Characterisation of the optical properties of InGaN MQW structures using a combined SEM and CL spectral mapping system

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Abstract: We demonstrate the ability of a combined scanning electron microscope and cathodoluminescence (CL) spectral mapping system to provide important spatially resolved information. The degree of inhomogeneity in spectral output across a multi-quantum well sample is measured using the SEM-CL system as well as measuring the efficiency roll-off with increasing carrier concentration. The effects of low energy electron beam modification on the InGaN/GaN multi quantum wells have also been characterized.

Key words: InGaN/GaN quantum wells; cathodoluminescence; spectral mapping; electron beam irradiation

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1. Introduction

Electroluminescence and photoluminescence are commonly used to characterize the spectral output and efficiency of semiconductor samples. These techniques, however, have limitations compared with cathodoluminescence (CL) microscopy and spectroscopy, in particular for providing spatially-resolved information at the sub-micron scale[1, 2]. In this paper it will be demonstrated how a combined scanning electron microscope (SEM) in conjunction with CL spectral mapping, can be used to effectively characterize the optical properties of a multi-quantum well (MQW) sample.

2. Sample

The sample used in this study was a highly light emitting blue InGaN/GaN MQW sample grown on a sapphire substrate using MOCVD, by EpiPlus, Taiwan. The sample consists of a 2.5 μm GaN buffer layer, 100 nm n-GaN, 5 InGaN/GaN (2 nm/16 nm) quantum wells, 50 nm p-AlGaN and a 30 nm capping layer of p-GaN.

3. Experimental details

Optical properties of the InGaN/GaN MQW sample were studied using an FEI Quanta 200 ESEM equipped with a Gatan MONOCL3, modified to allow complete CL spectra to be collected simultaneously using an Ocean Optics QE65000 optical CCD spectrometer. Spatially-resolved spectral maps were generated using a Moran Scientific system attached to the SEM-CL system.

4. Results

4.1. Quantum efficiency

Using the SEM-CL system the external quantum efficiency (EQE) of the MQW sample can be measured directly. By using an appropriate choice of accelerating voltage, carriers can be directly injected into the quantum well region. Therefore by changing the beam current we can change the carrier density being injection in to the MWQ region.

A 25 μm^2 area was exposed to increasing beam currents at 15 kV and the spectrum was collected for 500 ms. From Fig. 1 we can see that the InGaN MQW sample follows the well documented efficiency roll-off behaviour seen in GaN based devices[3]. The presented method has the ability to be extended to spatially-resolved efficiency.

4.2. Time resolved CL

To determine the effects of the electron beam on the MQW sample, time resolved spectra were collected using the SEM-CL system. A 25 μm^2 area was irradiated at 15 kV and 10 nA. A full spectrum was collected every 50 ms for 5 min.

The time resolved spectra show a sharp decrease in CL intensity for approximately 30 s, followed by gradual increase in intensity. The change in CL intensity is also accompanied by a peak shift to higher energy (Fig. 2). The CL peak due to the GaN capping layer and substrate shows no change in intensity or shift in wavelength indicating that the electron beam is directly modifying the MQW region. The origin of this peak shift

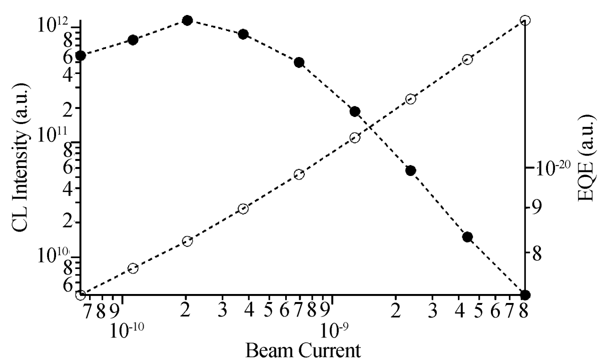

Fig. 1. Total CL intensity (open circles) and EQE (closed circles) of 25 μm^2 area of MQW sample measured at 15 kV at room temperature.

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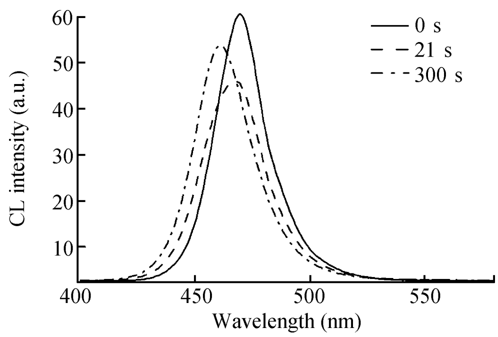

Fig. 2. Selected time resolved CL spectrum at 15 kV and 10 nA.

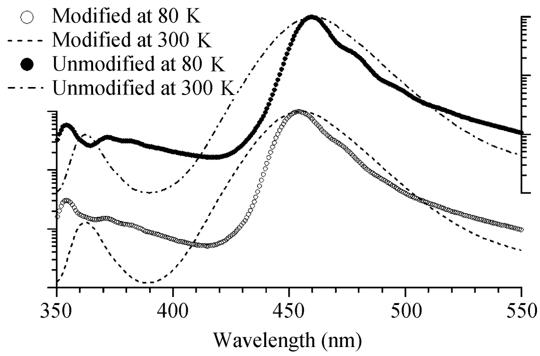

Fig. 3. Extracted spectrum from beam modified and unmodified regions in the spectral maps at room temperature and 80 K.

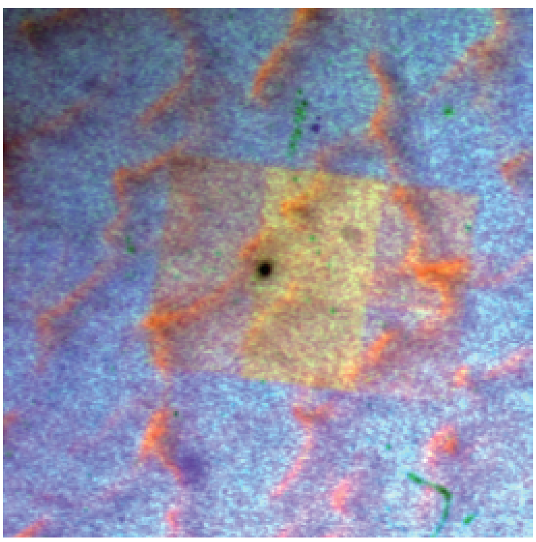

Fig. 4. Pseudo colour image of CL spectrum form sample at 300 K. Green: GaN substrate; Blue: low energy half of MQW peak; Red: high energy half of MQW peak (Colour in electronic copy only).

remains unclear and is the subject of further studies.

4.3. Spectral CL mapping

Spectral CL maps of the MWQ sample were collected at 15 kV and beam current of 7 nA at room temperature and 80 K. The scans were of 315 μm^2 area with and a scan time of 10 ms/pixel. A fresh region of specimen together with a

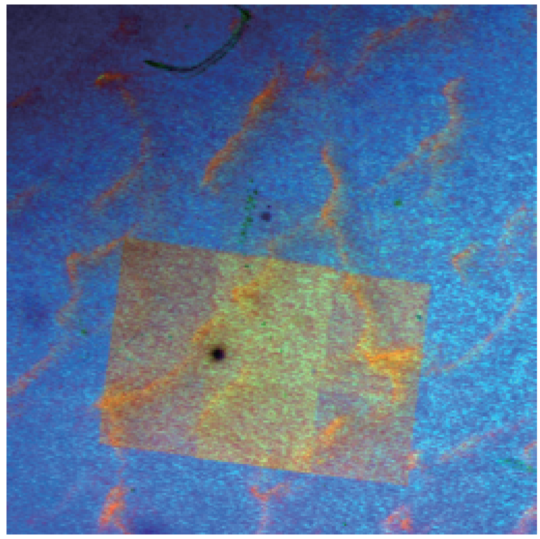

Fig. 5. Pseudo colour image of CL spectrum form sample at 80 K. Green: GaN substrate; Blue: low energy half of MQW peak; Red: high energy half of MQW peak (Colour in electronic copy only).

previously electron beam irradiated area were imaged using the Moran Scientific spectral CL imaging system, where a full spectrum is collected simultaneously at each pixel.

From the spectral CL map, spectra from beam modified regions and unmodified regions could be extracted from specific regions of specimen. Two distinct CL emission peaks are observed in the extracted spectra (Fig. 3), a large blue peak due to the MQW region and a smaller UV peak due to the GaN Buffer Layer. These spectra confirm that the MQW emission has been modified by the electron beam.

A pseudo colour image was generated to illustrate the peak shift due to the beam modification (Figs. 4 and 5). Here the spatially-resolved peak shift to higher energy can clearly be seen. The CL maps show how the peak emission wavelength varies spatially providing a measure of the inhomogeneity of the MQW emission across the sample (see Figs. 4 and 5).

5. Conclusions

In this study we have demonstrated the benefits of a combined SEM and spectral CL mapping system to characterize InGaN/GaN MQW samples. This study has shown the ease in which properties such as the quantum efficiency can be directly measured. The advantages of spectral mapping have also been shown in its ability to display MQW spectral peak shift as well as electron beam irradiation effects at high spatial resolution.

References

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