolar diffusivity, we can conclude that the participation of excitons in the diffusion process is essential to explain the large values of the diffusivity at low T. Third, we show that the diffusion length and its T-dependence can also be obtained from the shift induced by the strain-related energy gap variations around dislocations with an edge component as observed in hyperspectral CL maps, while the width of the intensity profiles is hardly affected by T [6]. For the same sample, the two complimentary approaches show a good agreement in the resulting diffusion lengths. By probing the CL of the buried QW intersecting the dislocation, we can unambiguously confirm that the dislocation line in bulk GaN far from the surface acts as a nonradiative sink.



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