Strong Microcavity Effects in InGaN/GaN Heterostructures on Si-Substrates

J. Christen[1], C. Hums[2], A. Hoffmann[2], Th. Hempel[1], S. Petzold[1], A. Dadgar[1], A. Krost[1]
[1]*Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany*
[2]*Institute of Solid State Physics, Technical University Berlin, Germany*

Microcavity effects in semiconductor optoelectronic devices have attracted much attention due to the potential of high-efficiency light-emitting diodes and low-threshold lasers. The enhancement of the spontaneous emission by microcavity effects has been demonstrated for resonant cavity LEDs and high-finesse GaN microcavities with distributed Bragg reflectors have been realized. Due to the refractive index step at the air - epilayer and the sub-strate - epilayer interfaces, cavity effects are also observed in GaN layers without Bragg reflectors but with a sufficiently small surface roughness. This Fabry-Perot-Interference (FPI) effect is dramatically enhanced when silicon is used as a substrate. While the reflectivity at the GaN/sapphire interface is only 2.6% (for λ_{InGaN}=436nm) the GaN/Si interface yields a significantly larger reflectivity of ~ 11%. The series of samples for our investigation were grown by MOCVD at 800°C on Si(111) substrate. Following a ~ 25 nm AlN nucleation layer, a nominally 1.1µm thick GaN layer (including a 12nm AlN layer insertion for stress balancing and defect reduction) was grown, followed by a final ~ 100nm thick InGaN layer with varying In-content. In this way, a low-finesse GaN-microcavity of nominal d = 1.227µm is formed. Photoluminescence (PL) was performed under vertical excitation and detection in plan view and in cross section in a He-flow-cryostat at 6K<T<300K. For angle-resolved PL the sample was mounted on a pivoted sample holder which allowed one to change the angle of detection between 0° - 90° keeping a fixed angle of 90° between the paths of excitation and detection. Fig. 1 shows a typical 6K PL spectrum obtained for the sample with [In] = 0.21. Although the finesse of this naturally formed FPI is very small (around 1) a strong effect of the microcavity is clearly visible and up to 6 FPI modes are resolved. A simple 3-layer FPI model (air/nitride/silicon, see inset) yields reasonable good quantitative agreement over more than two orders of magnitude using the wavelength-dependent refractive index of GaN and Si and a thickness of d = 1.224 µm. The dependence of the FPI maxima on the angle of incidence is depicted in Fig. 2 for the 5 most intense FPI maxima together with the theoretical fit, again visualizing the good agreement with the simple FPI model. A more improved model includes the additional optical effect of the 100nm InGaN layer. The samples were subsequently coated with both, an anti-reflecting λ/4-layer of SiO_2 ($n(SiO_2)$ = sqrt{n(GaN)}) as well as a mirror layer of Au (R = 30%) and Al (R < 90%) on top, in order to reduce and to enhance the microcavity effect, respectively.