AlGaN based Heterostructures grown on h-BN by quasi van der Waals Molecular Beam Epitaxy for Ultra-Violet Light Emitting Diodes

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Ultra-wide bandgap aluminum gallium nitride ($Al_xGa_{1-x}N$) materials are widely investigated for numerous applications taking advantage of their direct bandgap going from 3.4 to 6 eV. Despite the lack of bulk substrates, which remain difficult to find and very expensive, $Al_xGa_{1-x}N$ heterostructures have led to the development of a broad range of optical and electronic devices [1], in particular regarding ultra-violet (UV) light emitting diodes (LEDs) grown on sapphire substrates [2]. Indeed, UV LEDs focus a lot of attention due to strategic applications (e.g. in environment, medical fields). Quasi van der Waals (VDW) epitaxy is attractive due to its potential to minimize the impact of the lattice-mismatch between the substrate and the heterostructure, as well as the ability to transfer the structure onto a designated substrate, enabling the creation of devices with innovative functionalities. Along this view, hexagonal boron nitride (h-BN) has demonstrated effectiveness in the growth of nitride-based LEDs [3,4].

By using molecular beam epitaxy (MBE), we have first shown the growth of AlN on h-BN [5], AlN being used as a template for the fabrication of $Al_xGa_{1-x}N$ heterostructures. Next, we obtained an emission in the deep UV with the fabrication of strain-induced $Al_yGa_{1-y}N$ quantum dots [6].

Here, we have studied the growth conditions and characterization of $Al_xGa_{1-x}N$ heterostructures on h-BN templates. The templates were deposited on sapphire via metal organic vapor phase epitaxy, followed by MBE grown $Al_{0.7}Ga_{0.3}N$ / AlN heterostructures. The structural properties of the layers were investigated by atomic force microscopy, scanning electron microscopy and X-Ray diffraction measurements. An improvement of the structural quality was observed as the AlN and $Al_{0.7}Ga_{0.3}N$ thicknesses were increased, as well as a significant influence of the h-BN template thickness. As a next step, Si-doped n-type $Al_{0.7}Ga_{0.3}N$ layers were used as templates for the fabrication of $Al_{0.3}Ga_{0.7}N$ (nominal composition) QDs based UV LEDs. Surfaces exhibiting RMS roughnesses around 2-3 nm at the micro-scale were obtained and electroluminescence in the UVC, down to 270 nm, was obtained at room temperature. The electric characteristics were investigated through current-voltage and transmission line method measurements, while EL and optical power were also examined, showing different operation modes as a function of the injected current. This work was supported by ANR funding DOPALGAN <ANR-22-CE51-0035> and GANEX (ANR-11-LABX-0014).

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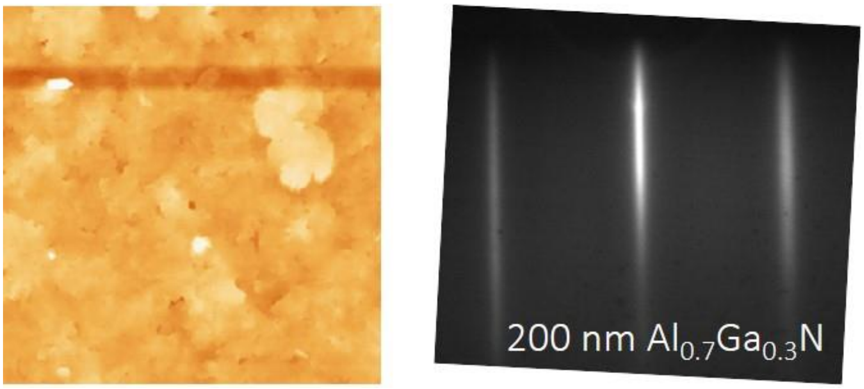

Fig. 1: (left) Atomic force microscopy image (2 x 2 µm^2) of an MBE $Al_{0.7}Ga_{0.3}N$ layer grown on h-BN and (right) a reflection high energy electron diffraction photograph of the same layer at the end of the growth showing a streaky pattern.

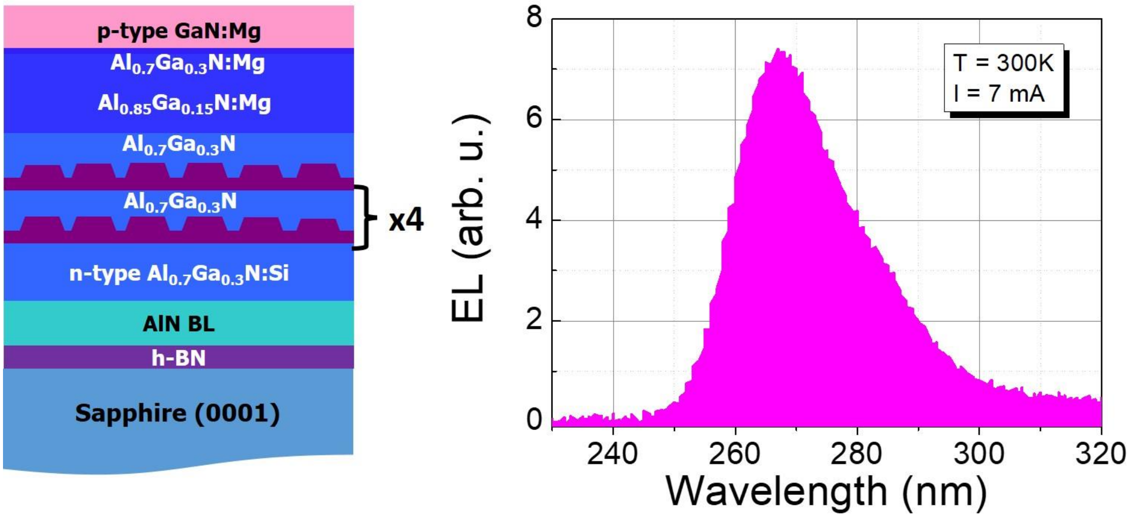

Fig. 2: (left) Schematic of the ultra-violet (UV) LED structure with five planes of $Al_{0.3}Ga_{0.7}N$ (nominal composition) quantum dots and (right) electroluminescence (EL) spectrum of an LED device (310 x 310 µm^2) showing an emission in the deep UV, centered at 267 nm.