Cathodoluminescence mapping of localized light emission on III-V nanowire heterostructures

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Nanowires (NW) have opened a new way to form self-assembled heterostructures at the nanoscale. They provide flexible means to design quantum confined nanostructures, like quantum dots, discs and other insertions. They also enable fabrication of nanowire-based devices with new functionalities by tailoring their band structure. Moreover, several studies have already used this approach and demonstrated single NW Light Emitting Devices (LEDs) and photodetectors. [1-5]. For studying optical properties of these nanostructures, full spectroscopic capabilities at high spatial resolution (~1 nm) become mandatory. Scanning transmission electron microscopes (STEM) equipped with high efficiency cathodoluminescence (CL) spectroscopy devices are now able to fulfill this requirement and image the sample structure at the same time. In this contribution, we will discuss recent results that correlate optical properties of III-V Quantum Discs (QDiscs) and other nanoscale insertions in NW with their morphology and structure.

We used a VG HB-501 STEM featuring a Cold Field Emission Gun (Cold-FEG) providing high currents (~200pA) in small probe (~0.5 nm). The CL set-up was designed and built in-house and has a high solid angle parabolic mirror and an optical system that preserves the most of the collected light [6]. The system also has a cooled sample stage (150K) to enhance light emission and prevent sample damage.

Sequences of three 15 nm thick InGaN inclusions within GaN nanowires have been analysed [4] (Figure 1). These inclusions are too large to cause quantum confinement, but, due to the Volmer-Weber growth mode, they have an In gradient, as demonstrated by STEM-EDX, which possibly creates a band gap minimum on the top of the inclusion. In correlation to this morphology, CL maps show the emission to be most intense on the top on the InGaN inclusion (Figure 1). Moreover, in average, the emission energy decreases from the first to the third inclusion, in agreement with the increasing In concentration in each one. The increase of Indium on the inclusions is related to the elastic strain relaxation during growth. These findings elucidate the polychromaticity observed in InGaN insertions growth in identical conditions.

GaN QDiscs with AlN barriers are subject to high carrier localization due to the high band gap difference between these materials. We have studied a sequence of 20 GaN/AlN QDiscs built within single NWs (Figure 2). HAADF images show that the QDiscs thickness varies from 1 to 3.4 nm. Luminescence maps indicate clearly the energy difference between different QDiscs and can distinguish, for instance, QDiscs that are separated spatially by 6 nm and spectrally by 4 nm (Figure 2). High resolution images correlated with light emission show that QDiscs thicker than about 2.6 nm (i.e. 10 monolayers (ML)) emit below the GaN band gap evidencing the Quantum Confined Stark Effect. Moreover, the growth of AlN on the side walls apparently creates a compressive strain that blue-shifts the emission of QDiscs of identical size. [3]. In this study, the luminescence seems to take place most likely at the centre of the QDisc and diffusion length of carriers is as short as about 5 nm.

References

[1] F. Qian et al. Nano Lett. **5** (2005) p. 2287.
[2] L. Rigutti et al. Nano Lett. **10** (2010) p. 2939.
[3] L. F. Zagonel et al. Nano Lett. **11** (2011) p. 568.
[4] G. Tourbot et al. Nanotechnology **23** (2012) 135703.
[5] G. Jacopin et al. Applied Physics Express **5** (2012) 014101.
[6] M. Kociak et al. International Patents WO 2011/148072 and WO 2011/148073.

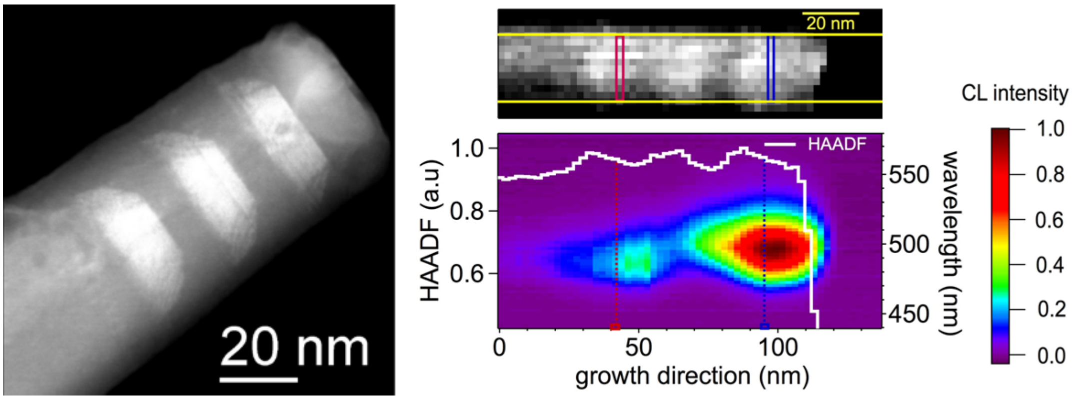

Figure 1: *(left) HAADF image showing the InGaN inclusion inside the GaN NW. (right) CL spectrum image with simultaneously acquired HAADF image. (top-right HAADF image. (bottom-right) Spatial-spectral plot showing the position (horizontal axis) and wavelength (vertical axis) along 3 InGaN inclusions. Note that the energy of the third one is lower than the first one and the middle shows no luminescence.*

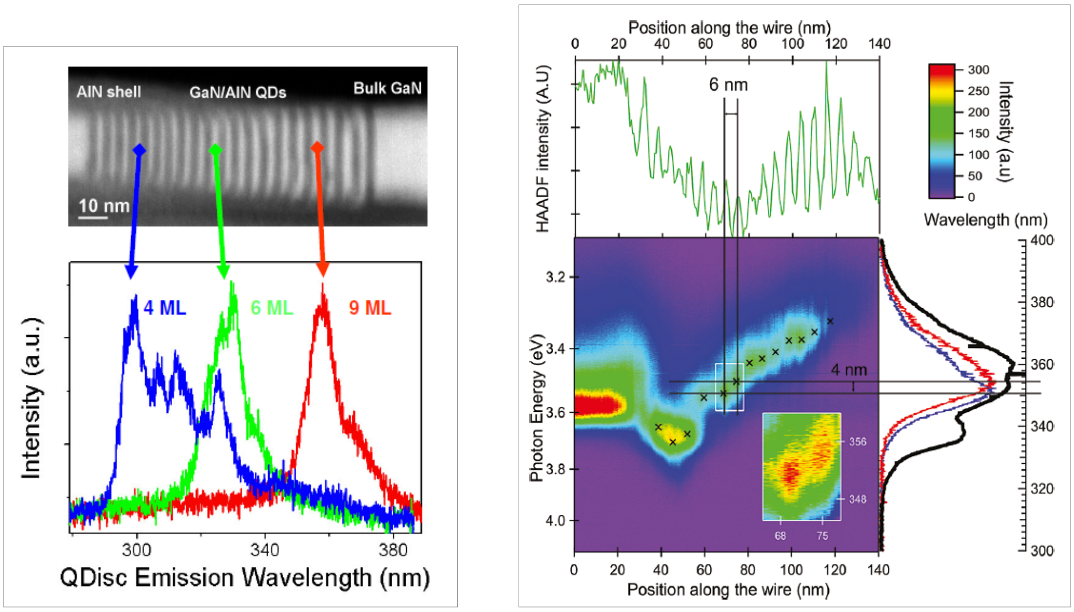

Figure 2: *(left) Spectra from 3 GaN/AlN QDiscs inside a NW. (top-left) HAADF image showing the sample structure. (bottom-left) Spectra for QDiscs with 4, 6 and 9 Monolayers (ML). (right) Projected CL map. (top-right) HAADF profile indicating a QDisc in each peak. (bottom-right) Spatial-spectral plot showing the position (horizontal axis) and wavelength (vertical axis) along 20 GaN/AlN QDiscs with the GaN bulk NW on the left.*