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Material Growth and Device Fabrication of GaN-Based Blue-Violet Laser Diodes

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Abstract: Studies on first GaN-based blue-violet laser diodes (LDs) in China mainland are reported. High quality GaN materials as well as GaN-based quantum wells laser structures are grown by metal-organic chemical vapor deposition method. The X-ray double-crystal diffraction rocking curve measurements show the full-width half maximum of 180″and 185″for (0002) symmetric reflection and $(10\bar{1}2)$ skew reflection, respectively. A room temperature mobility of $850\mathrm{cm}^2/(\mathrm{V}\cdot\mathrm{s})$ is obtained for a 3μm thick GaN film. Gain guided and ridge geometry waveguide laser diodes are fabricated with cleaved facet mirrors at room temperature under pulse current injection. The lasing wavelength is 405.9nm. A threshold current density of $5\mathrm{kA/cm}^2$ and an output light power over 100mW are obtained for ridge geometry waveguide laser diodes.

Key words: metalorganic chemical vapor deposition; GaN-based laser diodes; multiple quantum wells; ridge geometry structure; threshold current density

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1 Introduction

Since the demonstration of first InGaN multiple quantum wells laser diode[1], GaN-based multiple quantum wells structure laser diodes (LDs) have attracted more attention because of their potential application in high-density optical storage, display, laser printing and lighting. Many universities and companies focused their research on the nitride semiconductors. Great progress has been achieved in GaN template growth, n-type and p-type doping of GaN, InGaN MQWs growth and photoluminescence mechanism[2,3], and AlGaN growth and doping[4,5]. Meanwhile, the techniques about ohmic contact to n-type and p-type GaN and cleaving of wurtzite GaN on sapphire developed rapidly[6~8]. Although several groups have reported the pulsed and continuous-wave operation of InGaN MQW laser diodes at room temperature[9~12], the growth and fabrication of GaN-based laser diodes are still challenging and more research works are needed. Here we report the first pulsed operation of GaN-based LDs at room temperature in China mainland.

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2　Experiment

The GaN-based materials and LDs structures were grown in a closed-space showerhead metalorganic chemical vapor deposition (MOCVD) reactor. (0001) C-face sapphire was used as substrate. The MQWs LDs consist of a 20nm thick GaN buffer layer grown at low temperature of 550 ℃, a 2μm thick GaN :Si, a 0.9μm thick $Al_{0.2}Ga_{0.8}N$/GaN :Si, a 0.1μm thick GaN :Si, an $In_{0.15}Ga_{0.85}N$/GaN MQW structure consisting of five 3nm thick undoped $In_{0.15}Ga_{0.85}N$ well layers separated by 5nm-thick undoped GaN barrier layers, a 20nm $Al_{0.2}Ga_{0.8}N$:Mg, a 0.1μm GaN :Mg, a 0.6μm $Al_{0.2}Ga_{0.8}N$/GaN :Mg, a 0.2μm GaN :Mg. The 20nm $Al_{0.2}Ga_{0.8}N$ is served as blocking layer to prevent electrons from escaping from the active region. The 0.1μm n-type and p-type GaN layers are light-guiding layers. The 0.9μm n-type and 0.6μm p-type $Al_{0.8}Ga_{0.2}$-N/GaN SLs are used as cladding layers. The ridge-type LDs structure was formed by using IBE technology. A Ni/Au contact was evaporated onto the p-type GaN layer, and a Ti/Al contact was evaporated onto the n-type GaN layer as the ohmic contacts. The facets of the laser cavity were formed by cleaving along the $(11\bar{2}0)$ direction of wurtzite sapphire.

The LDs was measured at room temperature with HP pulse generator. Pulse width was 200ns, duty cycle was 0.01 %. The output light was detected by a photo-multiplier connected to a Tektronix TDS210 oscilloscope and a computer system.

3　Results and discussion

The growth of high quality GaN materials is a premium for the realization of GaN-based LDs. By optimization of growth parameters, we have improved the quality of GaN epilayers significantly, as being revealed by both double crystal X-ray diffraction measurements and Hall measurements. Figure 1 shows rocking curves of a GaN film. The full-width half maximum is 180″ and 185″ for (0002) symmetric reflection and $(10\bar{1}2)$ skew reflection, respectively. These values are among the best results ever reported for GaN epilayers, which indicates relatively low density of both edge type and mixed type threading dislocations. This GaN sample also shows a room temperature mobility of 850cm^2/(V·s) which is just next to the best results reported by Nakamura *et al*.[13]. GaN epilayers with above structural and electrical qualities can be obtained routinely and are used as templates for the further growth of laser diodes structures.

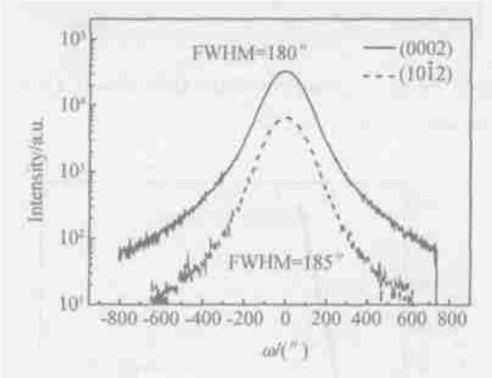

Fig. 1　Double-crystal X-ray diffraction rocking curve of a GaN film

The first GaN-based LD we have fabricated was gain guide type with stripe width of 5μm and cavity length of 800μm. Figure 2 shows the schematic diagram of the LDs' layer structure. The threshold current is about 2A, corresponding to a threshold current density of 50kA/cm^2. The second GaN-based LD was a ridge waveguide type with ridge width of 8μm and cavity length of 800μm. The threshold current of this LD was reduced significantly to 320mA, corresponding to a threshold current density of 5kA/cm^2. Improvements in the material quality is one of the reason for the reduced threshold current density. The one order of magnitude reduction in threshold current density must have other reasons. We speculate that lateral current spreading in the p-type AlGaN superlattice cladding layer may account for that. Most of the p-type AlGaN superlattice cladding layer are etched away in the ridge geometry, which in turn leads to the elimination of the lateral current spreading. It can also be seen that the LD can be operated to output optical power over 100 mW with reasonable linearity. The threshold voltage is 22.7V.

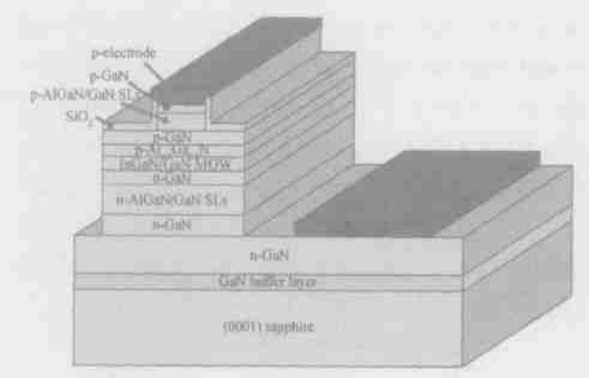

Fig. 2 Schematic diagram of the GaN-based LDs layer structure

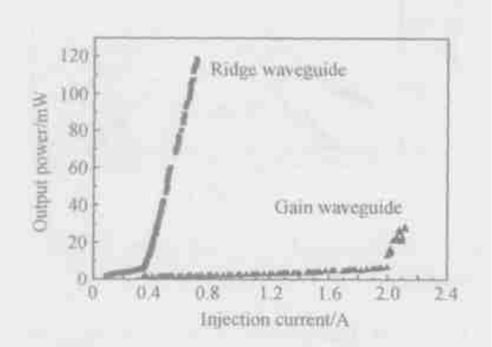

Fig. 3 Laser diode output optical power as a function of pulse current injection The threshold current of the gain waveguide and ridge waveguide GaN-based LDs are 2A and 320mA, respectively.

Figure 4 shows the optical spectra of the measured LD. These spectra were measured using a monochromator which has a resolution of 0.1nm. The lasing wavelength is about 405.9nm. At injection current (280mA) below the threshold, spontaneous emission which had a full width at half maximum (FWHM) of 16nm was observed. This indicates that the LD had a smooth interface and a uniform composition distribution. Above the threshold current, strong stimulated emission were observed. At the current of 400mA the FWHM of the spectrum was 1.6nm. Cavity mode of the stimulated emission was not observed due to the limitation in the resolution of the spectrometer. The peak in the stimulated emission spectrum may contain several stimulated emission modes.

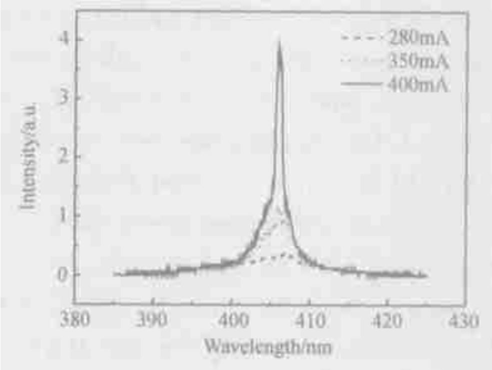

Fig. 4 Optical spectra of the GaN-based LD The width of the stimulated emission peak is about 1.6nm.

4 Conclusion

First GaN-based blue-violet LDs in China mainland are reported. High quality GaN materials as well as GaN-based quantum wells LDs structures are grown by metal-organic chemical vapor deposition method, and characterized by the X-ray double-crystal diffraction rocking curve measurements and Hall measurements. The full-width half maximum of 180″and 185″for (0002) symmetric reflection and $(10\bar{1}2)$ skew reflection, respectively, demonstrate high crystal quality of the GaN film. A room temperature mobility of 850cm^2/(V·s) is obtained for a 3μm thick GaN film. Gain guided and ridge geometry waveguide LDs are fabricated with cleaved facet mirrors under pulse current injection. The lasing wavelength is 405.9nm. A threshold current density of 5kA/cm^2 and a output power over 100mW are obtained for ridge geometry waveguide laser diodes.

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References

[1] Nakamura S, Senoh M, Nagahama S, et al. InGaN-based multi-quantum-well-structure laser diodes. Jpn J Appl Phys, 1996, 35: L74

[2] Watanabe K, Nakanishi N, Yamaqzak T, et al. Atomic-scale strain field and In atom distribution in multiple quantum wells InGaN/GaN. Appl Phys Lett, 2003, 82: 715

[3] Kim D J, Moon Y T, Song K M, et al. Structural and optical properties of InGaN/GaN multiple quantum wells: the effect of the number of InGaN/GaN pairs. J Cryst Growth, 2000, 221: 368

[4] Lee C R. N-type doping behabior of Al$_{0.15}$Ga$_{0.85}$N:Si with various Si incorporations. J Cryst Growth, 2002, 246: 25

[5] Li J, Oder T N, Nakarmi M L. Optical and electrical properties of Mg-doped p-type Al$_x$Ga$_{1-x}$N. Appl Phys Lett, 2002, 80: 1210

[6] Kwak J S, Lee K Y, Han J Y, et al. Crystal-polarity dependence of Ti/Al contacts to freestanding n-GaN substrate. Appl Phys Lett, 2001, 79: 3254

[7] Lee C H, Lin Y J, Lee C T. Investigation of oxidation mechanism for ohmic formation in Ni/Au contacts to p-type GaN layers. Appl Phys Lett, 2001, 79: 3815

[8] Jang J S, Park S J, Seong T Y. Effects of surface treatment on the electrical property of ohmic contacts to (In)GaN for high performance optical devices. Phys Status Solidi A, 2002, 194: 576

[9] Nakamura S, Senoh M, Nagahama S, et al. InGaN/GaN/AlGaN-based laser diodes with modulation-doped strained-layer superlattices grown on an epitaxially laterally overgrown GaN substrate. Appl Phys Lett, 1998, 72: 211

[10] Nakamura S, Senoh M, Nagahama S, et al. Violet InGaN/GaN/AlGaN-based laser diodes operable at 50 ℃ with a fundamental transverse mode. Jpn J Appl Phys, 1999, 38: L226

[11] Kneissl M, Bour D P, Van de Walle C G, et al. Room-temperature continuous-wave operation of InGaN multiple-quantum-well laser diodes with an asymmetric waveguide structure. Appl Phys Lett, 1999, 75: 581

[12] Bader S, Hahn B, Lugauer H J, et al. First european GaN-based violet laser diode. Phys Status Solidi A, 2000, 180: 177

[13] Nakamura S, Mukai T, Senoh M, et al. In situ monitoring and Hall measurements of GaN grown with GaN buffer layers. J Appl Phys, 1992, 71: 5543

GaN基蓝紫光激光器的材料生长和器件研制*

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摘要: 报道了国内首次研制成功的 GaN 基蓝紫光激光器的材料外延生长、器件工艺和特性. 用 MOCVD 生长了高质量的 GaN 及其量子阱异质结材料,以及异质结分别限制量子阱激光器结构材料. GaN 材料的 X 射线双晶衍射摇摆曲线(0002)对称衍射和$(10\bar{1}2)$斜对称衍射半宽分别为 180″和 185″; 3μm 厚 GaN 薄膜室温电子迁移率达到 850cm^2/(V·s). 基于以上材料,分别成功研制了室温脉冲激射增益波导和脊型波导激光器,阈值电流密度分别为 50 和 5kA/cm^2,激光发射波长为 405.9nm,脊型波导结构激光器输出光功率大于 100mW.

关键词: 有机化学气相沉积; GaN 基激光器; 多量子阱; 脊形结构; 阈值电流密度

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