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Room Temperature Ultraviolet/Blue Light Emitting Devices Based on AlGaN/GaN Multi-Layered Structure

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We have developed high performance blue LED and UV LED based on p-n GaN homojunction and AlGaN/GaN heterojunction structure with output power up to several mW at RT. The process for the fabrication of newly developed LEDs and their characteristics are presented in this paper.

1.Introduction

Bright light emitting diode(LED) in red to green region and several mW laser diode (LD) in red region have been commercially available. To realize a new full color display system, blue LED has been eagerly demanded. Besides, the practical shorter wavelength LD enables us to develop very-compact and high density optical storage systems and small medical equipments.

In this field, recently, a great advance has been given by 3M[1] and several groups. It is noted that blue-green LD's with emission wavelength of 512nm at room temperature (RT) have been recently developed by using ZnCdSe-based quantum well structure. However, the wavelengths of their LD or LED are still in the blue/green to green/blue region. Therefore, development of much shorter wavelength (violet to UV) LED and LD is strongly desired.

Gallium nitride (GaN), aluminum nitride (AlN) and their alloys $Al_xGa_{1-x}N(x>0)$ is the promising candidate as the material for fabrication of such short wavelength light emitters, because they have direct transition type band structure with the band gap energy from 3.39eV to 6.2eV at RT which corresponds to the wavelength from 375nm to 200nm.

Recently, we[2] succeeded to overcome various problems in growing nitrides on the sapphire substrate and to grow high quality GaN film with a specular surface free of crack by the prior deposition of a thin AlN buffer layer in MOVPE growth of nitrides. The electrical and optical properties as well as the crystalline quality can be remarkably improved at the same time[3]. By using such a high quality GaN film, the UV stimulated emission at RT by optical pumping was achieved[4,5]. Practical bright mis-type blue-LED's have been developed by using the same GaN film[6].

As concerns the conductivity control of n-type nitride film, silicon was found to act as a donor impurity in GaN[7,8] as well as in AlGaN[9].

We[10] succeeded to produce p-type GaN in 1989 and p-type AlGaN in 1991 by low energy electron beam irradiation (LEEBI) treatment of Mg-doped film for the first time, respectively.

On the basis of these results, we develop the first p-n GaN homojunction and AlGaN/GaN heterojunction blue and UV LED. In this paper, process for the fabrication of blue and UV LED, and their performance are described.

2.Experiments and Results

A horizontal type MOVPE reactor operated at an atmospheric pressure was used for the growth of GaN and AlGaN films. TMGa, TMAl and NH_3 were used as source gases and H_2 as a carrier gas. Polished sapphire (0001) crystals were used as a substrate. In our process, before nitride growth, a thin AlN layer about 50nm thick was deposited at 600°C by feeding TMAl and NH_3 diluted with H_2.

The electron concentrations and resistivities of GaN can be easily controlled by changing silane flow rate from the undoped level of less than $10^{15}cm^{-3}$ up to near by $10^{19}cm^{-3}$. The intensity of cathodoluminescence of the near band-edge emission increases with the increase of doping level of Si in GaN film.

Doping of Magnesium (Mg) was carried out during the growth of GaN and AlGaN alloy film by supplying biscycropentadienylmagnesium (Cp_2Mg) as a Mg source gas. We can easily obtain the desired Mg concentration and its profile in nitrides by controlling the supply flow rate of Cp_2Mg. Mg-doped nitrides tend to become low resistivity by low energy electron beam irradiation (LEEBI) treatment. It was found that the film tends to show p-type conduction by the LEEBI treatment. Hole concentration at RT up to about $1.4x10^{17}$ cm^{-3} can be achieved.

The typical EL spectrum at RT observed from the newly developed p-n homojunction diode is shown in fig.1. It shows broad blue emission peaking at 423 nm, which is due to the Mg-associated centers related transition in the p-GaN layer. Sharp UV emission peaking at 375 nm is also observed, which is thought to originate from band-to-band transition in n-type GaN layer. With the increase of the injection current, the intensity of the latter emission overcomes that of the blue one. The output power at RT under pulsed operation of more than 1.5mW with a forward current of 90mA and the bias voltage of 5.0V have been achieved, which is the highest power ever reported in the LED mode operation of blue LED.

AlGaN/GaN heterostructure have been constructed by modulating the flow rate of TMGa and TMAl during growth. The PL measurements of AlGaN/GaN multi-layered structure clearly showed quantum size effect[11]. By using AlGaN/GaN double heterostructure (DH), the threshold power for UV stimulated emission by optical pumping can be decreased to about $110KW/cm^2$, which is about one sixth of that of homostructure. The threshold power of the DH structure varied with the thickness of the GaN active layer. The experimental results agree quite well with the calculated one.

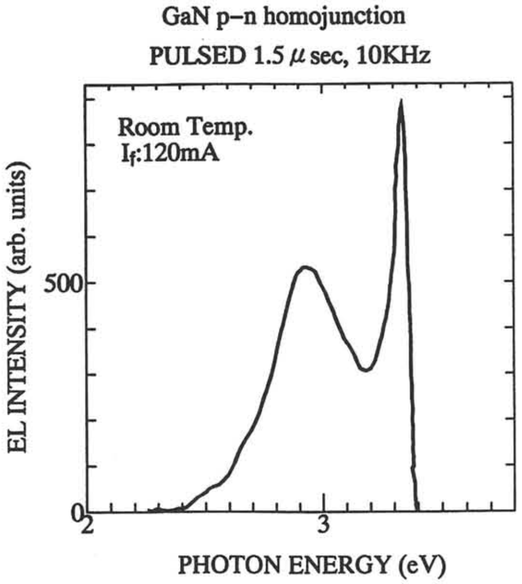

Fig.1 Typical EL spectrum of GaN p-n homojunction LED.

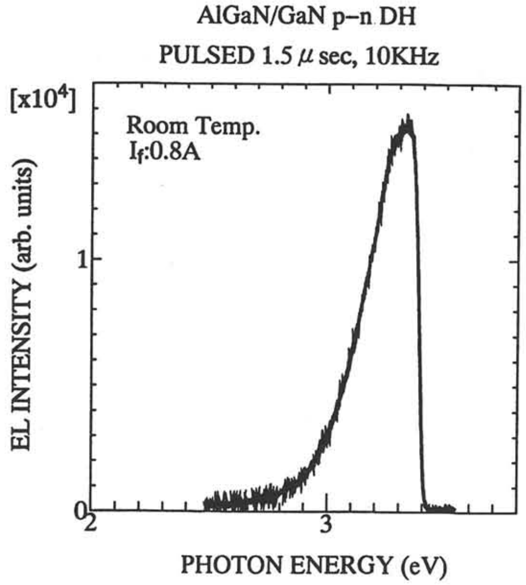

Fig.2 Typical EL spectrum of AlGaN/GaN DH LED.

The P-$Al_{0.1}Ga_{0.9}N$/n-GaN/N-$Al_{0.1}Ga_{0.9}N$ DH diode also showed good I-V characteristics. The peak wavelength of the broad blue emission is somewhat shorter than that of homojunction and its spectrum overlaps that of bandedge emission as shown in fig.2, due to the bandgap shift of P-cladding layer. The output power of the DH-LED at RT is more than 4mW at a forward current of 500mA, which is also the highest figure to date.

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