Extended Abstracts of the 1996 International Conference on Solid State Devices and Materials, Yokohama, 1996, pp. 65-66

Invited

Fundamentals of the Nitride Based Laser Diode

I.Akasaki, S. Sota, H. Sakai and H.Amano

Department of Electrical and Electronic Engineering, Meijo University, 1-501 Shiogamaguchi, Tempaku-ku, Nagoya 468, Japan

Group III nitride based separate confinement heterostructure (SCH) single quantum well (SQW) structure with various active layer thickness was fabricated. It shows UV to violet lasing depending on the thickness of the active layer by current injection at room temperature.

1. INTRODUCTION

Group III nitrides have large and direct band gaps ranging from 1.9eV to 6.2eV. Therefore, application to light sources and detectors in the short-wavelength region is expected. The lack of substrate materials with lattice constant and thermal expansion coefficient close to those of group III nitrides, and the difficulty in obtaining p-type films, however, have long prevented the use of nitride. Use of low temperature deposited thin buffer layer changed drastically the situation.[1,2] High quality group III nitrides can be grown on the sapphire substrate using the buffer layer. Realization of p-type GaN was achieved by low-energy electron beam irradiation treatment or thermal treatment of such high-quality films doped with Mg.[3,4] Today, bright blue-, blue-green- and green-light emitting diodes (LEDs) composed of group III nitrides are commercially available.[5-7] Recently, Nakamura et al. succeeded in fabricating violet laser diode (LD) with GaInN multi-quantum well active layer for the first time.[8] They used multiple quantum well GaInN/GaN active layers. Threshold current density (J_{th}) was about 4.0KA/cm^2, which is much higher than that expected from theoretical calculation.[9] In this paper, we first consider the reason of the discrepancy of the J_{th} between calculation and experiment. Second, we report the first ultraviolet (UV) lasing at 376nm, which is the shortest to date by current injection from AlGaN/GaN/GaInN separate confinement heterostructure (SCH) having single quantum well (SQW) structure.

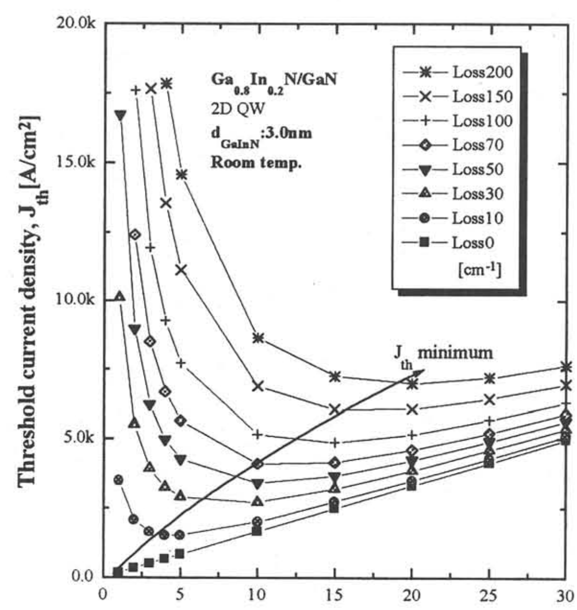

Fig.1 Estimated threshold current density of nitride-based MQW as a function of the number of GaInN quantum well layers in the active layer.

2. EXPERIMENT

Figure 1 shows the calculated result of the dependence of the J_{th} of the nitride based MQW on the number of GaInN well layers in the active layer. In this calculation, wurtzite dipole matrix element was used.[10] Effective mass of electron and hole in the well layer were assumed to be $0.2m_0$ and $0.8m_0$, respectively. As shown in the figure, if the total loss (=propagation loss + mirror loss) is negligibly small, J_{th} increase with increase of the number of quantum well. However, if the total loss is large, there are the optimum number of quantum well in order to achieve the lowest J_{th}. In this paper, we tried to fabricate QW LD with the number of well layer as little as one. Fig.2 shows the structure of the light emitting devices grown with the AlN buffer layer on sapphire. This device has basically separate confinement heterostructure (SCH) structure consisting of one $Ga_{0.9}In_{0.1}N$ active layer, GaN waveguide layers with total thickness of 0.2μm, and $Al_{0.15}Ga_{0.85}N$ cladding layers about 0.5μm thick for both p-type and n-type sides. Si was used as donor, while Mg was used as acceptor. Thermal treatment[4] was performed to transform Mg-doped layer from insulating to low-resistive p-type. Free carrier concentration of each layer is shown in the figure. 400μm wide mesa was made by reactive ion etching, then 10μm wide Ni and 400μm wide Al/Ti were deposited on the p-GaN surface and etched n-GaN surface, respectively. The sapphire substrate was scribed by the diamond-cutter from the back side. Long cavity of 1.0mm was employed in order to reduce

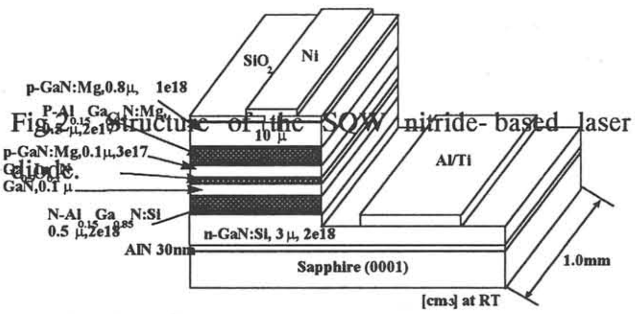

Fig.2 Structure of the SQW nitride-based laser diode.

the effect of reflection loss. No facet coating was done. The device was operated at room temperature under pulse-biased condition with pulse width of 0.3μs and duty ratio of 1.0%. Emission spectrum was measured by single pass

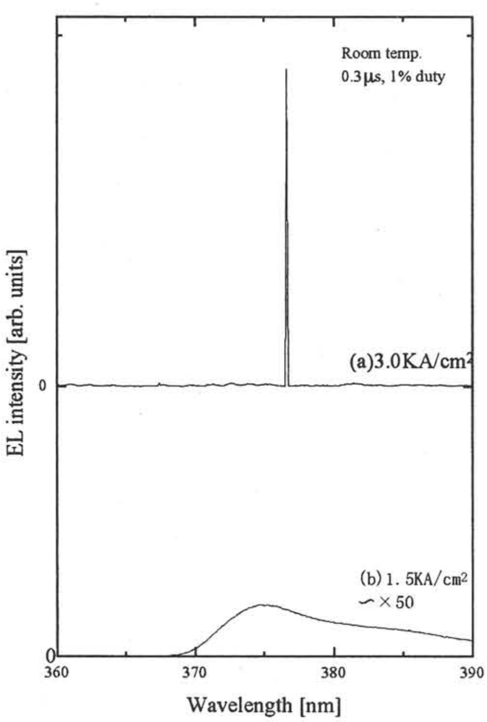

Fig.3 Emission spectrum below(b) and above(a) J_{th} from the device having very thin quantum well.

monochromator, while total light output power was monitored by large Si photodiode. Output intensity was not calibrated.

Fig.3 shows the emission spectra at the current density of $1.5KA/cm^2$ (Fig.3(b)) and $3.0KA/cm^2$ (Fig.3(a)) from one side edge of the device having the very thin GaInN quantum well with thickness of 1.5nm. Strong and very narrow emission is clearly observed when current density exceeds $2.9KA/cm^2$. The FWHM was as narrow as 0.15nm when current density was $3.0KA/cm^2$. The device having 5.0nm thick GaInN quantum well also shows lasing at about 402.6nm. However, the J_{th} is as large as $40KA/cm^2$. The quality of the quantum well might be responsible for the difference of the property of these two devices.

3.SUMMARY

We demonstrated the first UV LD by current injection at 376nm at room temperature, which is the shortest wavelength from semiconductor laser diode.

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