Abnormal PL spectrum in InGaN MQW surface emitting cavity

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ABSTRACT

We report the observation of an abnormal photoluminescent (PL) spectrum from a HeCd laser pumped InGaN multiple quantum well (MQW) vertical cavity. The device is fabricated using standard MOCVD deposition on a (0001)-oriented sapphire substrate. The layer structures are: 10nm nucleation layer, a 4um bulk GaN layer, InGaN MQWs, and a final 200nm GaN cap layer. The InGaN MQWs consist of 10 pairs of 5 nm GaN barrier and 3 nm $In_{0.1}Ga_{0.9}N$ well. The peak emission of the as-grown MQWs sample was ~420nm. A dielectric distributed Bragg reflectors (DBR) were then coated on the top layer, followed by a laser lift off from sapphire substrate, and subsequently another DBR coated on the bulk GaN bottom surface. The cavity has a quality factor of ~520 from 400-490nm. The device was pumped by a focused CW HeCd laser from the bulk GaN side. When the laser is focused onto the InGaN MQWs, a photoluminescent spectrum centered at the designed MQW wavelength was observed as expected. However, when the focused position was moved toward the bulk GaN region, an additional abnormal PL peak around 460nm was observed. This is far outside the designed MQW wavelength.

Keywords: InGaN, GaN, MQW, vertical cavity, photoluminescence

1. INTRODUCTION

Group III-nitride semiconductor material has attracted great research interests in recent years. This is a promising material system for next generation optoelectronic applications, in particular in the visible to ultra violent region. Its application in solid state lighting has been gaining a lot of progress. It is also an important material for blue-UV laser diodes. The optical properties of III-nitride material are in general still less well investigated compared to other more matured III-V semiconductor in the infrared region. Photoluminescent spectrum is a common method for characterizing the optical properties of a material. It is also known that the radiation properties of an excited material can be modified by a cavity. A well designed cavity can be monolithically integrated to the semiconductor to enhance its radiation efficiency.

Planar semiconductor microcavities have been an attractive device structure for such an application. It has the advantage of circularly symmetric vertical surface emission and small cavity volume to enable strong light-matter interaction and enhance lighting emitting efficiency. The technology for fabricating such a device structure has been well developed for the infrared III-V semiconductor lasers. i.e. vertical cavity surface emitting laser (VCSEL). It has also been demonstrated on III-nitride based devices [1-3]. In this study, we have fabricated InGaN multiple quantum wells in a monolithically integrated microcavity and optically pumped it with HeCd laser to study the device photoluminescent spectrum. An emission spectrum centered at the designed QW emission wavelength 419nm with full width half max bandwidth of 20nm was observed when the HeCd laser is focused on InGaN quantum wells. However, when the focus spot was moved away from the QW toward the bulk GaN region, we saw the presence of an unexpected 460nm photoluminescent emission peak with also ~20nm linewidth. This emission wavelength was not in the designed QW emission. We have studied the variation of these two PL emission peaks versus various vertical pump focus positions and pump power levels.

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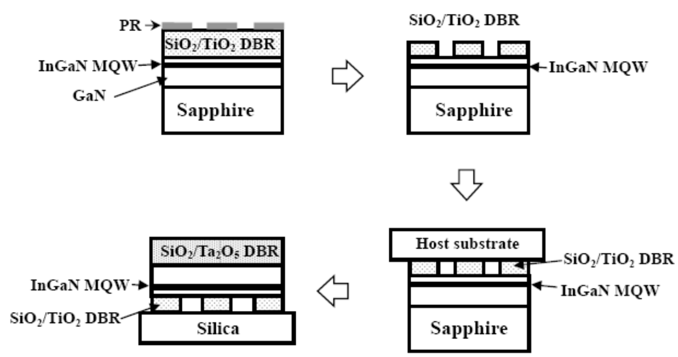
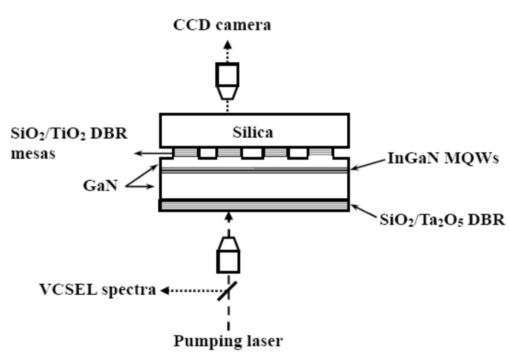
2. EXPERIMENTS

The GaInN multiple quantum microcavity was fabricated by standard metal organic chemical vapor deposition (MOCVD) on a (0001)-oriented sapphire substrate followed by dielectric coating runs to form vertical surface microcavity. The process steps are schematically shown in Fig. 1(a). The device layer structure consists of a 30-nm GaN nucleation layer, a 4-μm GaN bulk layer, MQWs consisting of 10 periods of 5-nm GaN barriers and 3-nm $In_{0.1}Ga_{0.9}N$ wells, and a 200-nm GaN cap layer. A 6-pairs of SiO_2 and TiO_2 were evaporated on the top of the grown structure to form the top dielectric distributed Bragg reflector (DBR). The reflectivity of the SiO_2/TiO_2 DBR at 419 nm was 99.5%. Next, an array of circular SiO_2/TiO_2 DBR mesas with diameters of 60 μm was formed by standard lithography and chemical wet etching process. To deposit the bottom dielectric DBR, the structure was subjected to a laser lift-off (LLO) process using a KrF excimer laser to remove GaN/InGaN from sapphire substrate. The GaN surface after LLO was further polished to a surface roughness of about 1 nm for deposition of the bottom dielectric DBR. The bottom DBR consists of 8 pairs of SiO_2 and Ta_2O_5. The final thickness of the epitaxial structure after LLO and polishing process was about 4μm. The Ta_2O_5 was used to reduce the absorption of the pumping beam at 325 nm. The reflectivity of the SiO_2/Ta_2O_5 DBR at 410~490 nm was 97%. The detailed process procedure was described in our previous report [4].

The micro-PL measurement is shown in Fig. 1(b). The InGaN QW microcavities were optically pumped by a CW HeCd laser at 325 nm. The beam size is about 3.5mm in diameter after HeCd laser passes through a beam expander. The pump laser is focused by a 15X microscope objective. The focused spot size was measured to be 2μm in diameter. The microcavities were pumped from the SiO_2/Ta_2O_5 DBR side. The light emission from the VCSEL sample was collected from the same side by an imaging optics into a fiber and delivered to a spectrometer with resolution of 0.05 nm.



(a)



(b)

Fig.1. (a) Fabrication steps of InGaN MQW microcavities. (b) Micro-PL measurement setup. The device was pumped by a focused CW HeCd laser at 325nm.

3. EXPERIMENTS

We first measured the PL spectrum of an as grown reference sample, which did not have the dielectric DBR cavity. The PL spectrum is shown in Fig. 2. The pump was focused on the InGaN multiple quantum wells. The QW emission was at 419nm wavelength. The ripples were due to the Fabry-Perot etalon effect of the 4um GaN/InGaN substrate. Note that there is a small plateau from 440nm to 460nm with PL intensity about one third of the 419nm peak value. This additional plateau of emission is abnormal. The PL peak at 382nm (3.25meV) is thought to be from the bulk GaN. This peak is close to the reported Zinc Blende GaN band gap energy 3.2meV. There is another much weaker peak at 365nm, which matches to the often quoted Wurtzite GaN band gap energy 3.4eV. There is another small peak at 391nm, which might be due to bounded defect states.

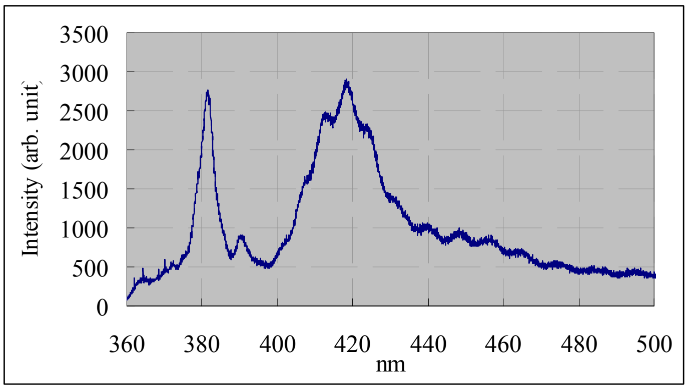


Fig. 2. As grown InGaN multiple quantum well PL. The ripples were due to the Fabry-Perot etalon effect of the 4um GaN/InGaN substrate.

We then measured the PL of an InGaN MQW microcavity. The pump was again focused on the InGaN multiple quantum wells. The Spectrum is shown in Fig. 3. The expected strong cavity resonant modes were observed. However, the 382nm peak was not as clearly present and there was an additional broader photoluminescent peak at 365nm with ripples on its right wing.

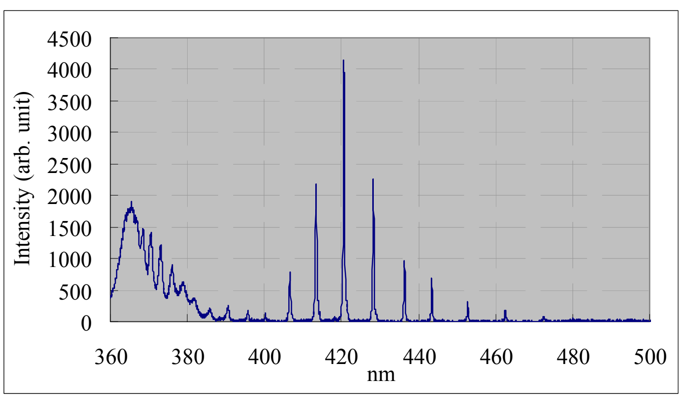


Fig. 3 The PL spectrum of an InGaN multiple quantum well microcavity. The pump was focused on the multiple quantum well.

The focus of the pump laser was gradually moved away from the MQW toward the bulk GaN direction. The typical spectra were shown from Fig. 4 (a) to (f) at various positions as labeled in the plots. The 419nm peak value decreased fairly fast when the focus position was moved away from MQWs, while the 460nm peak increased but not as fast. The increase of the abnormal 460nm peak is rather unusual. The peak monotonically increased until the pump focus spot at 135um away from the quantum well position, which was far outside the microcavity.

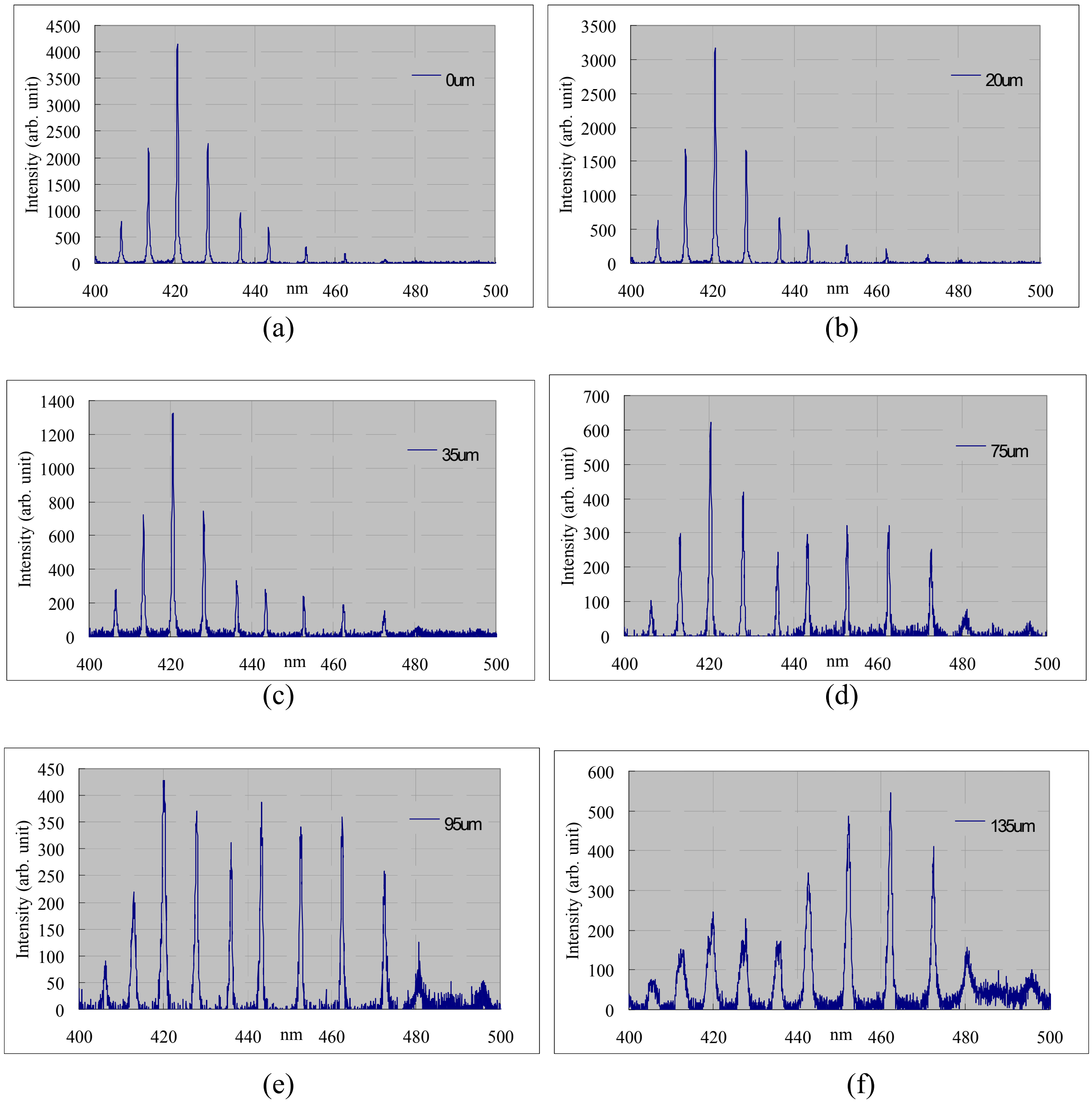


Fig. 4. (a)-(f) are the PL spetra at various pump focus positions. The labels are the pump focus position measured from the quantum well toward the bulk GaN region. The quantum well 420nm peak decreases when pump focus is moved away from quantum well, while the abnormal 460nm peak increases.

4. CONCLUSION

We have fabricated InGaN multiple quantum well microcavities to study the device photoluminescent property. The device was pumped by a focused HeCd laser at 325nm. The cavity resonant emission at the quantum well designed wavelength at 419nm was observed as expected. However, the excited cavity axial modes can extend to well outside the quantum well emission bandwidth. More over, when the pump focus was moved away from the quantum well region, i.e. a divergent pump beam, an unusual emission peak outside the quantum well wavelength at 460nm was observed. This peak increases as the pump focus is moved away from quantum well, while the quantum well emission decreases. This unusual behavior might be related to certain nonlinear property of the GaN material and requires further study.

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