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Fabrication and Characterization of $In_xGa_{1-x}N$ Quantum Dots using NNAD Growth Technique

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1. Introduction

The formation of nanometer size materials such as quantum dots (QDs) has attracted much interest for their uses in meso-scopic research such as QD laser. The growth of III-nitrides related materials such as GaN, InGaN and AlGaN have attracted a great amount of attention because of their future application in white light-emitting diodes (LEDs) [1]. It has been reported that the blue light emitting diodes and laser diodes (LDs) with high output power and luminescence efficiency has been achieved by using InGaN multi quantum wells (MQW) structure as an active layer. However, there are some problems predicted theoretically such as phase separation effect or weakness of thermal stability of electrical carriers in shallow InGaN quantum well or high threshold current density [2]. These phenomena can be improved by reducing the dimension of the active layer structure like quantum dot structure because of the enhanced exciton binding energy and carrier localization effect [3]. Thus, growth and characterization of InGaN quantum dot structure becomes very important for the optical devices with high power and high luminescence efficiency.

Many researchers have been reported that the formation of InGaN quantum dot by molecular beam epitaxy (MBE) and metal organic vapor deposition (MOCVD) method. The commonly adopted methods including self-organization, which is characterized by Stranski-Kranstanov (S-K) growth mode, anti-surfactant-assisted growth, selective growth, and the other new methods, are emerging recently to obtain the QDs [4].

In this work, we used our recently developed method nitridation of nano alloyed droplet (NNAD) in growth procedure. NNAD technique may be a considerable interest in the formation of InGaN QDs.

2. Experimental procedure

The InGaN QD structures were deposited on the of GaN layer grown on the c-plane (0001) sapphire substrate. The growth was carried out in the MOCVD system with horizontal quartz reactor. During the MOCVD growth, trimethylgallium (TMG), TrimethylIndium (TMI) and ammonia (NH_3) were used as Ga, In and N precursors, respectively. Prior to growth, the substrate was etched with H_2SO_4:H_3PO_4(3:1) solution for 5 min at 130℃ to remove the surface native oxide layer, and then the sapphire substrate was heated under hydrogen ambient at 1040℃ for 5 min to etch the oxide layer on the substrate surface thermally. Low temperature GaN buffer layer was deposited directly on the substrate for 2 min by feeding TMG and NH_3 with H_2 as a carrier gas. Further, 1.5 µm GaN was grown on the buffer layer at 1040℃.

After the growth of the GaN layer, the substrate was cooled down to 700℃ to form of In and Ga droplets. The formation of In and Ga droplets was performed using the TMI and TMG for 3 min without NH_3. After the growth of droplet, nitridation process was carried out by flowing only NH_3 under N_2 ambient for 20 min. We named this method NNAD (Nitridation of Nano Alloyed Droplet) growth technique.

InGaN QDs were characterized by scanning electron microscopy (SEM), atomic force microscopy (AFM), double crystal X-ray diffractometry (DCXRD). The optical property of the InGaN QDs was investigated by photoluminescence (PL).

3. Results and discussion

InGaN QDs are fabricated on GaN epilayer on sapphire (0001) substrate. A topographic AFM image of this GaN substrate is shown in Fig. 1 (a). The surface consists of flat monolayer terraces and very smooth with an rms roughness of 0.775 nm. The pits indicate the presence of threading dislocations, of which the GaN substrate have a density of 5.0×10^8 cm^{-2}. Fig. 2(b) shows the DCXRD rocking curve of the GaN grown on sapphire substrate. The full width at half maximun (FWHM) of GaN pseudo substrate is 424 arcsec which indicate a good crystalline quality.

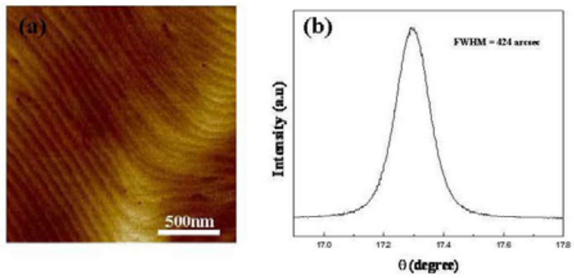

Fig. 1. (a) AFM image of the GaN on sapphire substrate. (b) DCXRD spectrum of GaN on sapphire substrate.

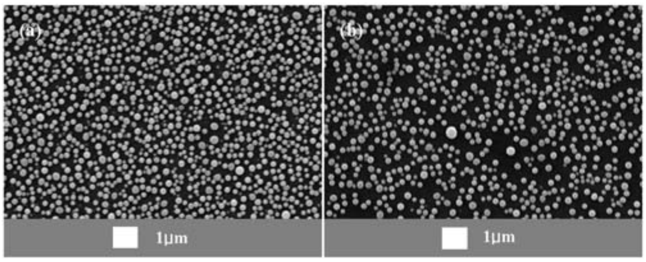

Fig. 2. SEM image of In+Ga alloy droplets on GaN on Sapphire substrate for different precursor flow rate (a) TMI: 20.0 sccm, TMG: 0.5 sccm, (b) TMI: 15.0 sccm, TMG: 0.3 sccm.

In order to study the InGaN QD grown by NNAD method, an In + Ga droplets were formed. Figure 2 shows the planar view SEM image of In+Ga alloy droplet. In NNAD technique, the size and density of droplets were important parameter for growth InGaN QDs. We can see that the droplet density is reduced by decreasing TMI and TMG flow. The droplet size as well as change with respect to the growth temperature. We can confirm that the In + Ga droplets are spherical in shape and evenly distributed on the GaN on sapphire substrate. The diameter of droplets was 150 – 200 nm.

Figure 3 shows the three dimensional AFM image of InGaN QDs which grown at 700℃. The density of the InGaN QDs is 1.0×10^8 cm^{-2} and the average diameter and height are 40 and 70 nm, respectively. However, uniformity and density of InGaN QDs was not good, because of the uncontrolled self-organization method. So we will try to control the formation of InGaN QDs by NNAD growth techniques through further studies.

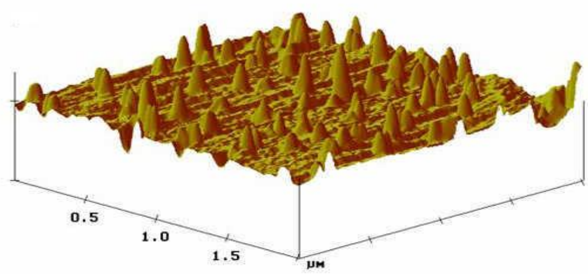

Fig. 3. 3-D view AFM image of InGaN QDs surface on GaN/ sapphire substrate.

Figure 4 shows the room temperature PL spectrum of InGaN QDs grown by NNAD method. A strong band edge emission of GaN template is observed at 365 nm and an emission from the InGaN QDs is seen around 430 nm. The broad emission from QDs is attributed to inhomogeneous size or composition of grown QDs. Our experiments are under study to optimize the growth parameters. Further experiments are under investigation to fabricate the red, green and blue emission InGaN QDs which will be presented during the conference.

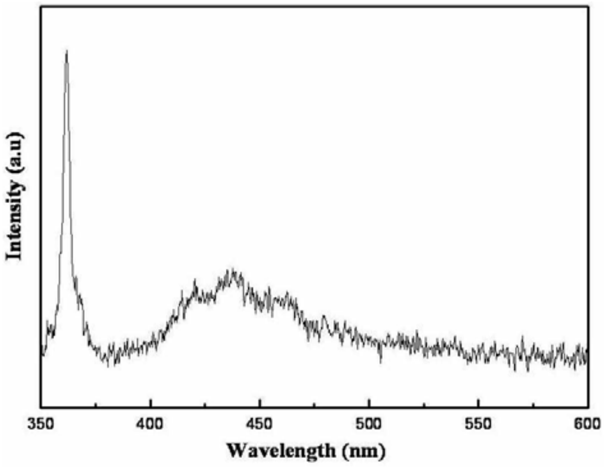

Fig. 4. RT PL spectrum of InGaN QDs on GaN/ sapphire substrate.

4. Conclusion

In conclusion, we have fabricated InGaN QDs by NNAD growth technique using MOCVD. The average diameter and height of QDs was 40 and 70 nm with QDs density 1.0×10^8 cm^{-2}. AFM has confirmed the dense pattern of QDs on GaN surface. PL measurement has confirmed that InGaN emission.

Acknowledgements

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