Influence of internal electric fields on the carrier dynamics in GaN/(Al,Ga)N multiple quantum wells with different orientation and strain state

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In group-III nitride based quantum well (QW) structures, large internal electric fields due to pyro- and piezopolarization can strongly influence the carrier recombination dynamics. In particular, the separation of electrons and holes due to internal electric fields in the MV/cm range can result in rather long radiative lifetimes reducing the efficiency of UV-emitting devices based on these systems. We have investigated the carrier dynamics of GaN/(Al,Ga)N multiple QWs (MQWs) grown on different substrates [6H-SiC(0001) and γ-$LiAlO_2$(100)] in order to change the orientation of the GaN layers and for different buffer layers [GaN and (Al,Ga)N on 6H-SiC(0001)] in order to change the strain state of the GaN quantum wells. This material combination is a candidate for UV-emitters.

All samples were grown by molecular beam epitaxy. Two sets of samples were investigated. The first set consists of two samples of a 15-period MQW with 5 nm GaN and 10 nm $Al_{0.1}Ga_{0.9}N$ layers. One sample is grown on 6H-SiC(0001) resulting in the conventional C-plane GaN(0001). The other sample is realized on γ-$LiAlO_2$(100) leading to M-plane GaN($1\bar{1}00$) layers, which are free of electrical polarization along the growth direction. The second set of samples comprises two series of 15-period GaN/$Al_{0.15}Ga_{0.85}N$ MQW structures on 6H-SiC(0001) using different buffer layers (GaN and $Al_{0.15}Ga_{0.85}N$). Each series consists of three samples with a GaN QW thickness of 1.5, 2.3 and 5.4 nm, while the (Al,Ga)N barrier layer thickness was kept constant at 15 nm. Unstrained GaN QWs were realized using an 1-μm GaN buffer layer, while the compressively strained QWs were achieved using an 1-μm $Al_{0.15}Ga_{0.85}N$ buffer layer. The samples were characterized in-situ by reflection high-energy electron diffraction and ex-situ by transmission electron microscopy, atomic force microscopy, x-ray diffractometry, and cw-photoluminescence spectroscopy. The time-resolved photoluminescence (PL) signal was excited by the third harmonic of a Ti:sapphire laser with 150 fs pulses and detected with a streak camera with a nominal time resolution of 2 ps.

The carrier dynamics of the first set of samples are shown in Fig. 1. The C-plane sample has a PL decay time of 5.8 ns. In contrast, the decay time of the M-plane sample, which has the same layer thicknesses, is strongly reduced (by more than one order of magnitude). At low temperatures, the measured decay time corresponds to the radiative lifetime, which is inversely proportional to the square of the overlap integral of the electron and hole wavefunctions. This strong reduction of the radiative lifetime is therefore direct evidence for the absence of electric fields in the M-plane sample.

Another possibility to reduce internal electric fields may be the usage of strained GaN quantum wells. In Figs. 2(a) and (b), the PL decay curves for several GaN/(Al,Ga)N MQWs with different GaN thicknesses as indicated are shown for unstrained GaN wells (GaN buffer layer) and strained GaN wells [(Al,Ga)N buffer layer], respectively. While for the thinner wells (1.5 and 2.3 nm) no significant change in the PL decay time is observed (neither with well thickness, nor with different buffer layers), the samples with the thickest wells (5.4 nm) exhibit a strong increase of the PL decay time. However, the change is less pronounced for the strained sample, which may indicate a weaker internal electric field in the strained sample. We will discuss the results for both sets of samples in view of band diagrams based on self-consistent Schrödinger-Poisson calculations including the internal electric fields.

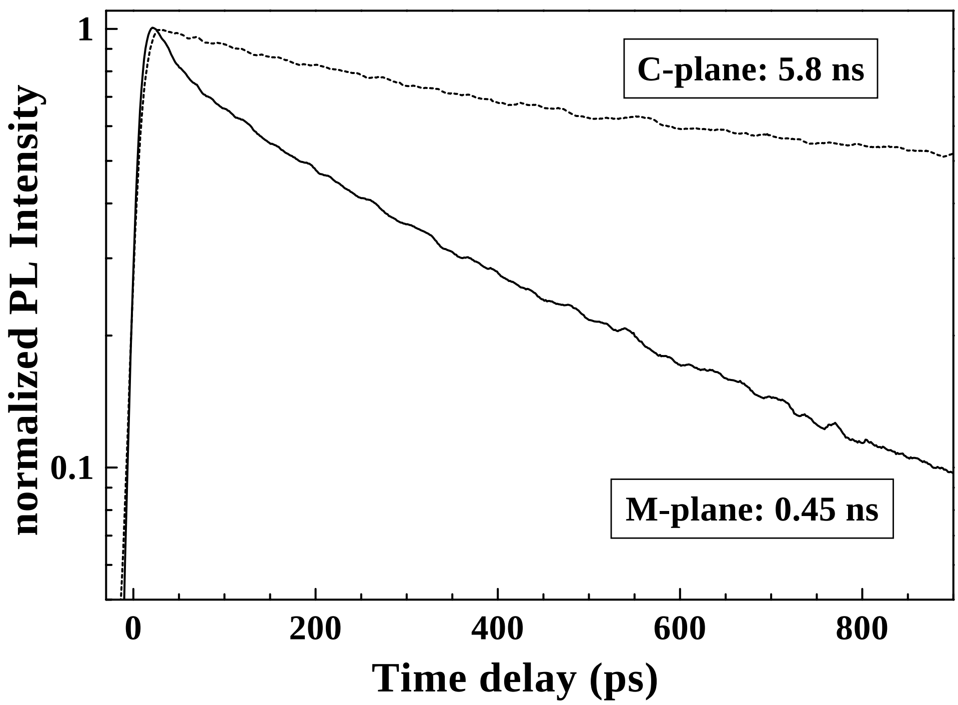

Figure 1: PL transients for the C-plane (on 6H-SiC) and M-plane (on γ-$LiAlO_2$) GaN/(Al,Ga)N MQW structures for a temperature of 7 K detected at the energy of the corresponding maximum of the time-integrated PL spectra.

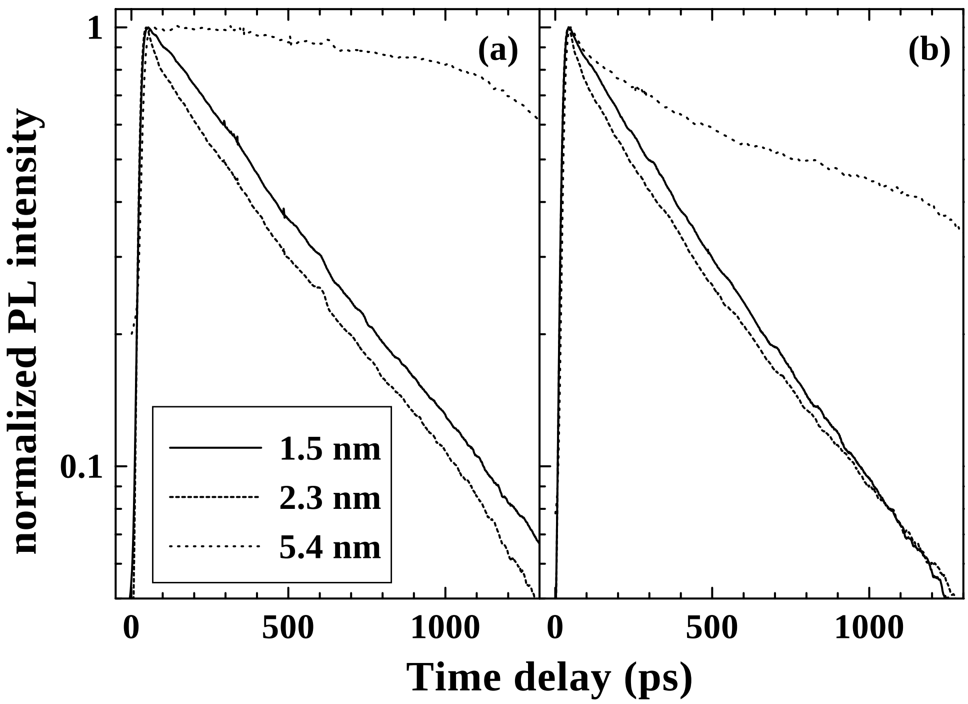

Figure 2: PL transients of the GaN/(Al,Ga)N MQWs with (a) GaN and (b) (Al,Ga)N buffer layer for a temperature of 9 K detected at the energy of the corresponding maximum of the time-integrated PL spectra.