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Original research article

Evaluation of the optical properties of the InGaN/GaN quantum well nanopillar arrays prepared via MOVPE approach

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The III-nitride nanoarchitectures have shown innumerable fascinating peculiarities and conceivable applications in optoelectronic nanodevices. Among them, the geometry of quantum well is considered one of the topmost research and deserve particular attention. Herein, we have originally developed a method for the epitaxial growth of InGaN/GaN quantum well nanopillar arrays on c-sapphire substrate via metal-organic vapor phase epitaxy approach. The influences of the MOVPE growth parameters on the optical behaviour of the InGaN/GaN QWs have been investigated. The results embarked that the developed InGaN/GaN nanopillars quantum well on c-sapphire may be used as light emitting device under the conditions that the diameter of the pillar should be around 1000 nm and the separation distance among these pillars should be less than 1000 nm. At these optimum conditions the fluorescence microscopy indicated that highly luminescent blue light is observed, implying the possibility of the developed nanopillar to be served as promising LED device.

1. Introduction

The current advent of nitride groups has commenced a novel district in the field of semiconductors and nanodevices [1–3]. The nitride groups such as gallium nitrides (GaN), indium nitrides (InN) and aluminum nitrides (AlN), are all direct band gap semiconductors with energy gap values of 3.4 eV, 0.7 eV and 6.2 eV, respectively [4–6]. However, ternary alloys of these nitrides could be formed to span the whole visible spectral region and may be extended to the ultraviolet and infrared regions [7,8]. These unique characteristics render them superlative contenders for tailoring optoelectronic nanodevices, particularly visible light emitting diodes in the green and blue regions, which were hard to be achieved in the past. Moreover, these materials hold other appealing characteristics comprising high breakdown voltage with high mobility, high thermal and mechanical stabilities and their capability to operate in harsh environmental conditions which may arising a possible eagerness to be combined into numerous electronic applications [9–11]. The decrease of the size of nanostructures below the excitonic Bohr radius may result in unique physical features altered with the degree of quantum confinement [12–14]. The quantum confinement nanostructures with various morphologies such as nanotubes [15,16], nanonails [17], nanoplatelets [18–20], nanopyramids [21], nanowires [22–27], nanorods [28–31] and nanopores [32–35] have been developed and inves-

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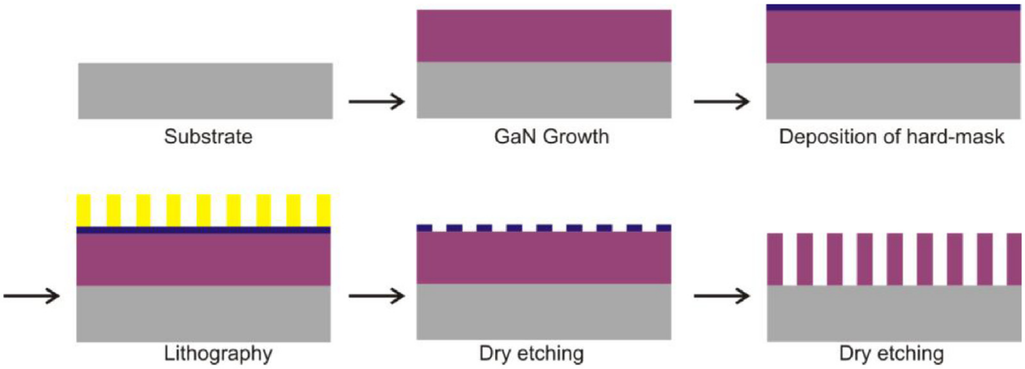

Fig. 1. Fabrication process of the nanopillars LEDs.

tigated. The most common used techniques for the growth of nanoarchitectures are chemical vapour deposition [36,37] and metal vapour epitaxy [38]. The understanding of the impact of the MOVPE growth parameters on the structure and optoelectronic characteristics of the QWs is an essential constraint to guarantee the reproducibility and stability of these nanoarchitectures. From this regard, Herein, we have originally developed a method for the epitaxial growth of InGaN/GaN quantum well nanopillar arrays on c-sapphire substrate via metal-organic vapour phase epitaxy approach with an in situ silane flow injection. The influences of the MOVPE growth parameters on the optical behaviour of the InGaN/GaN QWs have been investigated.

2. Experimental

The nanopillar arrays were fabricated with different sizes. The GaN based layers were grown on c-plane sapphire in a vertical 3 × 2” FT showerhead metal organic vapor phase epitaxy (MOVPE), using Trimethyl- and Bis(cyclopentadienyl) magnesium (Cp_2Mg), Trimethylindium (TMIn), Ammonia (NH_3), Silane (SiH_4), and Triethylgallium (TMGa, TEGa). An in situ thermal baking (for 5 min at 1050 °C under Hydrogen, H_2) and a nitridation step (additional 2 min with NH_3) were performed before the growth procedure. After a nucleation step (1 min at 530 °C) a high temperature GaN buffer layer was grown (45 min at 1040 °C) followed by an n-doped GaN layer (with SiH_4 doping). The active region of the LED structure is built by InGaN/GaN single or 5-fold multi quantum wells which are grown and Nitrogen (N_2) as the carrier gas and at lower temperatures 860 °C for the barrier and 720 °C for the well. The layer stack was terminated by a p-doped layer (with gradual increase of Cp_2Mg flow, 11 min at 1000 °C). The total thickness of the stacks varied depending of the growth times of the n-GaN and the number of quantum wells between 4 and 5.5 μm. After the growth, an in situ acceptor activation step was added (30 min at 800 °C under N_2). Next, a 450 nm SiO_2 film was grown on the GaN film by chemical vapour deposition. Photo-lithography has been used to produce the etch pattern. Nanpillarss with diameters ranged from 400 nm to 2000 nm with different distances were fabricated. The patterns were etched into the SiO_2 film in an inductive coupled plasma ion etching machine (SI500C Dry Etcher-SENTECH INSTRUMENTS GmbH). The plasma is formed in a C_4F_8:Ar (25:7 sccm) gas mixture with 800 W ICP power and 200 W bias at a pressure of 0.5 Pa. After etching the GaN, the samples were dipped in HF for 5 min to remove the remaining oxides. The etched depth was measured by a Dektak 3030 profilometer and scanning electron microscopy (FE-SEM. The etching experiment was performed at ambient temperature by changing the etching parameters. The flow rates of the used gases are $CH_4/H_2/SF_6$ = 18.5/61.5/9 sccm at pressure of about 0.6 Pa. Fig. 1 shows that the process of the nanopillar arrays of the developed MQW LED.

Rigaku-ultima powder diffractometer with a CuK_α rotator anode is employed to measure the XRD of the specimens along the scanning range from 20° to 80° at current of 150 mA and working potential of 50 kV. Field emission scanning electron microscope (JEOL-JSM 7600F) was used. The temperature dependent Photoluminescence (PL) spectra have been recorded for the InGaN/GaN nanpillars at temperature range from 20 K to 280 K by using PL-OXFORD-IN.CO machine.

3. Results and discussion

3.1. The structural properties of developed nanopillars

The morphology of the grown InGaN/GaN nanostructural quantum wells on the c-oriented sapphire substrate was emphasized. Fig. 2 depicts the FE-SEM images for the grown materials. One may note that the InGaN/GaN nanostructures have pillars shape with diameter around 1000 nm and height of 1240 nm, separated from each other by distance around 1000 nm (as shown in Fig. 2a) and diameter of 2000 nm with height of 1240 nm, separated by 500 nm distance (as presented in Fig. 2b). However, these nanopillars are well distributed along the sapphire substrate and highly uniform. There are no defects