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Spatially Resolved Imaging of the Spectral Emission Characteristic of InGaN-MQW-LEDs by Scanning Electroluminescence Microscopy

Peter Fischer [1a], Jürgen Christen[1], Margit Zacharias[1]
Veit Schwegler[2], Christoph Kirchner[2], Markus Kamp[2]

[1] Institute of Experimental Physics, Otto-von-Guericke University, 39016 Magdeburg, Germany
[a] Phone: ++49-391-6712361 Fax: ++49-391-6711130 email: peter.fischer@physik.uni-magdeburg.de
[2] Department of Optoelectronics, University of Ulm, 89069 Ulm, Germany

1. Introduction

Recently, intense research on wide band-gap III-nitride has been performed and successfully led to the development of blue and UV Light-Emitting Diodes (LED)[1-7]. This could be achieved due to improvements of epitaxial growth and processing. To control the quality of micro- and nanostructured semiconductor devices it is not sufficient to get macroscopically averaged data or to record information from a single local spot, but it is mandatory to scan over the whole device. Scanning micro-electroluminescence (μ-EL) allows the direct correlation of morphological and optical properties at the same sample position. This fast non-destructive technique visualizes inhomogeneities from the epitaxial growth process as well as from the sample processing.

2. Experimental

The scanning μ-EL system is based on a modified optical microscope [8,9]. For EL-mode an overall spatial resolution of $\Delta x = 1\mu m$ is obtained. A high resolution piezo stage and a DC-motor scanning stage enable the scanning with a resolution of 1 nm and 250nm, respectively. A complete μ-EL spectrum is recorded at each pixel (x,y) and stored during the scanning over 128 x 100 pixels. The EL is dispersed by a 0.5m spectrometer and detected by a liquid nitrogen cooled CCD camera. All μ-EL measurements were performed at room temperature. After a scanning image is completed a 3-dimensional data set $I_{EL}(x, y, \lambda)$ is obtained and all types of data cross sections through this tensor can be subsequently generated. Typical examples of such extracted information are local EL spot spectra $I_{EL}(\lambda, x_i, y_i)$, EL wavelength images, i.e. mappings of the local emission peak wavelength $\lambda_{Peak}(x,y)$, sets of monochromatic EL images $I_{EL}(\lambda_i, x, y)$ as well as EL spectrum linescans $I_{EL}(\lambda, s(x,y))$.

The near-UV Light-Emitting Diode is grown by low pressure MOVPE in a horizontal reactor on a sapphire substrate. The structure consists of 2 μm GaN and 1 μm Si-doped GaN followed by an active region of four InGaN (3 nm) / GaN (7 nm) layers with a nominally Indium contents of 9%, 100 nm Mg-doped AlGaN with a nominally Al contents of around 7 %, and finally 300 nm p-doped GaN. The doping concentrations are about $3x10^{17}\,cm^{-3}$ and $5x10^{18}\,cm^{-3}$ for p- and n-GaN, respectively. Photolithography is used to define the mesa structure. Chemically-assisted ion-beam etching (CAIBE) transfers the pattern using a conventional photoresist mask. A second lithographic step defines the n- and p-contact area, using lift-off technique and subsequent metallization with Ni/Au contacts. The LED is investigated from the p-contact as well as from the substrate side.

3. Results and Discussion

Spatially and spectrally resolved μ-El is measured in dependence of the injection current density. The results of the investigation from the substrate side are presented in Fig. 1 for low current density (Fig. 1 (a)-(d) and for a higher current density (Fig. 1 (e)-(h)). The integral EL spectra presented in Fig. 1 (a) and Fig. 1 (e) show the result of integrating over all single μ-EL spectra detected from the scanned area. A strong emission is observed at around 410 nm and 415 nm, respectively. Fig. 1 (b) and Fig. 1 (f) present the logarithmic scaled EL intensity images. Bright areas correspond to high intensities. The roughness of the sapphire substrate backside is directly visible here. The EL intensity images show that high intensity areas become larger with higher injection currents, but intensity fluctuations are still observed. The wavelength images (Fig. 1 (c) and (g)) show the peak emission wavelength of the investigated area. The emission mainly fluctuates between 407 nm and 419 nm. For low current density the LED emits around 410 nm and a very small redshift in the center of the device is observed (Fig. 1 (c). However, for higher injection conditions, the integral emission spectrum shows a red shift to wavelengths of around 415 nm due to ohmic heating. Spatially resolved measurements (Fig. 1 (g)) reveal the most pronounced red shift from beneath the p-contact ($\lambda \approx 419$nm), corresponding to the highest current densities. The histogram images in Fig. 1 (d) and (h) correspond to the wavelength images and show the redshift of the center of the emission wavelength. With increasing current density the wavelength distribution slightly broadens.

4. Conclusion

In conclusion, an InGaN/GaN MQW LED is comprehensively micro optically characterized. The non-destructive μ-EL probes the relevant properties of the optically active region of the device under operation. It reveals all deficiencies from either epitaxial growth or processing and is found to be very powerful technique to analyze LEDs. The EL intensity mappings show inhomogeneities. An integral and a local emission redshift are observed, both caused by thermal effects.

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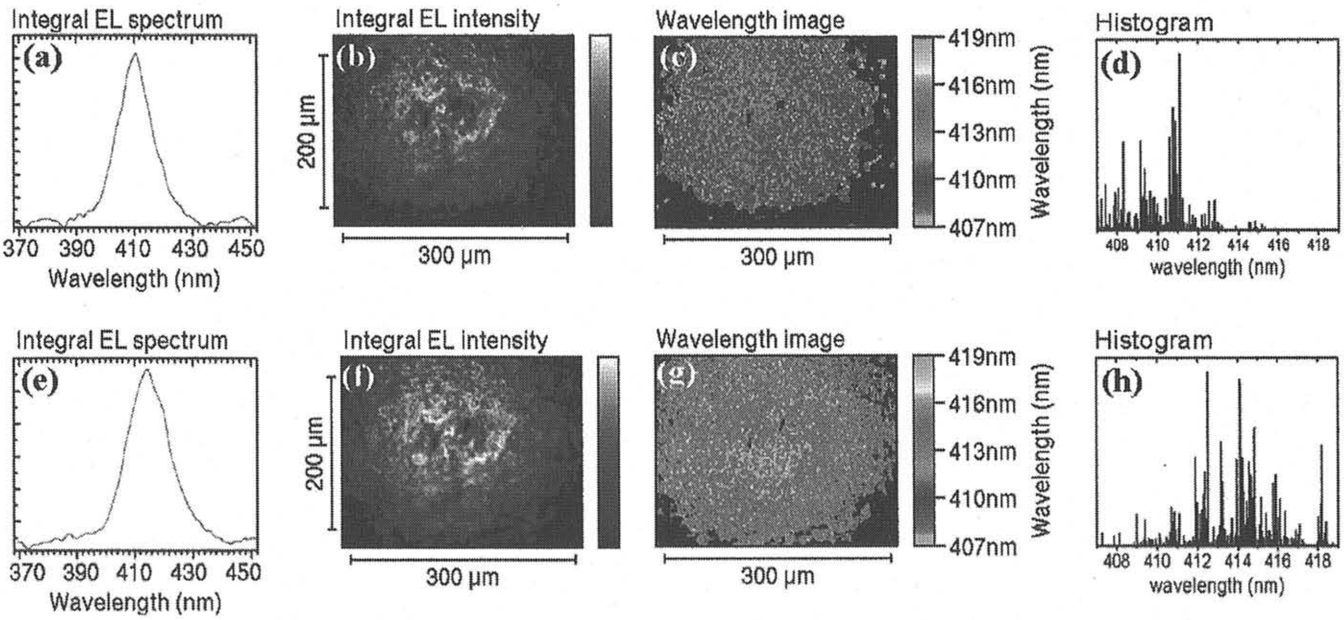

Fig. 1: Integral EL spectrum, integral EL intensity image, wavelength image and histogram of the wavelength image for low current density (Fig. 1 (a)-(d)) and for high current density (Fig. 1 (e)-(h)).