Magneto-Photoluminescence Properties of an AlGaN/GaN 2DEG grown on Bulk GaN

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Landau level (LL) splitting of the density of states at moderate magnetic fields (~1T) is typical for high-quality 2-dimensional electron gases (2DEGs) confined in semiconductor heterostructures. In magneto-transport measurements this LL splitting leads to characteristic Shubnikov-de Haas oscillations in the longitudinal resistance and the occurrence of the quantum Hall effect. Reports on the optical detection of LLs in magneto-photoluminescence (PL) spectra are so far speculative for 2DEGs formed in AlGaN/GaN heterostructures.

Here, the LL splitting in a 2DEG (n_e~2.8e12cm^{-2}) confined at an $Al_{0.06}Ga_{0.94}N$/GaN interface is spectroscopically confirmed (Fig. 1). The ultra-pure GaN/AlGaN/GaN (1µm/16nm/3nm) layer stack [1] was grown by MBE on 650µm thick semi-insulating GaN with a vendor-specified density of threading dislocations (n_{TDD}) < 1e6cm^{-2}. Atomic force microscopy reveals 5x5µm^2 surface sections without a single defect, statistically verifying the defect level to < 4e6cm^{-2} [2]. An active area is laterally defined in Hall bar geometry, allowing for simultaneous measurements of magneto-transport and –PL under steady illumination at low-temperatures and magnetic fields up to 15 Tesla (Fig. 2). The B-field induced oscillations commence in both cases at ~2T. Identical frequencies governing both oscillation types confirm the inherent 2D nature of the discussed PL features. The energy splitting between the PL LLs allows for extraction of an effective electron mass of ~0.24 m_e. Optical detection of the 2DEG represents a contactless method - even on wafer level - independent of e.g. lateral device definition, electrical contact issues or parasitic conduction paths.

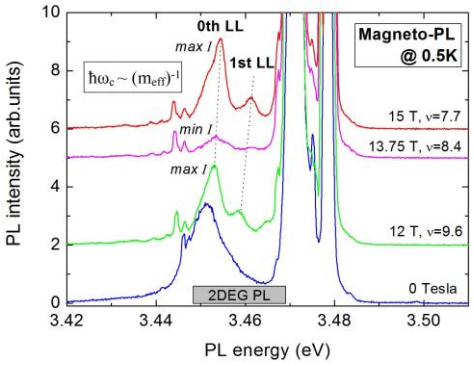

Fig. 1: The PL spectral band from the 2DEG at the AlGaN/GaN heterojunction detected at ~3.45eV. Characteristic splitting of the band into Landau levels in a magnetic field is visible, along with prominent changes in the intensity.

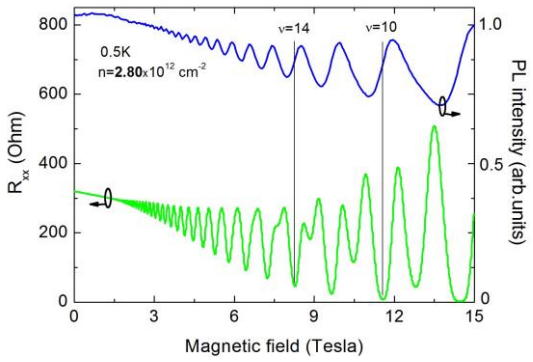

Fig. 2: Simultaneously recorded B-field induced PL intensity oscillations (top) along with magneto-transport oscillations (bottom) from an AlGaN/GaN 2DEG.

[1] S. Schmult, F. Schubert, S. Wirth, A. Großer et al., J. Vac. Sci. Technol., B 35 (2), 02B104, 2017.

[2] R. Hentschel, J. Gärtner, A. Wachowiak, A. Großer, T. Mikolajick, and S. Schmult, submitted.

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Supplementary Pages (Optional)

The following figures and captions deliver further confidential information on the structural, optical and transport properties of the AlGaN/GaN heterostructure described above.

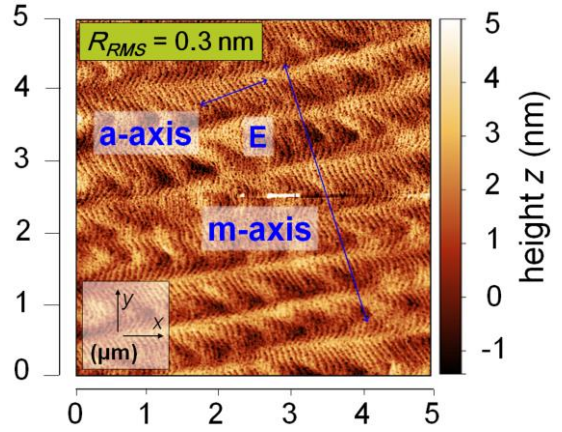

Fig. 3: Surface morphology scanned by AFM of a 5x5µm² section of the AlGaN/GaN heterostructure showing no surface defect originating from dislocations. The ripple structure originates from monolayer steps (260pm) resulting from the crystal miscut with respect to the a- and m-directions (from [2]).

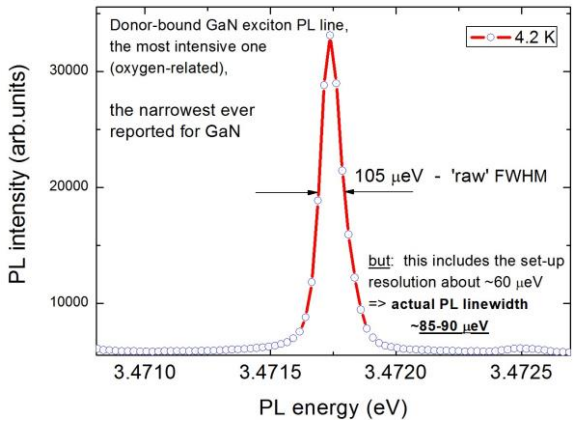

Fig. 4: Donor-bound exciton PL originating from the MBE-grown 1µm thick GaN buffer with a linewidth of <100µeV proves the excellent crystalline quality of the epitaxially-grown layer stack.

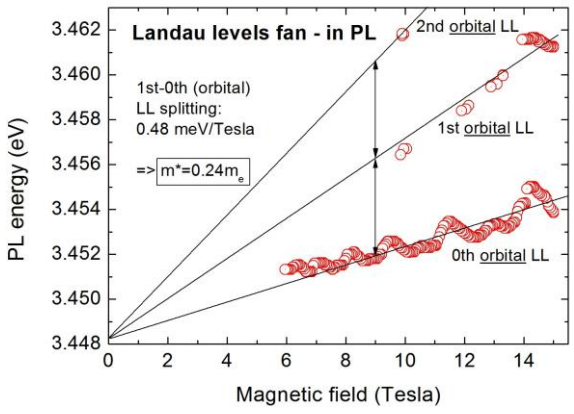

Fig. 5: Landau level fan obtained from evaluation of magneto-PL data (c.f. Fig. 1). From the separation of the LLs an effective electron mass of $0.24m_0$ is extracted.

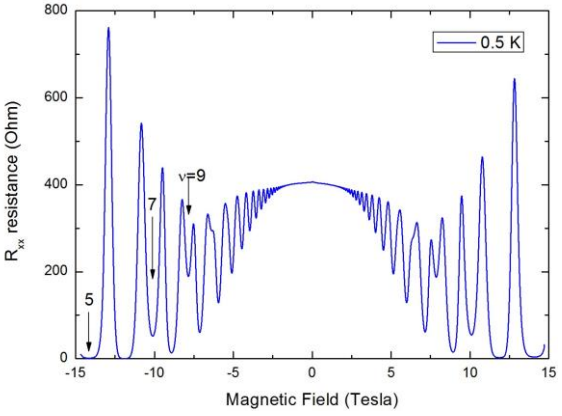

Fig. 6: Longitudinal magneto-resistance of the AlGaN/GaN 2DEG without illumination. At high magnetic fields pronounced zero-resistance states and odd filling factors are identified.

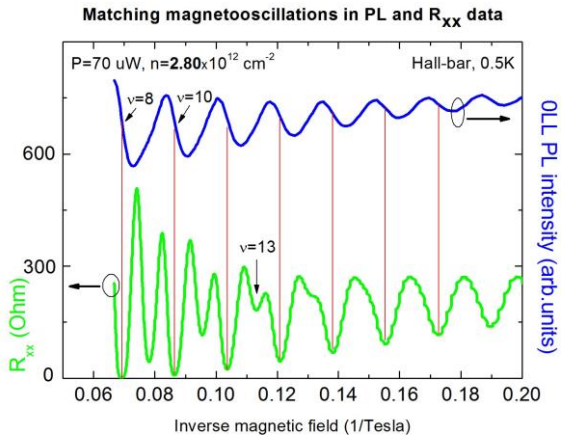

Fig. 7: Magneto-PL and -transport data plotted vs. the inverse magnetic field. Despite the shift between the respective minima and maxima, the oscillation frequency is proportional to the 2D density, yielding identical values for the spectroscopic and electrical measurements.