Γ-to-X Bandgap Cross-Over in (In,Ga,Al)P Epilayers Grown on (100) and High-Index GaAs Substrates

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Abstract

$(Al_{0.5}Ga_{0.5})_{0.5}In_{0.5}P$-$(Al_{0.8}Ga_{0.2})_{0.5}In_{0.5}P$ layers and light-emitting diodes (LED) with GaP barriers were investigated by means of electroluminescence (EL), photoluminescence (PL) and photoluminescence excitation (PLE) spectroscopy. The structures were grown by molecular beam epitaxy side-by-side on (100), (211)A and (311)A GaAs substrates.

PL and EL studies were performed at low temperature to understand the reason of significantly higher electroluminescence efficiency for the structures grown on surfaces strongly tilted towards the <111> direction. We observe that PL at low temperatures is dominated by the indirect gap transitions between the holes at the Γ point of the Brillouin zone for the valence band and electrons at the X point of the conduction band, which are allowed at low temperature due to the alloy disorder. We see that structures grown on surfaces inclined towards the <111> direction show a significant shift of the Γ bandgap energy towards higher energies as compared to (100) surface. The Γ point transition energies are revealed as 2.330 eV for (100); 2.355 eV for (311) and 2.360 eV for (211) substrate orientations. Even more important, the Stokes shift between the X PL maximum and the Γ exciton-like enhancement in the PLE spectrum of the structures diminishes for higher substrate tilt angles as compared to the (100) surface: 58 meV (100); 50 meV (311) and 45 meV for the (211) substrate orientations. This brings the Γ point into the resonance with the X minimum for high-index surfaces.

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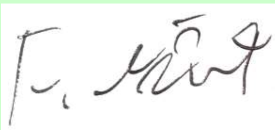
Signed	
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Radiative and non-radiative processes in InGaN quantum well LEDs

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We have investigated a series of state-of-the-art InGaN/GaN single and multi quantum well light emitting diodes by means of differential carrier lifetime measurements. Combined with basic electroluminescence characterization this allows us to extract the A, B and C recombination coefficients of the ABC-model as a function of quantum well number in the active region and temperature giving insight into the radiative and non-radiative processes within the active region, as well as allowing to identify the actively pumped volume in the active region.

Differential carrier lifetime measurements are usually (e.g. in VCSELs) performed by modulating the electric pumping of the device and monitoring the optical or electrical response. We have found that for LEDs this may lead to misleading results since the measurement then includes parasitic effects like the modulation of the space charge zones in the p-n-junction. Instead we inject the additional carriers by resonant optical pumping of the electrically driven device.