Growth of $Al_yGa_{1-y}N$ Quantum Dots by Molecular Beam Epitaxy for UV Light Emitting Diode Designs

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Three dimensional (3D) growth modes leading to the formation of nanometer-sized 3D islands have been extensively explored for the fabrication of quantum dots (QDs). In particular, taking advantage of a strain induced 2D-3D growth mode transition III-Nitride QDs have been successfully fabricated, mainly in the GaN/AlN system. However, p-type doping, which is a prerequisite for the realization of LEDs, is very challenging for AlN due to an acceptor ionization energy of hundreds of meV. Growth of QDs on $Al_xGa_{1-x}N$ materials with $x \leq 0.5$ is therefore highly desirable since p-type doping for x up to 0.5 has been shown [1].

Indeed, $Al_xGa_{1-x}N$-based UV LEDs are seen as the next technology in replacement to the mercury lamp, offering numerous advantages [2]. However, a drop in the efficiency of such LEDs (for $\lambda < 350$ nm) is observed. Part of this drop is due to the low structural quality of the active region with typical dislocation densities > 10^9 cm^{-2}. Our approach to improve the radiative efficiency in the LED active region is to confine carriers in 3D in QDs instead of 1D in quantum wells [3]. In this work, we investigate the influence of growth conditions (deposited amount, composition and/or crystal orientation) on the morphological, structural and optical properties of $Al_yGa_{1-y}N$ QDs grown on $Al_{0.5}Ga_{0.5}N$.

The samples were grown on (0001) and (1-100) oriented sapphire substrates in order to fabricate (0001) and (11-22) oriented $Al_{0.5}Ga_{0.5}N$ layers, respectively. The active region is made of $Al_yGa_{1-y}N$ (with y = 0 or 0.1) QD planes capped in $Al_{0.5}Ga_{0.5}N$. The $Al_yGa_{1-y}N$ deposited amount to grow the QDs typically ranges between 1.5 and 2.5 nm. The QD morphology has been characterized by Atomic Force Microscopy and Scanning Electron Microscopy (SEM). Surface QDs observed by SEM are presented in the figures below. In the (0001) orientation, the QDs present an isotropic shape, with lateral sizes ~ 20 nm and 5 nm for GaN (fig. 1) and $Al_{0.1}Ga_{0.9}N$ (fig. 2) QDs, respectively. In the (11-22) case, chains of QDs are observed (fig. 3), with an elongation and ordering along the <1-100> axis. In all cases, high QD densities, ranging between 1 and 9×10^{11} cm^{-2}, are obtained. Next, the QDs were characterized by photoluminescence (PL) experiments using a frequency-doubled Ar laser at 244 nm and/or a mode-locked frequency-tripled titanium-sapphire laser with a 2 ps pulse width and a wavelength of 260 nm. PL measurements show a blue-shift for $Al_{0.1}Ga_{0.9}N$ QDs compared to GaN QDs, going from ~ 3-3.2 eV to ~3.6-3.9 eV. In comparison, PL peaks near 3.65-3.75 eV are observed for (11-22) QDs. Therefore, depending on the QD growth process, a significant shift to shorter wavelengths is obtained, down to the UV-B range with $\lambda \sim 315$ nm. The origin of these blue-shifts can be related to one or several contributions: an increase of the bandgap energy, a size reduction of the QD and/or reduction of the internal electric field (F), which will be discussed. Finally, the potential of such QDs for UV emission will be analyzed and the main characteristics of QD-based UV LEDs presented.

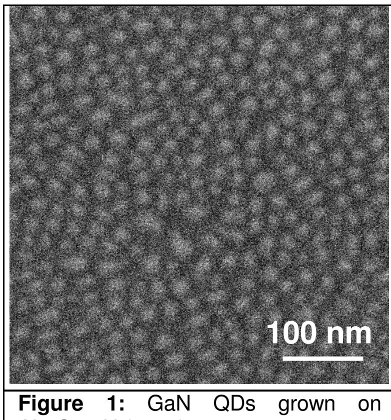

Figure 1: GaN QDs grown on $Al_{0.5}Ga_{0.5}N$ (0001).

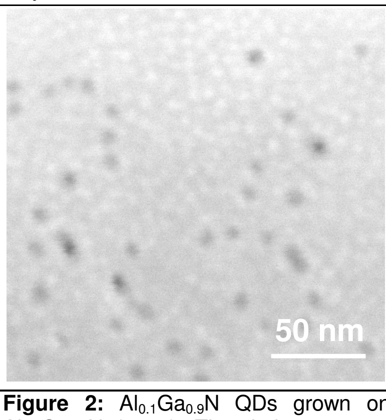

Figure 2: $Al_{0.1}Ga_{0.9}N$ QDs grown on $Al_{0.5}Ga_{0.5}N$ (0001). The dark spots are attributed to threading dislocations.

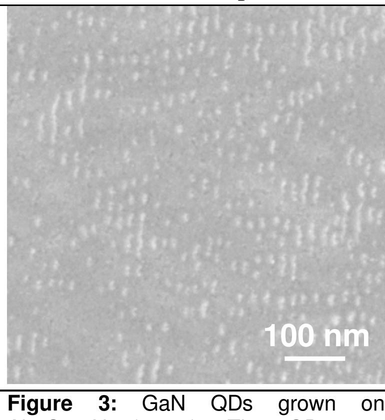

Figure 3: GaN QDs grown on $Al_{0.5}Ga_{0.5}N$ (11-22). The QDs are elongated and aligned along <1-100>.

REFERENCES:

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[3] J. Brault et al., Semicond. Sci. Technol. **29**, 084001 (2014 and references therein.