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ENHANCING THE PHOTOLUMINESCENCE OF InAsP/InP STRAINED MULTIPLE QUANTUM WELLS BY H^+ IONS IMPLANTATION

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Abstract: InAsP/InP strained multiple quantum wells (SMQWs) were grown by gas source molecular beam epitaxy (GSMBE). The effects of H^+ ions implantation on the photoluminescence (PL) of InAsP/InP SMQWs and the effects of rapid thermal annealing (RTA) on the PL of implanted InAsP/InP SMQWs were investigated. Our results show that the quantum wells (QWs) PL intensities increase under lower H^+ ions implantation energies (doses) and the QWs PL intensities decrease with the rise of implantation energies (doses). During the implantation process, some tunnelling H^+ ions annihilate the interface defects inside the QWs and some H^+ ions introduce some damage into the QWs structure. The competition between these two processes influences the QWs PL intensities. After RTA, the implanted QWs PL peak positions are blue shifted compared with that of as-grown sample at low temperature 10K and the quantity of blue shift increases with the rise of implantation energies (doses). It is attributed to the defects diffusion and the intermixing of different elements between the well layer and the barrier layer during RTA.

Key words: ions implantation; photoluminescence; quantum well intermixing (QWI)
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氢离子注入法提高 InAsP/InP应变多量子阱发光特性

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摘要: 采用气态源分子束外延系统生长了 InAsP/InP应变多量子阱,研究了 H^+注入对量子阱光致发光谱的影响以及高温快速退火对离子注入后的量子阱发光谱的影响。发现采用较低 H^+注入能量(剂量)时,量子阱发光强度得到增强;随着 H^+注入能量(剂量)的增大,量子阱发光强度随之减小。H^+注入过程中,部分隧穿 H^+会湮灭掉量子阱结构界面缺陷,同时 H^+也会对量子阱结构带来损伤,两者的竞争影响量子阱发光强度的变化。高温快速退火处理后,离子注入后的量子阱样品发光峰位在低温 10K相对于未注入样品发生蓝移,蓝移量随着 H^+注入能量或剂量的增大而增加。退火过程中缺陷扩散以及缺陷扩散导致的阱层和垒层之间不同元素互混是量子阱发光峰位蓝移的原因。

关 键 词: 离子注入; 光致发光; 量子阱互混

Introduction

Ions implantation is extensively used in the fabrication of optoelectronic devices [1,2], as it offers more advantages compared with other surface modification techniques. It is well known that ions implantation can

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selectively modify the material surface properties without changing the bulk material and the concentration profile of implanted species can be easily changed under different implantation energy. Ions implantation is also acting as a post-growth technique to tailor the energy band-gap of materials. But damage can be introduced into materials during the process of ions implantation, which may deteriorate the device optical and electrical properties[3]. It is important for device fabrication to minimize or avoid the damage during implantation.

InAsP/InP QWs have been widely used as active materials of optoelectronic devices, such as lasers and modulators in the wavelength range of 0.9 ~ 1.5 μm[4~6]. In this paper, we present an interesting result that the PL intensities of InAsP/InP SMQWs can be enhanced after H^+ ions are implanted into the QWs structure. The mechanism of these PL enhancement phenomena is then analyzed in detail.

1 Experiments

InAsP/InP SMQWs were grown on InP (100) semi-insulated substrate by GSMBE. Firstly, a 300 nm InP buffer layer was grown on the substrate. Then two QWs that are composed of InP barrier layer and InAsP well layers were followed. The InAsP well layers are 6.6 and 3.2 nm, respectively (from bottom to top). Between the two well layers, there was a 300 nm InP barrier layer. Finally, a 700 nm InP layer was capped onto the structure.

The as-grown InAsP/InP SMQWs sample was cut into 7 pieces for ions implantation with different energies or doses. Prior to implantation, a 200 nm SN_x thin film was deposited onto the surface of 6 samples (pieces) by Plasma-Enhancement Chemical-Vapor Deposit (PECVD). H^+ ions implantation was carried out by a M-200 facility. After implantation, SN_x thin film was removed by diluted HF solution (1:10). The PL spectra were measured under the excitation of 514.5 nm line of an Ar^+ laser with 50 mW pumping power. The PL intensities of all samples are normalized by the PL intensities of the as-grown sample at room temperature.

2 Results and discussion

Fig. 1 shows the change of InAsP/InP SMQWs PL intensities with different implantation doses at the same energy of 25 KeV. In curve (a), PL peaks are at 1.21 and 1.3 μm, corresponding to luminescence from 3.2 nm well and 6.6 nm well, respectively. It can be seen that significant enhancement of PL intensity (with a factor of 2) is achieved in the sample with a low implantation dose ($10^{10}/cm^2$). Then the PL intensities of QWs decrease a little bit but still higher than that of the as-grown sample (with an enhancement factor of 1.6) when the implantation dose increases to $10^{12}/cm^2$. Further increase of the dose ($10^{14}/cm^2$), however, leads to the decrease of PL peak intensities to the half of the as grown sample.

It is known that ions implantation introduces crystal lattice damage into the QWs structure. With the increasing of implantation energies or H^+ doses, the damage becomes more serious, which is reflected by the decrease of PL intensities of the QWs. So it is necessary to understand the mechanism of PL intensities enhancement of the ions implanted InAsP/InP SMQWs. It is known that surface roughening of samples is beneficial to the escaping of photons emitting from QWs and thus to a certain degree results in the enhancement of PL intensities due to light angular randomization[7]. To study this effect in our ions implanted samples, we used atomic force microscopy (AFM) to measure the surface roughness which was characterized by the root-mean-square (RMS) value, as shown in Fig. 2. It is seen that the RMS of the as-grown and ions implanted QW samples were 0.720, 0.753, 0.749,

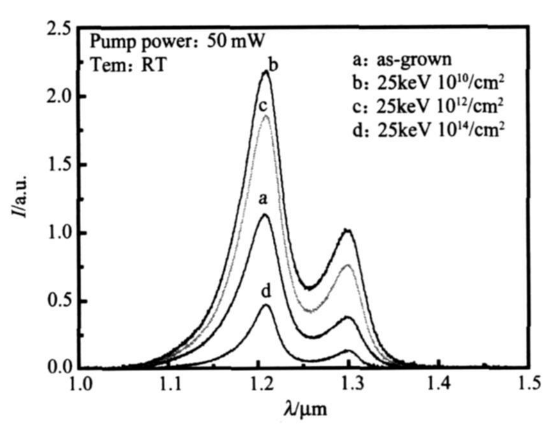

Fig. 1 PL measurements of the as-grown and H^+ ions implanted samples for different doses

图 1 未注入样品光谱及 H^+ 注入样品光谱随注入剂量的变化

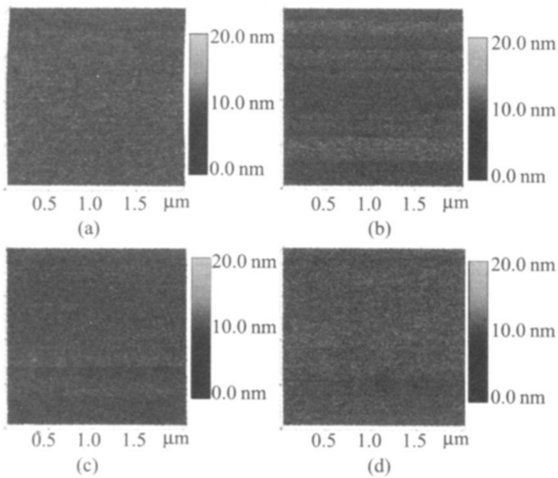

Fig 2 The AFM images of the sample surfaces after H^+ ions implantation with different doses (a) as grown (b) $1\times10^{10}/cm^2$ (c) $1\times10^{12}/cm^2$ (d) $1\times10^{14}/cm^2$

图 2 未注入样品表面的 AFM 图及不同注入剂量注入后样品表面 AFM 图 (a) 未注入 (b) $1\times10^{10}/cm^2$ (c) $1\times10^{12}/cm^2$ (d) $1\times10^{14}/cm^2$

0.814 nm, respectively. These results indicate that H^+ ions implantation does not significantly change the surface morphology in our samples. Therefore, contribution of surface roughening to PL intensities enhancement of ions implanted samples can be neglected.

We simulated the concentration distribution of H^+ ions by Trim-2000 with implantation energy of 25 keV and the result shows that H^+ ions is mainly distributed at 35 nm under the QWs surface (235 nm under the SN_x surface). Molecular simulations in both silicon and III-V semiconductors show that even at very low energies (~100s eV), ions channeling along <110> direction is possible. Thus a small fraction of the order ~0.1% of the implanted ions are scattered onto the directions aligned with the <110> axes[8]. In our experiments, the smallest implantation energy is 25 keV that is much higher than 100 eV. In addition, the mass of H^+ is very small, and some H^+ ions have enough energy to penetrate deeply into the QWs structure along the low index direction. These H^+ ions can passivate the interface defects inside the QWs structure which leads to the increase of PL intensities[9]. However, with the increase of H^+ ions dose, more and more H^+ ions tunnelled into the quantum well layers and the high density H^+ ions in the QWs may damage the QWs structure and form high density nonradiative centers, which results in the decrease of PL intensity[10].

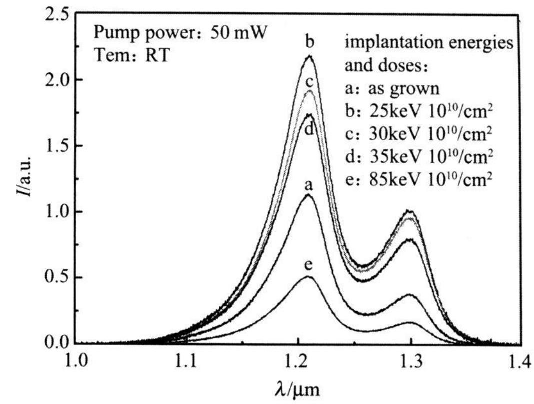

Fig 3 PL measurements of the as grown and H^+ ions implanted samples for different ion implantation energies

图 3 未注入样品光谱及 H^+注入样品光谱随注入能量的变化

Fig 3 shows the measured PL spectra of the QW samples implanted with different ions energies, but with a fixed dose ($10^{10}/cm^2$). It can be seen that low implantation energy leads to the significant increase of PL intensities. As implantation energy increase, the QWs PL intensities decrease and it is only about half of the as-grown sample when the energy is at 85 keV. It is known that the peak distribution of the implanted H^+ ions under the sample surface is proportional to the ion energy, i.e. the higher the implantation energy is the deeper of the H^+ ions distribution under the sample surface is. Then, the peak position of H^+ ions profile in InAsP/InP SMQWs gets closer to the QW layers with increase of implantation energy. Thus, more and more H^+ ions will easily reach to the well layers and affect the efficiency of PL emission. In the process of ions implantation, H^+ ions and the crystal lattice interchanged energy as a result of collision which generated some sorts of defects, such as vacancy and interface atoms in the samples. Therefore, higher implantation energy introduces more structural damage to the QWs and then decreases the PL intensities.

Finally we studied the annealing effect on the PL emission of the H^+ ions implanted InAsP/InP SMQWs structures. Samples were thermally annealed at 700℃ with duration of 30 seconds. To avoid material decomposition, the surface was covered with an InP substrate. It is known that ions implantation introduces crystal damage by generation of the defects like vacan-

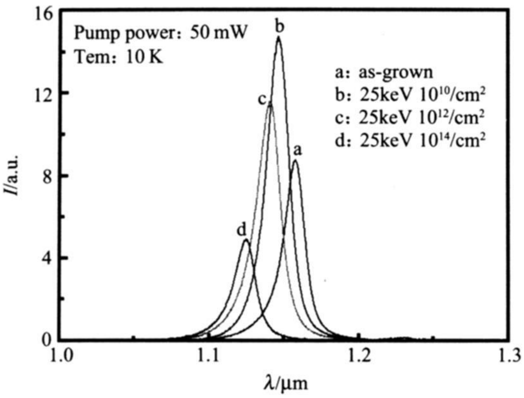

Fig 4 10K PL measurements of the as-grown and H^+ ions implanted samples for different doses after annealing at 700℃ for 30s
图 4 低温 10K, 未注入样品光谱及经不同剂量注入后的样品 700℃快速退火 30s后的光谱

cy and interface atoms. Annealing process could trigger the defects diffusing into the well layers, which leads to the decrease of the QW PL intensities. On the other side, due to the concentration gradient between the well and barrier, the elements at around the interface will inter-diffuse which leads to the narrowing of quantum well layer (called quantum well intermixing). The quantum well intermixing results in the upper movements of the bottom of conduction band and lower movements of the top of valence band, which is reflected by the blue shift of the PL peaks in the annealed samples. This QW intermixing phenomenon with PL peak blue-shift was observed in the InGaAs/InGaAsP laser structure by using inductively coupled argon plasma processing[11]. The value of the blue-shift increased with the rise of implantation dose. Fig. 4 shows the PL measured at 10 K. It is seen that larger blue-shift is observed in higher dose implanted samples. When an implantation dose of $10^{14}/cm^2$ is used, a significant blue shift (33 nm) of the peak position of the implanted QWs is observed in comparison with that of the as grown sample.

3 Conclusion

InAsP/InP SMQWs were implanted by H^+ ions with different implantation energies and doses. After H^+ ions implantation, the QWs PL intensities firstly increased and then decreased with the rise of implantation energies or doses. During the implantation, some H^+ ions introduced damage into the QWs structure and some tunnelling H^+ ions annihilated interface defects inside the QWs. The competition between these two processes determined the QWs PL intensities. 10 K PL peak positions of the implanted QWs were blue-shifted upon thermal annealed at 700℃ with duration of 30 seconds. And the quantity of the blue-shift was increased under higher implantation energies or doses. It was attributed to the defects diffusion and the intermixing of QW/barrier material during RTA.

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