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Direct Patterning of the Current Confinement Structure for p-Type Column-III Nitrides by Low-Energy Electron Beam Irradiation Treatment

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Partial low-energy electron beam irradiation (LEEBI) treatment was used to fabricate UV/blue light emitting devices based on column-III nitrides having directly patterned current confinement structure. Newly developed devices show very low leakage reverse current, stable operation at high current injection and strong violet emission at room temperature.

1. Introduction

The demand for the fabrication of practical light emitting diode (LED) and laser diode (LD) in the blue to ultraviolet (UV) region have been increasing. The realization of such devices leads to the actualization of compact and high density optical storage systems, full color flat panel displays and medical engineering systems.

Column-III nitrides, AlN, GaN, InN and their alloys AlGaInN are promising for application to blue, violet and UV light emitting devices such as LEDs and LDs, because they have direct large bandgap from 1.9eV for InN to 6.2eV for AlN. Difficulty in growing high-quality thin films on the dissimilar substrate and difficulty in controlling conductivity, especially in achieving p-type conductivity have restricted their device applications for a long time.

Recent developments of the technology and understanding the mechanism of the heteroepitaxial growth on highly mismatched substrate enable us to grow high quality epitaxial film. In the case of the growth of GaN, AlGaN, and GaInN on the sapphire substrate, high crystalline quality epitaxial film with a specular surface free of cracks can be grown by MOVPE using thin AlN[1] or GaN[2] as the buffer layer.

By doping with Si, we can control the donor concentration in the GaN[3], AlGaN[4] and GaInN films from the undoped level up to near 10^{19} cm $^{-3}$ without deterioration of the crystalline quality and surface flatness. Recently, GaN and AlGaN doped with Mg (GaN:Mg, AlGaN:Mg) having distinct p-type conductivity have been achieved by low energy electron beam irradiation (LEEBI) treatment[5], or by thermal annealing[6]. P-type GaN:Mg without any treatment has also been realized by Moustakas et al[7]. Establishment and understanding the technique for the heteroepitaxial growth of column-III nitrides on the sapphire substrate, and realization of GaN and AlGaN having distinct p-type conductivity[1, 5] have led to the accomplishment of percent-efficiency class short wavelength LEDs based on GaN[8, 9].

For the realization of low threshold current density LDs, band-to-band transition of emission and carrier confinement, as well as optical confinement, are essential which means that there must be large band discontinuities between the active layer and the cladding layer for both the conduction band and the valence band. In addition, fabrication of current confinement structure is necessary to realize such LDs. In the case of the LEEBI treatment, the region showing p-type conductivity is rigorously restricted to the irradiated area. Therefore, the LEEBI treatment is excepted to be effective in realizing current confinement structure. In this study, the partial LEEBI treatment was used to fabricate current confinement structure. Luminescent and electrical properties of the LEEBI-treated p-type GaN:Mg are discussed. Characteristic of the blue light emitting device in which p-type current confinement structure was directly patterned by the LEEBI treatment is also shown.

2.Experimental

A horizontal MOVPE reactor was used to grow GaN, GaInN, and AlGaN films. We used a dual flow-channel MOVPE reactor for the growth of column-Ⅲ nitrides, which is expected to prevent parasitic reactions between metalorganic source gases and ammonia (NH_3). Thus we can grow high-quality column-Ⅲ nitrides and their alloys. Trimethylaluminum (TMAl), trimethylgallium, trimethylindium, and NH_3 were used as source gases and hydrogen (H_2) as a carrier gas. Bis-cyclopentadienyl magnesium (Cp_2Mg) was used as the Mg source. Polished (0001) sapphire was used as a substrate. In our process, before the column-Ⅲ nitride growth, a thin AlN buffer layer about 50 nm thick was deposited at 600 ℃ by feeding TMAl and NH_3 diluted with H_2 into the reactor.

GaN:Mg was grown on the sapphire substrate by feeding Cp_2Mg as a Mg source gas[10] using AlN buffer layer[1]. Conventional SEM system combined with pattern drawing system was used for the patterned LEEBI treatment. The electron beam was focused on the sample surface. Sample current was on the order of nA. Accelerating voltage was 15KV. Treatment was done at room temperature (RT). Temperature rise of the sample by the LEEBI treatment is calculated to be less than 100 degree.

We also fabricated AlGaN:Mg/GaN:Mg/GaInN /GaN:Si/AlGaN:Si stacked heterostructure. The stacked heterostructure was grown selectively on the n^+-GaN. Stripe with a width of 10 μ m in stacked heterostructure was treated with the LEEBI treatment of the Mg-doped layers.

To fabricate light emitting devices, Au/Pd were deposited on top of the stacked heterostructure as an ohmic contact. Stripe with a width of electrode on p-layer was 200 μ m.

3.Results

Hole concentration of the LEEBI-treated p-GaN increased as the electron beam current increased in an extent of current range. Hole concentration up to $2*10^{18}$ cm^{-3} and resistivity of 0.2 Ωcm at RT was achieved. Change of blue luminescence intensity strongly depends on the irradiation time as well as the sample current. It steeply increased with a short treatment, and gradually decreased with a long treatment, which is reasonable if we consider the activation of Mg and the change of Fermi level in GaN:Mg with the LEEBI treatment.

Fig. 1 shows photograph of fluorescence microscope on sample surface with the partial LEEBI treatment. We can clearly see the enhancement of luminescence intensity by the partial LEEBI treatment.

Fig. 2 shows I-V characteristic of the newly developed devices. Fig. 2(a) shows I-V curve of the device with the LEEBI treatment, and Fig. 2(b) for that of the device without the LEEBI treatment. It is evident that the electrical properties of the Mg-doped nitrides was drastically changed by the LEEBI treatment. Therefore, current confinement structure has been established by the partial LEEBI treatment. We also observed the electroluminescence (EL) emission only from the partially LEEBI treated region. It is evident that the current confinement was achieved by the partial LEEBI treatment.

Fig. 3 shows EL spectrum of the devices under high current injection. This figure shows narrow and intense band-to-band transition from GaInN layer with a peak wavelength of 395.2nm and the FWHM of 0.11eV at RT.

4.Summary

AlGaN/GaN/GaInN stacked heterostructure was fabricated by MOVPE using the partial LEEBI treatment for the p-type current confinement structure. This device shows good I-V characteristic, strong and narrow violet emission at RT. Therefore, the patterned LEEBI treatment is effective for fabrication of very short wavelength laser diode based on column-Ⅲ nitrides.

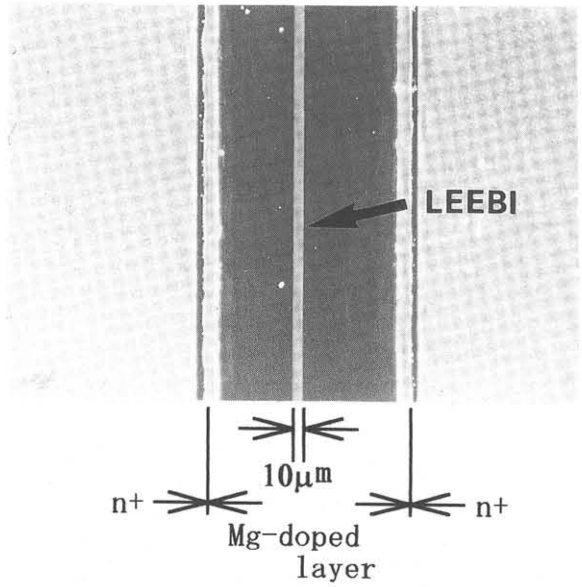

Fig.1 Photograph of fluorescence microscope of sample surface with the partial LEEBI treatment.

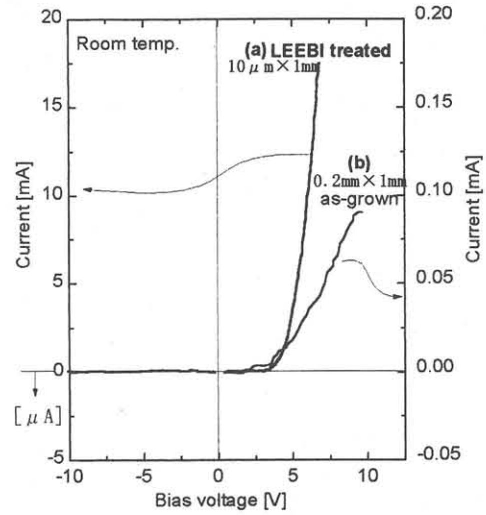

Fig.2 I-V curves of the AlGaN/GaN/GaInN stacked heterostructure (a) with and (b) without the partial LEEBI treatment. Stripe width of electrode on p-layer is 200 μ m. Stripe width of the LEEBI treated region is 10 μ m.

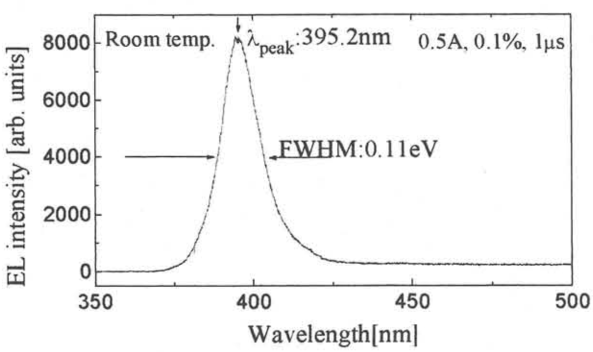

Fig.3 EL spectrum of the devices under high current injection of 0.5A.

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