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ZnO Nanorods-on-GaN Heterojunction Light-Emitting Diode Grown by Vapor Cooling Condensation Method

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1.Introduction

Zinc oxide (ZnO) is a promissing material for fabricating short-wavelength light-emitting devices, such as LEDs[1] and laser diodes (LDs)[2] due to its wide band gap (~3.37 eV) and high exciton binding energy (~60 meV). Various methods such as chemical vapor deposition, sputter, molecular beam epitaxy and vapor cooling condensation method have been used to deposit ZnO films[3-6]. Recently, because of great interests on the quantum confinement effect and nano-devices, one-diemensional ZnO nanorod-structure has been investigated widely[7,8]. In this study, a vapor cooling condensation method was used to grow ZnO nanorods on p-GaN at low temperature using anodic alumina membrane (AAM) template. The deposited ZnO nanorods were then used to construct two types of nano-heterojunction LEDs. And their electroluminescence was demonstrated and discussed.

2.Experiment

A 2 μm-thick undpoed-GaN layer and a 680 nm-thick Mg-doped p-GaN layer (3.7×10^{17} cm^{-3}) were grown on c-plane sapphire substrates using a metal-organic chemical vapor deposition (MOCVD) system. Then, the Mg-doped GaN was activated at 750^{o}C for 30 min in N_2 ambient. The layers of Ni/Au (20/100 nm) were deposited in sequence and annealed at 500^{o}C in air ambient for 10 min to perform the ohmic contact.

The ZnO nanorods were evaporated by using the AAM template put on the top of p-GaN layer. The purpose of using the AAM template was attributed to its ideal cylindrical pore's shape and controllable pore nanostructure. ZnO powder was put on the heating tungsten boat and the liquid nitrogen was used to cool down the sample temperature. The designed vapor cooling condensation system was reported, previously[6]. Besides, the pumping system provided a driving force to guide ZnO molecules passing through the nanoholes of AAM template and forming ZnO nanorods on the substrate. To grow the i-ZnO nanorods, ZnO powder of 0.85 g was put on the tungsten boat and then heated. For the growth of n-ZnO (ZnO:In) nanorods, ZnO powder of 0.85 g and In tablet of 0.06 g were put together on the tungsten boat for the tungsten boat for evaporation. The scanning electron microscopy (SEM) image of the ZnO nanorods deposited on p-GaN was shown in Fig. 1. Using the Hall measurement, the electron concentration and mobility of the i-ZnO film grown on sapphire substrate were 7.6×10^{15} cm^{-3} and 2.1 cm^2/V-s, respectively. The corresponding values for thus deposited n-ZnO film were 1.7×10^{20} cm^{-3} and 3.7 cm^2/V-s, respectively.

An ITO glass was put on the top of the ZnO nanorods to form the p-n (p-GaN/n-ZnO:In nanorods/ITO) and the p-i-n (p-GaN/i-ZnO nanorods/ITO) nano-heterojunction LEDs, as shown in Fig. 2. The current-voltage (I-V) relation and the electroluminescence (EL) spectra of the LEDs were measured by using an HP4156C semiconductor parameter analyzer and an ordinary spectrometer system, respectively.

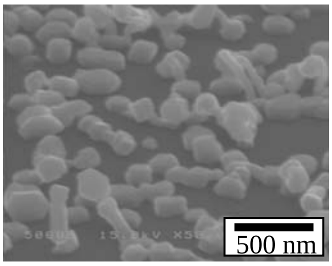

Fig. 1 SEM tilt 60^{o}-section image of ZnO nanorods/p-GaN.

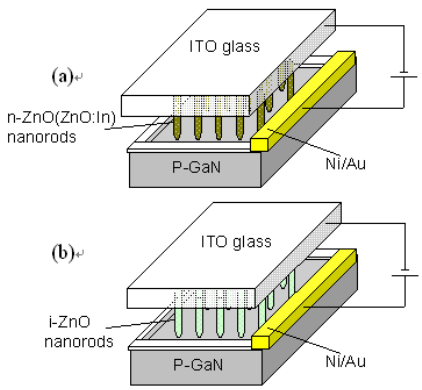

Fig. 2 Schematic configuration of (a) p-GaN/n-ZnO nanorods/ITO and (b) p-GaN/i-ZnO nanorods/ITO.

3.Results and discussion

The I-V characteristics of the p-n and the p-i-n nano-heterojunction LEDs were shown in Fig. 3. The reverse breakdown voltage and forward turn-on voltage of the p-n LEDs were -3.2 V and 0.9V, respectively. The reverse breakdown voltage and forward turn-on voltage of the p-i-n LEDs were -5.1 V and 2.3 V, respectively.

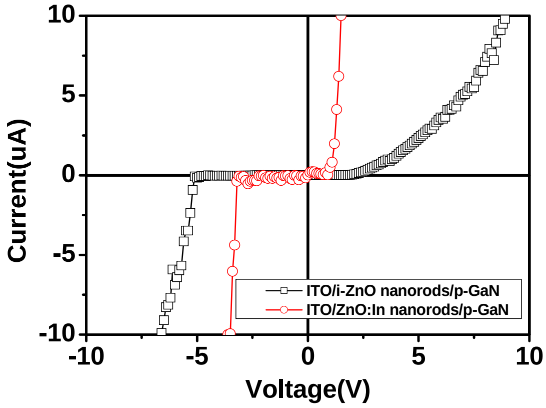

Fig. 3 Current-voltage characteristics of p-n and p-i-n nano-heterojunction LEDs.

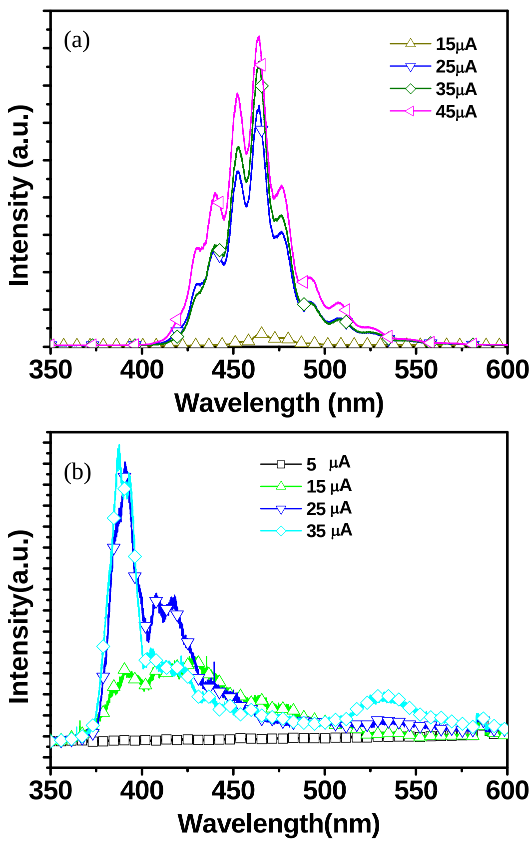

Fig. 4 EL spectra of the (a) p-n and (b) p-i-n nano-heterojunction LEDs.

Shown in Fig. 4(a) and (b) are the EL spectra of the p-n and p-i-n nano-heterojunction LEDs under various injecting currents, respectively. For the p-n (p-GaN/ZnO nanorods) nano-heteronjunction LEDs, a blue broad band, related to the deep Mg acceptors of p-GaN, was observed. This is attributed to the high carrier concentration of n-ZnO nanorods, compared with the hole concentration of p-GaN, causing the depletion region being located in p-GaN layer mostly, where the electrons and holes recombined mostly.

The EL spectra of the p-i-n nanostructure diodes showed a different feature. A narrower UV band peaked at wavelength of 386 nm and a blue broad band defect emission were observed. The UV band emission increased faster than the defect emission with the increase of injection current and became the dominant one under higher forward current. Considering the structure of the p-i-n LED, the i-ZnO nanorods were sandwiched between the p-GaN layer and an ITO glass and the depletion layer located mostly in the nanorods, which served as the recombination region of electron-hole pairs. Hence, the UV band was attributed to the near-band edge (NBE) emission of the i-ZnO nanorods while the p-GaN layer and the ITO layer were performed as a hole injection layer and an electron injection layer, respectively.

4.Conclusions

This study investigated the growth of ZnO nanorods using a vapor cooling condensation method at low temperature with the assistance of AAM template. Two types of ZnO nanorode based nano-heterojucntion LEDs were constructed. The EL emission of the LEDs was demonstrated. A broad blue band was observed in the EL spectra from p-n nano-heterojucntion LEDs. The UV emission peaked at 386 nm and the blue emission were observed from the p-i-n nano-heterojunction LEDs. The different spectra of the two types of LEDs were ascribed to the different depletion region in the structures, where the carrier recombination took place

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