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Characterization of GaNAs/GaAs and GaInNAs/GaAs Quantum Wells Grown by Plasma-Assisted Molecular Beam Epitaxy: Effects of Ion Damage*

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Abstract: The effects of ion damage on GaNAs/GaAs and GaInNAs/GaAs quantum wells (QWs) grown by plasma-assisted molecular beam epitaxy have been investigated. It is found that ion damage is a key factor affecting the quality of GaNAs and GaInNAs QWs. Obvious appearance of pendellösung fringes in X-ray diffraction pattern and remarkable improvement in the optical properties of the samples grown with ion removal magnets are observed. By removing nitrogen ions, the PL intensity of the GaInNAs QW is improved so as to be comparable with that of GaInAs QW. The stronger is the magnetic field, the more obvious the PL intensity improvement would be.

Key words: Ga(In)NAs; molecular beam epitaxy (MBE); ion damage; X-ray; photoluminescence (PL)

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1 Introduction

Recently, great attention has been paid to GaNAs ternary and GaInNAs quaternary alloys. By adding small amounts of N, direct band gap energies of the material are reduced. Due to an astonishing large bowing parameter in the energy band gap versus the composition and lattice to GaAs and Si substrate[1-4], Ga(In)NAs alloy is promising in the fundamental research and optoelectronic device applications, which, however, are hindered by the degradation of the crystalline quality and optical properties with the increase of N incorporation greatly. The degradation mainly results from the low-temperature growth, phase separation and ion damage to the growth in a molecular beam epitaxy (MBE) system. In the MBE growth of III-V nitride compound semiconductors, a plasma cell is commonly used to provide the activated nitrogen.[5-6] But both nitrogen ions and nitrogen molecular ions produced in the plasma cell can damage the grown films and degrade the crystalline quality and optical properties of the films.[5,7-9] Although only small amounts of N is required in the Ga(In)NAs layer, the ion damage is unavoidable. In this paper, the effects of ion damage on the quality GaNAs and GaInNAs QWs have been investigated. The results of the high-resolution X-ray diffraction (HRXRD) and photoluminescence (PL) measurements show that ion damage is a key factor affecting the quality of GaNAs and GaInNAs QWs.

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2 Experiment Procedures

The samples were grown in a VG Semicon V80H MKII MBE system on Si-doped GaAs (100) substrates, with DC active plasma acting as N source. The structure of GaNAs/GaAs QW consists of a 500nm GaAs buffer layer, a 5nm strained GaNAs layer, a 40nm GaAs layer and a 60nm $Al_{0.36}Ga_{0.64}As$ cap layer, while the structure of GaInNAs/GaAs QW consists of a 500nm GaAs buffer layer, a 100nm GaAs cap layer, a 6.8nm strained GaInNAs layer and a 6.8nm GaInAs layer separated by a 100nm GaAs layer. GaInAs/GaAs QW was used as a reference. The GaAs buffer layer was grown at 580 ℃, while the GaNAs layer at 500℃, and the GaInAs and GaInNAs layers at 460℃. The growth rate of GaAs was 1.5 μm/h. During the growth of GaNAs and GaInNAs layers, the background pressure was (1—5) $\times 10^{-3}$Pa.

To minimize the ion damage during the film growth, a pair of magnets was employed in our experiments. Figure 1 shows the schematic drawing of N plasma with Ion Removal Magnet (IRMs). The magnets, parallel to the exit of the DC plasma cell and the magnetic field, are perpendicular to the DC plasma cell axis. Due to the deflection of nitrogen ion in the magnetic field, high ion removal efficiency is expected.

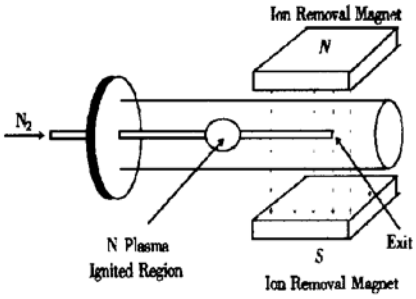

FIG. 1 Schematic Drawing of N Plasma with IRMs

The GaNAs/GaAs and GaInNAs/GaAs QWs grown with and without IRMs under the same growth conditions were investigated. HR XRD measurements were carried out using a JPN Rigaku SLX-1 A X-ray diffractometer. N composition and layer thickness were determined from the simulations of the experimental diffraction patterns based on the X-ray dynamical diffraction theory[10]. PL measurements were performed by a 514.5nm Ar-ion laser excitation source and a liquid-nitrogen cooled Ge detector.

3 Results and Discussions

HR XRD measurement is taken to study the effects of ion damage on the crystalline and interface quality of GaNAs/GaAs QW for the first time. Figure 2 shows the experimental and simulated X-ray diffraction patterns of the samples. For the best fit, the N composition is 2.2% and thickness is 5 nm for the GaNAs layer. As shown in Fig. 1, the pendellösung fringes of the sample grown with IRMs are clearer than that of the sample grown without IRMs. In particular, the pendellösung fringes on the right of the substrate peak only appear in the sample grown with IRMs. Since the pendellösung fringes is sensitive to the crystalline quality and the interface quality, the disappearance of the pendellösung fringes in the sample grown without IRMs is mainly caused by the structure defects and the interface destruction, as proves that reducing the ion damage can improve the quality of GaNAs/GaAs QW greatly.

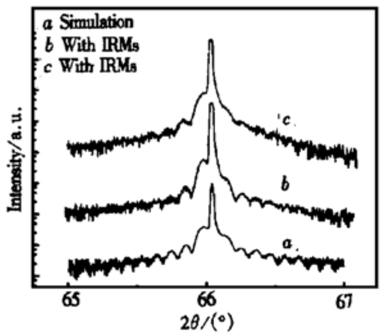

FIG. 2 Experimental and Simulated Diffraction Patterns of GaNAs/GaAs QW Grown with and Without IRMs The N composition and thickness of GaNAs layer are 2.2% and 5 nm, respectively.

The effects of ion damage on the optical properties of GaNAs/GaAs QW were also studied. Figure 3 shows the typical asymmetric PL spectra of the GaNAs/GaAs QWs at 10 K. *a* and *b* denote the samples grown with and without IRMs, respectively. The variation in PL peak energy of the two samples is negligible, which indicates that using IRMs does not affect the N incorporation. The PL peak intensity of the sample grown with IRMs is 12 times higher than that of the sample grown without IRMs under the same measurement conditions. And the full width at half maximum (FWHM) of the sample grown with IRMs is 40 meV, which is far less than 73meV, that for the sample grown without IRMs. Remarkable increase in the PL intensity of the sample grown with IRMs is mainly caused by the reduction of the nonradiative recombination centers due to the ion damage. The decrease in the FWHM of the sample grown with IRMs may originate from the improvement of the interface quality.

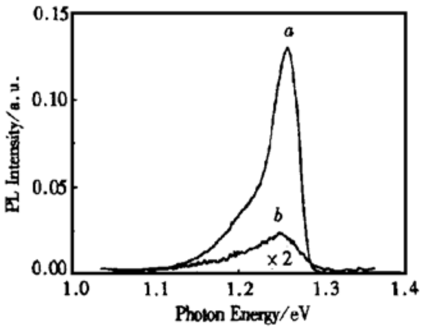

FIG. 3 Low Temperature (10K) PL Spectra of GaNAs/GaAs QW Grown with and Without IRMs

Similar effects of the ion damage on the optical properties of GaInNAs/GaAs QW have also been observed. Figure 4 is the PL spectra of GaInNAs/GaAs and GaInAs/GaAs QWs grown with and without IRMs at room temperature. The low energy peaks are from GaInNAs/GaAs QW, while the high energy peaks are from GaInAs/GaAs QW. It can be seen that the PL intensity of the GaInNAs/GaAs QWs grown with IRMs increases remarkably. In particular, the stronger is the magnetic field, the stronger the PL intensity would be. The PL intensity of the GaInNAs/GaAs QW grown under strong magnetic field is comparable with that of the GaInAs/GaAs QW. Different from GaNAs/GaAs QW, there is a small blue shift of the PL peak wavelength for the sample grown with IRMs. But obviously, there is no shift of the PL peak wavelength for the GaInNAs/GaAs QWs grown under different magnetic field. Since the GaInNAs and GaInAs QWs are grown under the same growth conditions and there is no variation in the PL peak wavelength for the GaInAs/GaAs QW, we believe that the small blue shift is attributable to the nitrogen composition fluctuation in the GaInNAs layer.

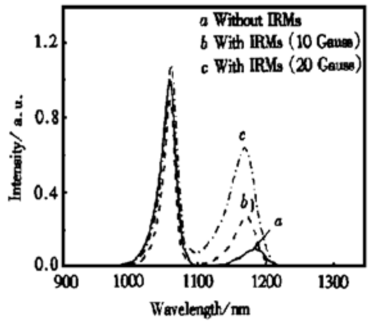

FIG. 4 Room Temperature PL Spectra of GaInNAs and GaInAs QWs Grown with and Without IRMs

4 Conclusions

GaNAs/GaAs and GaInNAs/GaAs quantum wells (QWs) grown by plasma-assisted molecular beam epitaxy have been investigated. It is found that ion damage is a key factor affecting the quality of GaNAs and GaInNAs QWs. Obvious appearance of pendellösung fringes in X-ray diffraction pattern and remarkable improvement in the optical properties of the samples grown with IRMs have been observed. By removing nitrogen ions, the PL intensity of the GaInNAs QW can be improved to be comparable with that of GaInAs QW. The stronger is the magnetic field, the more obvious the PL intensity improvement would be. Using IRMs mainly affects the crystalline quality and optical properties of GaNAs/GaAs and GaInNAs/GaAs QWs rather than N incorporation.

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离子损伤对等离子体辅助分子束外延生长的GaNAs/GaAs和GaInNAs/GaAs量子阱的影响*

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摘要: 研究了离子损伤对等离子体辅助分子束外延生长的GaNAs/GaAs和GaInNAs/GaAs量子阱的影响. 研究表明离子损伤是影响GaNAs和GaInNAs量子阱质量的关键因素. 去离子磁场能有效地去除了等离子体活化产生的氮离子. 对于使用去离子磁场生长的GaNAs和GaInNAs量子阱样品, X射线衍射测量和PL谱测量都表明样品的质量被显著地提高. GaInAs量子阱的PL强度已经提高到可以和同样条件下生长的GaInAs量子阱相比较. 研究也表明使用的磁场强度越强, 样品的光学质量提高越明显.

关键词: Ga(In)NAs; 分子束外延(MBE); 离子损伤; X射线衍射; 光致发光

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