Cathodoluminescence assessment of III-V nanowire heterostructures

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Nanowires (NW) have emerged as a platform to build complex, self-assembled, defect-free nanostructures and several studies have recently demonstrated single nanowire (NW) Light Emitting Diodes (LEDs) and light detectors. [1-5]. In particular, NWs are highly attractive as building blocks for III-nitride semiconductor devices. In the study of quantum dots, discs and other insertions, the assessment of optical properties with high spatial resolution (~1 nm) and full spectroscopic capabilities becomes of major importance. To fulfill this need, high efficiency cathodoluminescence (CL) spectroscopy systems in a scanning transmission electron microscope (STEM) are remarkable tools. In this contribution, we will show the relevance of using CL spectral imaging in a TEM to tackle the study of the optical properties of various III-N nanostructured NWs at the relevant scale – namely few nanometers. – We will give three selected examples.

We have used an optimized in-house build CL system featuring a high solid angle parabolic mirror and a carefully designed optical system that preserves the most of the collected light [6]. It is installed in a cold field emission gun (Cold-FEG) STEM, VG HB-501, that can be operated from 40 to 100 kV and can provide high currents (~200 pA) in small probes (~0.5 nm). The microscope is also fitted with a cold sample stage (150K) to enhance light emission and prevent sample damage. The STEM also features a fast electrostatic blanker and a flexible scanning module trigged by the CCD camera that allows for fast and reliable spectrum imaging acquisitions. Typical exposure times per spectrum in CL spectrum image ranges from 20 to 100 ms.

The first example of the application of this technique [3] consists in a study of GaN quantum discs (QDiscs) with AlN barriers in a stack built within single NWs. CL spectrum images could readily distinguish the light emission of single 2 nm thick QDiscs (Figure 1). This spectrum image, acquired in less than 6 minutes, has good spatial and spectral sampling (0.6 nm and 20 meV). High resolution images correlated with light emission show that QDiscs thicker than about 10 monolayers (ML) emit below the GaN band gap putting in evidence the Quantum confined Stark Effect. [3]

The second example [4] deals with the investigation of 15 nm thick InGaN insertions within GaN NWs. Our study revealed that light emission occurs only from regions with higher In content and that some insertions have no detectable luminescence. These findings are closely related to the morphology of the InGaN insertions, which present an In concentration gradient due to elastic strain relaxation.

Finally, we will present the case of InGaN radial and axial quantum wells (QWs) in GaN NWs (LED structure) [5]. They have been investigated to clearly assign each electroluminescence spectral feature to a given heterostructure on the single NW devices. It was possible to show that axial QWs, grown on the NW top, emit at lower energies than radial, non-polar, QWs, grown on the NW side walls. This result is probably due to the presence of high electric field and Stark Effect on the axial, polar, QWs. Thus, we could understand that at room temperature, at low current (< 1 μA), axial QWs are more active while at higher currents (up to 15 μA) carriers are more efficiently injected on radial QW and their emission becomes dominant [5].

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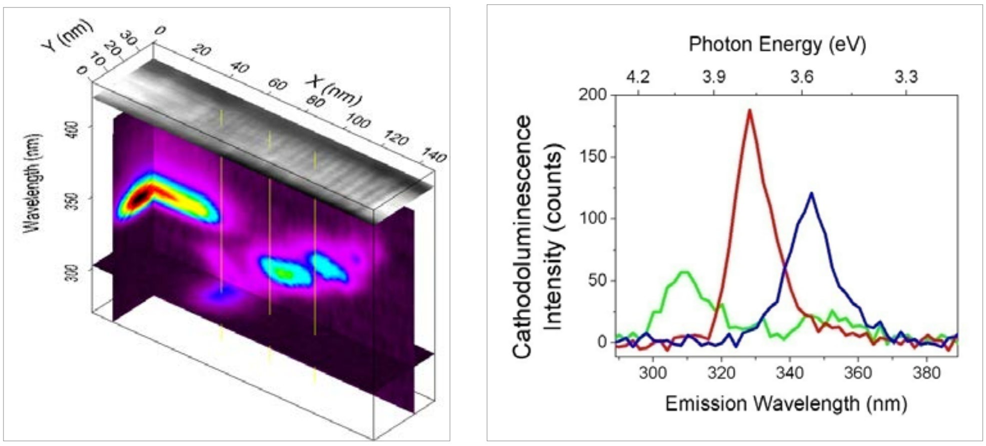

Figure 1: *(left) Cathodoluminescence spectrum-image acquired in less than 6 minutes on a stack of 20 GaN QDiscs separated by AlN barriers. HAADF image is shown on top and slices of the spectrum image are showed below. (right) Spectra selected at 3 different positions extracted from the spectrum image showed on the left (positions are indicated by yellow lines).*

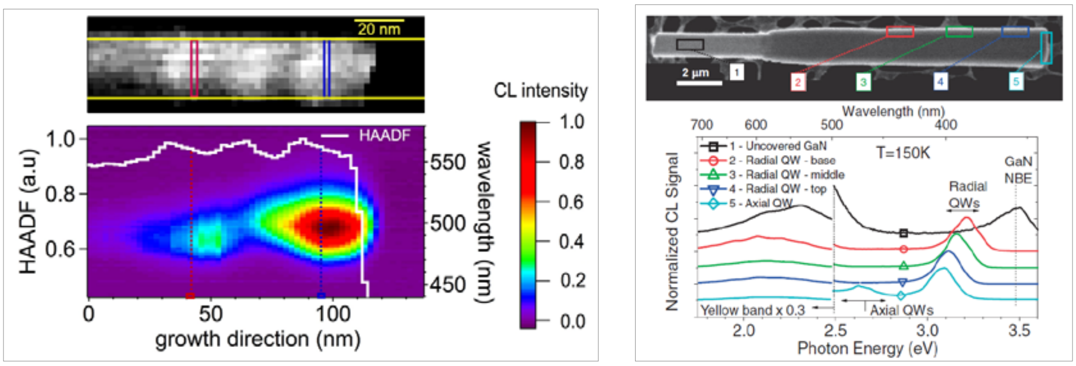

Figure 2: *(left) Cathodoluminescence spectrum-image acquired in the top part of the GaN with 3 InGaN insertions. (left-top) HAADF image, InGaN insertions appear in white. (left-bottom) Projected spectrum image showing the emission of first insertion at 487 nm and third insertion at 495 nm. (right) Image and selected area spectra from a GaN wire covered by radial and axial QWs. (right-top) HAADF image showing the wire and the QW overlayer on the right. (right-bottom) Spectra from selected area showing the energy difference between axial and radial QWs.*