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Material Growth and Device Fabrication of GaAs Based 1.3μm GaInNAs Quantum Well Laser Diodes*

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Abstract: Material growth and device fabrication of the first 1.3μm quantum well (QW) edge emitting laser diodes in China are reported. Through the optimization of the molecular beam epitaxy (MBE) growth conditions and the tuning of the indium and nitrogen composition of the GaInNAs QWs, the emission wavelengths of the QWs can be tuned to 1.3μm. Ridge geometry waveguide laser diodes are fabricated. The lasing wavelength is 1.3μm under continuous current injection at room temperature with threshold current of $1kA/cm^2$ for the laser diode structures with the cleaved facet mirrors. The output light power over 30mW is obtained.

Key words: GaAs based materials; GaInNAs quantum wells; molecular beam epitaxy; laser diodes
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1 Introduction

A GaAs based 1.3～1.5μm long wavelength GaInNAs quantum well has been recognized as a next generation material for various near-infrared opto-electronic device applications. In recent years, great experimental and theoretical progresses have been made to improve the optical quality and fabricate laser diodes and photodetectors of the GaInNAs quantum well (QW)[1～8]. It has been found that the most difficulty aspect for MBE growth of GaInNAs layers is primarily the incorporation of N into the InGaAs by use of the most advanced RF plasma activated atomic nitrogen source. This is due to the fact that N tends to cause a compositional inhomogeneity leading to a band tail extending to the band gap and decreasing optical transition matrix elements. In contrast, an increase in the In composition can also lower radiative transition energies. Moreover, an increased compressive strain effect on valence band can reduce the density of hole states and thus the transparency carrier density.

In our experiment, improvement of N source equipment performance by introducing an isolation gate valve between the RF N cell and the growth chamber has been established to diminish the nega-

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tive effects of N incorporation into the InGaAs materials during the growth. More In and less N are desirable in design consideration of QW, for extending the emission wavelength from 1.1～1.2μm of InGaAs quantum well to above 1.3μm of InGaNAs quantum wells. While the procedure is somewhat quite complex, higher In contents may result in higher strain, therefore making it difficult to retain a reasonable well width for effective carrier capture without misfit dislocations. After careful experimental research, a 38%～42% In and 1%～2% N are proved to be the optimized practical choice. These attempts have proved to be effective in improving optical and structural properties of the GaInNAs active layers. Finally the first 1.3μm single QW edge emitting laser diodes in China are successfully obtained.

2　Experiment

The GaInNAs QWs structures and devices samples were grown on GaAs (001) substrates in a Veeco Mod Gen Ⅱ MBE system. An Oxford Applied Research RF plasma cell separated by an isolation gate valve from the growth chamber was used to supply active N species. The plasma source was ignited and stabled outside growth chamber before the growth of N contented layers. For all of the GaInNAs QWs, the In composition was calibrated initially by high resolution XRD (HRXRD); assuming that In content is kept the same at identical growth conditions for InGaAs and GaInNAs QWs. The N contents varied by changing the N gas flow and plasma powers in order to get emission wavelengths of the GaInNAs QWs at 1.3μm. The N composition is then determined using HRXRD combined with dynamic simulation.

The GaInNAs QWs samples consist of a 300nm thick GaAs buffer layer, three periods of 6nm thick GaIn(N)As QWs separated by 20nm thick GaAs barriers and covered by a 50nm GaAs cap layer. The laser diode structure consists of a Si doped (n-type, $10^{18}cm^{-3}$) 300nm thick GaAs buffer layer, a Si doped (n-type, $10^{18}cm^{-3}$) 1.5μm thick $Al_{0.5}Ga_{0.5}As$ layer and three GaIn(N)As QW layers separated by 20nm thick GaAs barriers, then a Be doped (p-type, $5\times10^{18}cm^{-3}$) 1.5μm thick $Al_{0.5}Ga_{0.5}As$ layer and a Be doped (p-type, $10^{19}cm^{-3}$) 400nm thick GaAs cap layer. The growth temperature of the GaAs buffer and cap layers was 580℃ while the GaInNAs QW layers were grown at approximately 400℃. After the growth of cap layer, substrate temperature was maintained at 600℃ for 30min under As_2 flux as in-situ annealing processes.

The ridge geometry waveguide LD was then fabricated. The 20μm wide ridge stripe was pattered by a self-aligned mesa and chemically etched to the p-cladding AlGaAs layers. The 500μm long cavity was constructed by two cleaved facet mirror. The ridge was isolated with SiO_2 and followed by p-type contact (CrAu) metallization. The wafer backside was lapped and polished to a 125μm thick and followed by n-contact (AuGe/Ni/Au) metallization.

The PL measurements for the QWs samples were performed under the excitation of the 632.8nm line from a He-Ne laser (beam diameter is approximately 180μm) and detected by a cooled Ge detector. The three periods of GaInNAs QWs samples were measured by HRXRD using (004) reflection on a Philips system to deduce the In and N compositions of the QWs. A (110) cross-sectional dark-field TEM image was taken with a diffraction vector g = 002, sensitive to composition.

3　Results and discussion

The room temperature PL spectra of the three $Ga_{0.575}In_{0.425}N_{0.009\sim0.011}As_{0.99}$/GaAs (6nm/20nm) QWs samples (denoted as A, B, C) are shown firstly in Fig. 1. The peak wavelengths of GaInNAs/GaAs QWs are all around 1.3μm with the full width at half maximum (FWHM) less than 35meV, revealing quite good quality GaInNAs layers as further proved by XRD patterns and cross sectional TEM images.

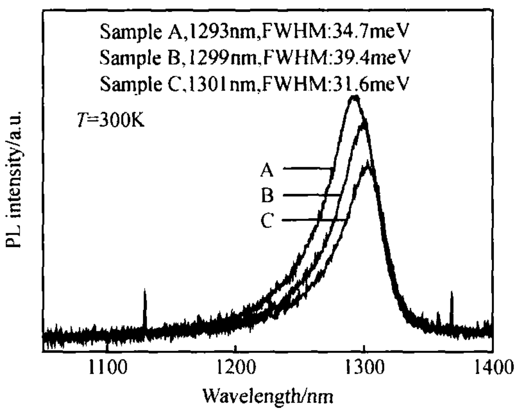

Fig. 1 Room temperature PL spectra of three GaInNAs/ GaAs QWs samples From samples A to C, the N contents linearly increased corresponding to the emission wavelengths from 1293 to 1301nm.

Figure 2 displays the XRD patterns of sample B and a reference $In_{0.36}Ga_{0.64}As$/ GaAs 3QWs structure. For all samples, the spectra show well-defined satellite diffraction peaks confirming good periodicity of the entire MQWs region. Pendellösung fringes can be clearly seen in curves *a* and *b*, indicating high film uniformity and smooth interfaces[9].

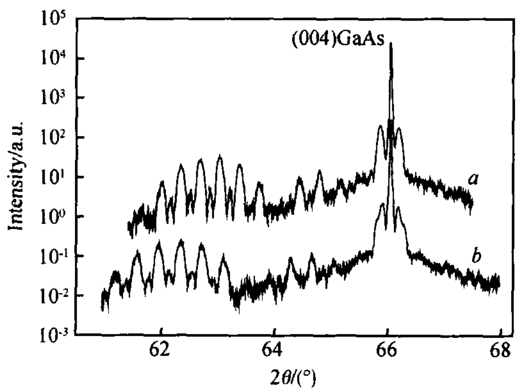

Fig. 2 Measured (004) X-ray rocking curves of $In_{0.36}Ga_{0.64}As$ 7nm/ GaAs (*a*) and sample B of $Ga_{0.575}In_{0.425}N_{0.01}As_{0.99}$ 6nm/ GaAs (*b*)

We show in Fig. 3 the high-resolution TEM image taken from sample B. The QW is well defined with flat interfaces. Although a weak contrast modulation is visible, indicating the existence of slight composition fluctuations, no dislocations or defects are observed. Apparently, the absence of structure defects, i. e. nonradiative recombination centers, is involved in the high PL efficiency in our GaInNAs/ GaAs sample.

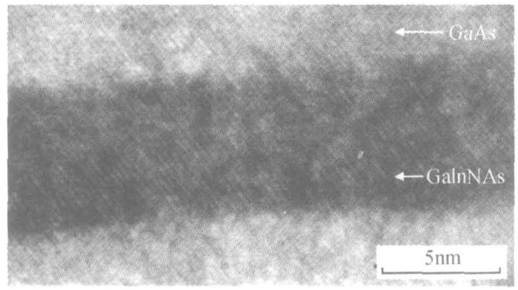

Fig. 3 High resolution cross-sectional TEM image taken from sample B of $Ga_{0.575}In_{0.425}N_{0.01}As_{0.99}$ 6nm/ GaAs QWs sample

These results indicate that high structural and optical qualities GaInNAs/ GaAs QWs have been realized. Keeping this in mind, the growth conditions reported here have been subsequently optimized by varying the growth temperature from 330 to 400 ℃ and GaAs growth rate from 0.5 to 1.5μm/ h. The RT PL half width in conjunction with the luminescence intensity were used as optimization criteria because the RT spectra are most important for the growth of the laser layers[10]. Generally, the role of N incorporation to InGaAs is three folds: (1) N incorporation to (In) GaAs promotes formation of various point defects leading to degradation of optical properties as shown in most previous reports[1,2,4,12~14]; (2) Incorporation of N leads to partial compensation of the net compressive strain in the InGaAs matrix material and results in a low density of dislocations, that is, in a low number of nonradiative channels[11]. We speculate that the strain compensation effect is dominant in our samples, while the possible luminescence degradation promoted by N incorporation has been suppressed. The crystalline defects associated with N incorporation, such as N interstitials and $(N\text{-}N)_{As}$ acting as electronic traps, have been proved to be involved in the nonradiative recombination of electron-hole pairs and responsible for the low luminescent efficiency[12~14]. The higher indium content in our samples, which brings a highly compressive strain in the epilayer, can make N atoms energetically prefer to occupy the As sub-lattice sites than the interstitial sites during the growth and/or in situ thermal processing; (3) Adding N to high In content InGaAs has another positive effect: improving the structure stability at high temperatures. It is found in our special annealing experiments that an 580 ℃ in situ thermal treatment on a $In_{0.425}Ga_{0.575}As/GaAs$ MQW leads to strain relaxation and diminished PL emission, which is in contrast with the intense luminescence from GaInNAs sample. This means that the presence of N, even in a small amount, improved the structure stability at high temperatures. Besides the strain compensation effect, we suppose that the high Ⅲ-N bond strengths can also play a role in impeding the formation and glide processes of dislocations[15]. The extensive study on the optical properties of the GaInNAs QWs will be discussed elsewhere[16].

Based on QWs growth experiments, as mentioned above, and serial studies on the laser design[17], the edge emitting laser diode has been made and measured immediately. The 20μm wide ridge stripe was pattered by a self-aligned mesa and chemically etched to the p-cladding AlGaAs layers. The 500μm long cavity was constructed by two cleaved facet mirror. The ridge was isolated with SiO_2 and followed by p-type contact (CrAu) metallization. The wafer backside was lapped and polished to a 125μm thick and followed by N-contact (AuGe/Ni/Au) metallization. As shown in Fig. 4, the LD lasing wavelength is 1.30μm under continuous current injection mode at room temperature. The threshold current for cleaved facets mirrors LD is around $1kA/cm^2$. The output power of about 30mW has been obtained.

4 Summary

High quality 1.3μm GaInNAs quantum wells have been grown by molecular beam epitaxy. The full width at half maximum of the room temperature PL spectra is around 30meV, indicating very good optical properties of the GaInNAs quantum wells. For the first time in China, ridge geometry waveguide edge emitting laser diodes are fabricated with lasing wavelength of 1.3μm under continuous current injection at room temperature. The threshold current is $1kA/cm^2$ for the LD structures with cleaved facet mirrors. The output light power over 30mW is obtained.

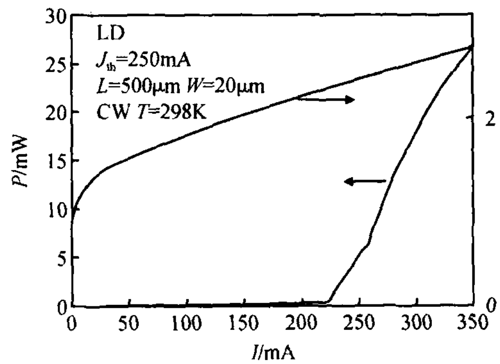

Fig. 4 P-I curve of the 1.3μm GaInNAs/GaAs QW edge emitting laser diode

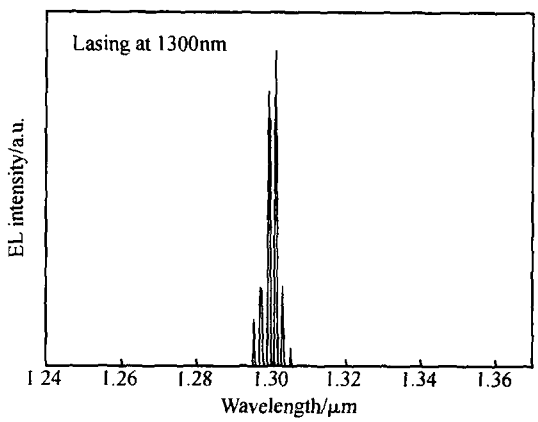

Fig. 5 Lasing spectra of the 1.3μm GaInNAs/GaAs QW edge emitting laser diode

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1.3μm GaAs 基 GaInNAs 量子阱生长与激光器研制 *

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摘要: 报道了中国第一只 1.30μm 单量子阱边发射激光器的材料生长、器件制备及特性测试. 通过优化分子束外延生长参数, 调节 In 和 N 组分含量使 GaInNAs 量子阱的发光波长覆盖 1.3μm 范围. 脊形波导条形结构单量子阱边发射激光器, 实现了室温连续激射, 激射波长为 1.30μm, 阈值电流密度为 1kA/cm², 输出功率为 30mW.

关键词: GaAs 基材料; GaInNAs 量子阱; 分子束外延; 激光器
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