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Effects of Growth Conditions on Optical Properties of GaInNAs/GaAs Quantum Well Grown by Molecular Beam Epitaxy*

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Abstract: During the process of molecular beam epitaxy employing a DC plasma as N source, the effects of the growth temperature, growth rate and As_4 pressure on the optical properties of GaInNAs Quantum Well(QW) are similar to those of InGaAs QW with the same In contents. In the range of 400 to 470℃, elevating growth temperature is beneficial to the improvement in the photoluminescence (PL) peak intensity of GaInNAs QW, but obviously broadens the full-width at half maximum PL peak. The improvement of optical properties and the reduction of N incorporation have been observed by increasing the growth rate. As_4 pressure mainly affects the optical properties of GaInNAs QW rather than N incorporation does.

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1 Introduction

Long wavelength (1.3 or 1.55μm) laser diodes have attracted much attention in recent years due to the minimum loss in the optical fiber communication. These wavelengths are accessible to InGaAsP/InP based on semiconductor active layers. However, laser diodes made from this material system exhibit a relatively low characteristic temperature (T_0) due to its poor electron confinement[1]. GaInNAs, grown on GaAs substrate, has been proposed to solve these problems[2]. Combining this material with AlGaAs, a conduction band energy discontinuity as high as 570 meV can be achieved[2], leading to the

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better electron confinement and better temperature characteristics. Due to the lattice matched with GaAs, GaInNAs/GaAs Quantum Well (QW) and well-established GaAs/AlAs DBR can be grown in one epitaxial process, as makes it possible to fabricate the GaAs-based long wavelength Vertical Cavity Surface Emitting Laser(VCSEL). Recently, 1.3μm GaInNAs edge-emitting laser diodes have been demonstrated with T_0 being 270K[3] and lifetime over 1000 hours[4]. GaInNAs VCSEL on GaAs substrate has been achieved[5]. Despite of the progress, the lasers still exhibit a relatively high threshold current density due to the inferior crystal quality of GaInNAs. It is well known that the growth temperature, growth rate and As_4 pressure are important parameters to affect the material quality in the Molecular Beam Epitaxy(MBE) growth process. However, the investigations into the influence of growth parameters on the optical properties of GaInNAs QW has not been widely available. In this paper, the effects of the growth temperature, the growth rate and As_4 pressure on the optical properties of GaInNAs QW have been investigated.

2 Experimental Procedures

The samples were grown in a VG Semicon V80H MKII MBE system on epi-ready GaAs (100) substrate, with DC active plasma used as N source. The growth temperature of GaInNAs and InGaAs layers was in the range from 400℃ to 500℃. The growth rate of InGaAs was in the range between 0.4 and 1.6 ML/s. During the growth of GaInNAs layer, the background pressure was 1—5×10^{-5} mbar. The samples consist of 500nm GaAs buffer layer, 6nm GaInNAs layer and 6nm InGaAs layer which were separated by 100nm GaAs layer and 100nm GaAs cap layer. The growth conditions of GaInNAs and InGaAs were identical except that N plasma was supplied during the growth of GaInNAs layer. The InGaAs layer was used as a contrast.

The N content of the GaInNAs layer was estimated from the photoluminescence (PL) peak separation between the GaInNAs QW and the InGaAs QW[6]. At room temperature, PL measurements were performed by the excitation using a 514.5nm Ar-ion laser and a liquid-nitrogen cooled Ge detector.

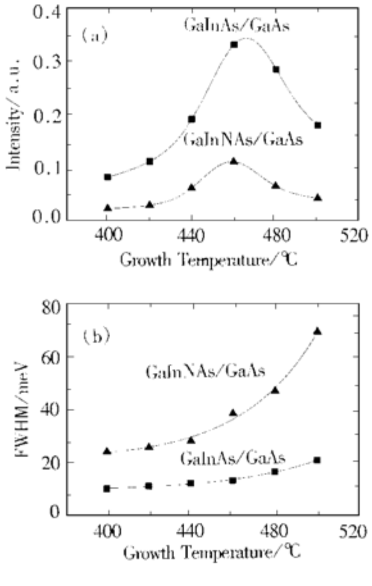

FIG. 1 (a) Variation of PL Peak Intensity of GaInNAs and InGaAs QWs with Growth Temperature, (b) Variation of FWHM of PL Peak of GaInNAs and InGaAs QWs with Growth Temperature

3 Results and Discussion

The variations of PL peak intensity and full width at half maximum (FWHM) of GaInNAs and In-

GaAs QWs according to the growth temperature were shown in Fig. 1. Both the PL peak intensities of GaInNAs and InGaAs QWs initially increased and then decreased with increasing of the growth temperature. The PL peak intensity was weak at lower growth temperature due to the insufficient migration of Ga and In on the growth surface, which can be remarkably improved by increasing the growth temperature. However, evident broadening of the PL peak FWHM of GaInNAs and InGaAs QWs can be observed with the increasing growth temperature. In situ reflection, high-energy electron diffraction observation revealed a transition from 2D growth-mode to 3D one during the growth of GaInNAs and InGaAs layers. The streaky pattern remained if the growth temperature was lower than 470℃, but became partial spotty when temperature was higher than 470℃. The emergence of 3D islands was considered to be responsible for the broadening of the FWHM of the PL peak. Alloy fluctuations also made a contribution to the line-width broadening[7]. Despite of the difference of the optical quality between the GaInNAs and InGaAs QWs, it was clear that the optimum growth temperature of GaInNAs QW was almost same with that of InGaAs QW.

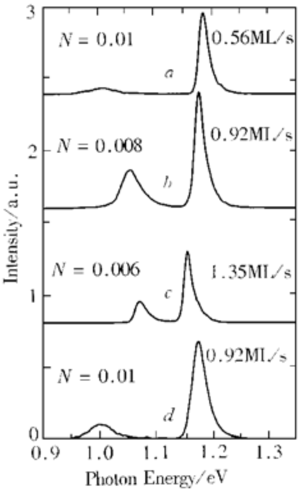

FIG. 2 Room Temperature PL Spectra of Samples Grown at Different Growth Rates

The nominal In content for all of the samples was 0.3. The lower energy peak was from GaInNAs QW and the higher energy peak was from InGaAs QW. The growth rates were 0.56, 0.92, 1.35 and 0.92ML/s for curves *a*, *b*, *c* and *d*, respectively.

The typical PL spectra of the samples grown at 460℃ at different growth rates 0.56, 0.92, 1.35ML/s were shown in Fig. 2. For all samples, the FWHMs of PL peak of the InGaAs QW were less than 20meV and those of GaInNAs less than 38meV, which indicates that the quality of these samples was good. As shown in Fig. 2*a*, *b* and *c*, the peak energy of InGaAs QW redshifted from 1.183eV to 1.156eV with the growth rates increasing from 0.56 ML/s to 1.35 ML/s. Accordingly, the peak energy of GaInNAs QW blueshifted from 1.002eV to 1.074eV. The redshift of InGaAs QW might mainly result from the reduction of In segregation[8]. Since the growth conditions of GaInNAs and InGaAs QWs were identical except for the difference of N plasma supply, large blueshift of GaInNAs QW mainly resulted from the variations of N incorporation. Because the N flux and plasma ionized current kept constant during the growth of GaInNAs layers for all these samples, the reduction of N incorporation was mainly caused by the increasing growth rates. As for the GaInNAs QW, it has been demonstrated in former reports[9,10] that the smaller the N fraction is, the better the optical properties should be. However, from Fig. 2*a*, *b* and *c*, the optical properties of GaInNAs QW were improved initially with the growth rate increasing and then degraded because of further increase. The improvement of the optical properties for the sample grown with 0.92ML/s partly resulted from the reduction of N incorporation, while the degradation of those for the sample grown with 1.35 ML/s evidently resulted from too high growth rate. The curves *a* and *d* in Fig. 2 denoted the PL spectra of the GaInNAs QW with same N content but grown at growth rates of 0.56 ML/s and 0.92 ML/s, respectively. The optical properties of the latter were much better than those of the former. Note that the optical properties of InGaAs QW were also the best when the sample was grown with 0.92 ML/s. Therefore the effects of growth rates on the optical properties of GaInNAs QW and InGaAs QWs were similar.

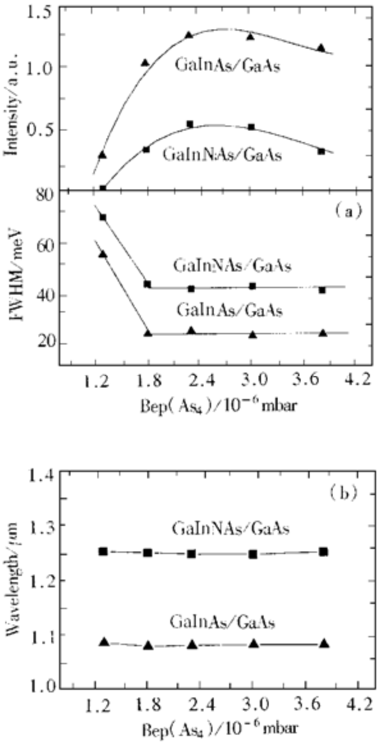

FIG. 3 (a) Dependence of PL Peak Intensity and FWHMs of GaInNAs and InGaAs QWs on As_4 Pressure, (b) Dependence of PL Peak Wavelengths of GaInNAs and InGaAs QWs on As_4 Pressure

The influences of arsenic pressure on the optical properties of GaInNAs and InGaAs QWs grown at 460℃ was shown in Fig. 3. The growth rate of GaAs kept 0.92 ML/s. During the growth of GaInNAs layers, N flux and plasma ionized current kept constant for all the samples. As shown in Fig. 3 (a), increasing As_4 pressure from 1.3×10^{-6} to 3.0×10^{-6} mbar, the PL peak intensity of GaInNAs and InGaAs QWs will be improved greatly while further increase will result in the decrease of the PL peak intensity slightly. Increasing As_4 pressure will also decrease the FWHMs of GaInNAs and InGaAs QW remarkably. The inferior optical properties of GaInNAs and InGaAs QWs grown below 1.3×10^{-6} mbar were caused by the insufficient As_4 pressure. However, the slight decrease of PL intensity of GaInNAs and InGaAs QWs grown at 3.8×10^{-6} mbar below was mainly caused by over suppression of surface migration of Ga and In. The wavelengths of GaInNAs and InGaAs QWs were hardly changed by varying As_4 pressure, as shown in Fig. 3(b), which suggested that there were no significant effects of As_4 pressure on N incorporation and In incorporation in the investigated range. The variation of As_4 pressure affected the optical properties of GaInNAs and InGaAs QWs more greatly than the N incorporation, as was different from that in the growth of MOCVD with DMHy as N source, in which the N incorporation was proportional to [DMHy]/{[DMHy]+[AsH_3]}[11]. In our experiments, the presence of N did not alter the growth behavior of GaInNAs QW. Just like the effects of the growth temperatures and growth rates on the optical properties of GaInNAs and InGaAs QWs, the effects of As_4 pressure on the optical properties of GaInNAs QW was similar to those of InGaAs QW.

4 Conclusions

The effects of growth conditions on the optical properties of GaInNAs QW grown by DC N plasma-assisted MBE were investigated. It has been found that the effects of the growth temperature, growth rate and As_4 pressure on the optical properties of GaInNAs QW are similar to that of InGaAs QW with the same In content. Therefore, the optimum growth conditions of GaInNAs QW can be contrasted with that of InGaAs QW. In the range between 400℃ and 470℃, elevating growth temperature is beneficial to the improvement in the PL peak intensity of GaInNAs QW, but obviously broadens the PL peak FWHM. The growth rate affects not only the N incorporation but also the optical properties of GaInNAs QW. The reduction of N incorporation was observed when we increase the growth rate. The optical properties of GaInNAs QW were improved initially when we increase the growth rate from 0.56ML/s to 0.92ML/s, and then degraded along with the further increasing to 1.35ML/s. As_4 pressure affects the optical properties of GaInNAs QW rather than N incorporation does.

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