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Growth and properties of InGaN based nanorods for LEDs : comparison between core/shell and axial MQWs structures

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Abstract

The control of the emission properties is challenging for InGaN nanorods based devices when using the SAG approach. It involves the growth of InGaN/GaN MQWs on the different facet of the nanorods which have each their own properties. Here, axial InGaN/GaN QWs in GaN nanorods are synthesized by a top-down process and exhibit a single emission. This process could be promising for solving the color mixing issue in InGaN based nanorods LED devices.

1. Introduction

InGaN based semiconductors have a direct bandgap that can be tuned across the entire visible spectrum through alloy engineering and therefore are very interesting for solid-state lighting. The performances of current LEDs may be increased through the use of nanostructures and nanorods which look promising for the integration of high efficiency devices. Nanorods exhibit great properties such as an efficient strain relieving capability. Large scale growth on lattice mismatch substrates and core-shell structures can then be considered. Still, the production of nanorods-based LEDs devices faces challenges such as color mixing that are related to morphological, optical and electrical properties which are linked to the synthesis process. Here we compare the properties of InGaN based nanorods with a radial core/shell MQWs structure grown by SAG with a axial InGaN/GaN QWs in GaN nanorods synthesized by a top down process

2. Experimental method

Selective area growth of GaN nanorods

Growth experiments were performed on SiN_x (30 nm thick) masked c-plane sapphire substrates covered with a 1.8 µm thick Ga-polar GaN layer. The pattern was defined with nano-imprint lithography (NIL) and consisted of arrays of circular holes of 460 nm and a pitch of 2 µm. Pulsed selective area growth (SAG) was used to grow GaN nanorods in an EpiQuest showerhead MOVPE reactor at 1000 °C under H_2. Trimethyl-gallium (TMGa, 4.2 Pa) and ammonia (NH_3, 1.3×10^4 Pa) were used as precursors and injected alternatively in the growth chamber for 5 s and 15 s, respectively. Between each pulse, a purge time of 1 s was introduced in order to promote the vertical growth along the (0001) axis. A total of 200 cycles was performed.

Growth of InGaN/GaN quantum wells by MOVPE

Growth of the InGaN/GaN quantum wells (QWs) was performed on bare GaN templates as well as on GaN nanorods on , the carrier gas was switched to N_2 and the temperature was decreased between 710 °C -770 °C during the growth of the wells. Trimethyl-indium (TMIn, 1.7 Pa) and triethyl-gallium (TEGa, 1.8 Pa) were used as precursors for the QWs. An AlGaN layer was grown on some samples after the growth of the QW using trimethyl-aluminum (TMA). A total of five QWs were grown and capped with a p-doped GaN layer grown at 900 °C under H_2. Bisethylcyclopentadienyl-magnesium (EtCp2Mg) was employed as p-dopant. During growth, the reactor pressure was kept at 200 Torr.

Top-down synthesis of GaN nanorods with axial InGaN/GaN quantum wells

Nanorods were defined by electron-beam lithography using nickel (100 nm thick) as the etch mask and a hybrid dry-wet etching process. The pattern consisted of different arrays of circular apertures with diameters of 800 nm-100 nm and a pitch of 3 µm. Etching of the nanopillars included two steps. First, the pillars were dry etched using inductively coupled plasma reactive ion etching (ICP-RIE). Then, a wet etching using a 2% buffered KOH solution was performed to remove any damaged materials induced by the dry etching process at the surface of the rods.

Nanorods morphologies, including diameters and heights were studied by Hitachi SU-4300 scanning electron microscope (SEM) using an acceleration voltage of 5 kV. The optical properties were analyzed by photoluminescence spectroscopy (PL) using an excitation wavelength of 325 nm. X-Ray diffraction was used to estimate the composition of the InGaN alloys.

3. Results

Nanorods were successfully synthesized by both SAG-MOVPE as well as by top down etching as shown in figure 1. Nanorods grown by SAG-MOVPE exhibit six m-planes sidewalls and a pyramidal and often truncated top. InGaN GaN QWs grown along the GaN nanorods facets typically exhibit different properties as the quantum confined stark effect and growth kinetics differ between the polar c-plane, the semi polar r-planes and the non-polar m-planes. As a result, the CL spectra exhibit different emissions that can be attributed to each different plane (see figure 2, from [1]). One should then carefully optimize the mask pattern to control the size of the surface of the different facets and/or the current injection [2].

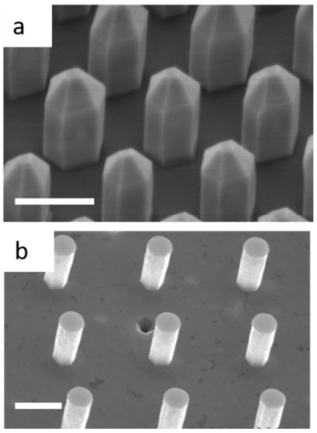

Fig. 1. (a) SEM image of GaN nanorods obtained by (a) SAG-MOVPE and (b) top down etching process. Scale bar is 800 nm.

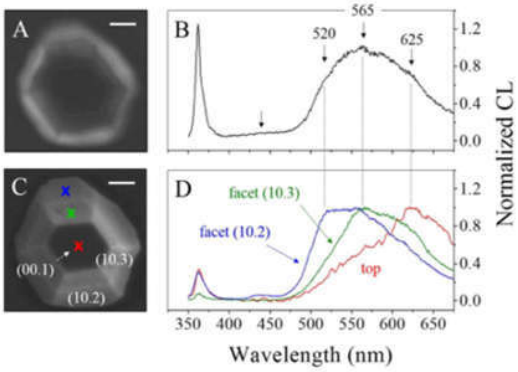

Fig. 2. Cathodoluminescence sprectra showing the different emissions from the InGaN/GaN MQWs grown on the different facet of the nanorods, from [1].

On the other hand, axial InGaN/GaN QWs in GaN nanorods synthesized by a top down process exhibit a single emission. It is shown that this emission can be influenced by the nanorods diameter as shown in figure 3. A blue-shift of 17 nm in the PL spectra has been measured for the nanorods with a diameter of 800 nm compared to the 2D reference. Such a shift can be attributed to the local strain engineering by relaxing the strain locally due to the nanorods structure [3].

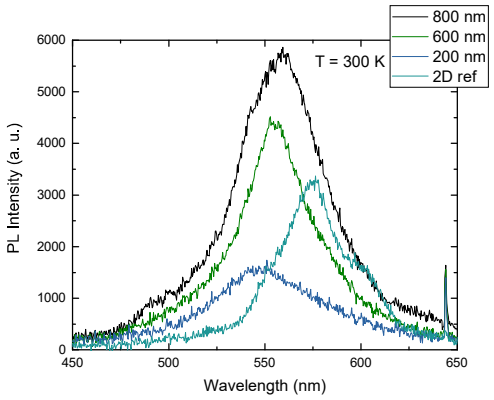

Fig. 3. PL spectra at 300 K of yellow-orange InGaN/GaN QWs. Emission shifts toward the blue as the diameter of the rods decreases.

This approach is very interesting since it has been demonstrated that by reducing further the nanorods diameters until 50 nm, green and blue emission could be achieved, solving the issue of the color mixing in SAG-based structures [3,4].

3. Conclusion

Nanorods with different active InGaN/GaN MQWs regions have been synthesized by SAG-MOVPE and a top-down process. With a SAG process, core/shell heterostructures could be obtained showing a different wavelength emission for each facet. Etching of axial InGaN/GaN MQWs through a nickel mask produced nanorods exhibiting a single emission from the MQWs. A further reduction of the nanorods diameter could be promising concerning the issue of the color mixing LED devices.

Acknowledgements

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