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Effect of Si doping on the photoluminescence properties of AlGaInP/GaInP multiple quantum wells

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Abstract

The influence of Si doping on the photoluminescence (PL) properties of $(Al_{0.3}Ga_{0.7})_{0.5}In_{0.5}P/Ga_{0.5}In_{0.5}P$ multiple-quantum-wells (MQWs) was studied. For the samples without p-type layers, the PL peak wavelength from $(Al_{0.3}Ga_{0.7})_{0.5}In_{0.5}P/Ga_{0.5}In_{0.5}P$ MQWs did not vary when Si was doped in MQWs, the PL peak intensity did not change obviously and the PL FWHM broadened. We consider that Si doping results in worse interface quality of $(Al_{0.3}Ga_{0.7})_{0.5}In_{0.5}P/Ga_{0.5}In_{0.5}P$ MQWs. However, for the full light-emitting diode (LED) structure samples, the PL intensity of MQWs obviously increased when Si was doped in MQWs. The PL intensity from MQWs with Si-doped barriers was about 13 times stronger than that of undoped MQWs. The PL intensity from MQWs with Si-doped barriers and wells was strong as 28 times as that of undoped MQWs. The reasons are discussed.

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Keywords: Quantum well; AlGaInP; Metalorganic chemical vapor deposition; Photoluminescence

1. Introduction

Significant advances in the light output performance of visible light-emitting diodes (LEDs) and light-emitting lasers (LDs) have been demonstrated using the AlGaInP alloy system [1–6]. When grown lattice-matched to a GaAs substrate, the $(Al_xGa_{1-x})_{0.5}In_{0.5}P$ alloy has a direct band gap of about 1.8–2.3 eV (about 680–540 nm) as the aluminum composition x is changed from 0 to 0.7. This property makes AlGaInP an excellent material for efficient LEDs with a wide color range.

High-brightness AlGaInP LED usually uses a double heterostructure or a multi-quantum-wells (MQWs) active region. The active region needed to be undoped in order to reduce the nonradiative recombination centers [1–5]. However, the condition of III-nitride compounds is quite different [7–15]. The photoluminescence (PL) intensity from Si-doped InGaN layers was approximately one order of magnitude stronger than that from the undoped layers [7,8]. The PL intensity of InGaN:Si/GaN:Si MQWs was obviously higher than that of undoped MQW sstructures [9], and the electron mobility was significantly increased [10]. The PL intensity of MQWs with Si-doped barriers was approximately 2500 times stronger than that of undoped MQWs [11], and the interface quality could be improved [12]. Furthermore, we notice that almost all of the successful InGaN laser structures have wells and barriers doped with Si or at least Si-doped barriers [13–16]. In this paper, we report the Si doping effects on the properties of $(Al_{0.3}Ga_{0.7})_{0.5}In_{0.5}P/Ga_{0.5}In_{0.5}P$ MQWs.

2. Experimental details

The samples examined in this study were grown by EMCORE GS/3200 LP-MOCVD. Si-doped GaAs substrates were cut 15 degree off the (1 0 0) plane towards the [0 1 1] direction. The source materials were TMGa, TMIn, TMAl, AsH_3, and PH_3. CP_2Mg and SiH_4 were used for p- and n-type doping reagents. The growth temperatures were generally between 620 and 720 °C. Two types of

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samples were investigated. The first type of samples was grown $(Al_{0.3}Ga_{0.7})_{0.5}In_{0.5}P/Ga_{0.5}In_{0.5}P$ MQWs without p-type layers above it. The second type of samples was grown full LED structure. Figs. 1 and 2 show the schematic diagrams of these two types. Fig. 1 shows the structure of the samples of $(Al_{0.3}Ga_{0.7})_{0.5}In_{0.5}P/Ga_{0.5}In_{0.5}P$ MQWs without p-type layers above it. The layers consisted of a 0.5-μm-thick n-GaAs buffer layer with carrier concentration of about $5\times10^{17}\,cm^{-3}$, a 0.5-μm-thick n-$(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$ cladding layer with carrier concentration of about $3\times10^{17}\,cm^{-3}$, a $(Al_{0.3}Ga_{0.7})_{0.5}In_{0.5}P/Ga_{0.5}In_{0.5}P$ MQWs active region, a 20-nm-thick unintentional doped $(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$ cladding layer with carrier concentration of about $3\times10^{17}\,cm^{-3}$. Fig. 2 shows the second type of samples with full LED structure. Compared with Fig. 1, a 15 periods $Al_{0.5}Ga_{0.5}As$:Si/AlAs:Si Bragg reflector was grown between the n-GaAs buffer layer and n-$(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$ cladding layer. After grown $(Al_{0.3}Ga_{0.7})_{0.5}In_{0.5}P/Ga_{0.5}In_{0.5}P$ MQWs active region, a 0.5-μm-thick p-$(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$ cladding layer with carrier concentration of about $6\times10^{17}\,cm^{-3}$, and a 5.0-μm-thick p-GaP current spreading layer with carrier concentration of about $5\times10^{18}\,cm^{-3}$ were grown. The MQWs consists of 10 periods of 10.0-nm-thick $(Al_{0.3}Ga_{0.7})_{0.5}In_{0.5}P$ barriers and 5.0-nm-thick $Ga_{0.5}In_{0.5}P$ wells.

For each type of samples mentioned above, three samples with different Si doping in MQWs were studied. Samples *a*, *b* and *c* were grown according to the structure shown in Fig. 1. Samples *A*, *B* and *C* were grown according to the structure shown in Fig. 2. The MQWs of samples *a* and *A* are undoped. The barriers of samples *b* and *B* are Si-doped. The barriers and wells of sample *c* and *C* are Si-doped. The doping dose in MQWs was the same as that of the n-$(Al_{0.7}Ga_{0.3})_{0.5}In_{0.5}P$ cladding layer. Other growth parameters of MQWs of these six samples were same.

After growth, the PL properties of these samples were characterized by using YAG laser 532 nm line with 2 W/cm^2 excitation density.

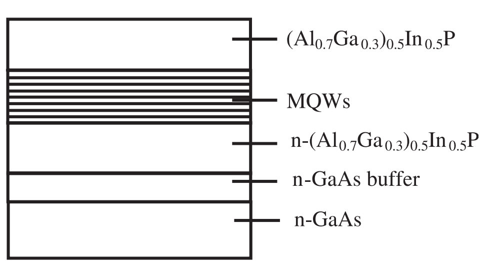

Fig. 1. The schematic structure of $(Al_{0.3}Ga_{0.7})_{0.5}In_{0.5}P/Ga_{0.5}In_{0.5}P$ MQWs.

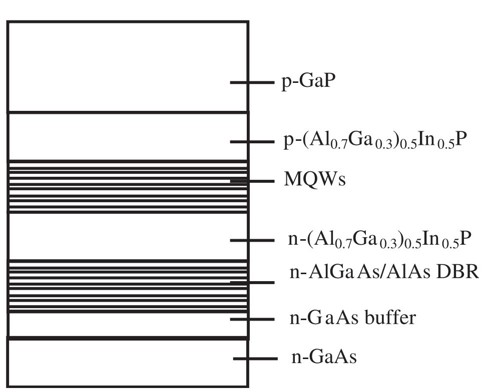

Fig. 2. The schematic structure of $(Al_{0.3}Ga_{0.7})_{0.5}In_{0.5}P/Ga_{0.5}In_{0.5}P$ MQWs LED wafer.

3. Experimental results and discussion

Fig. 3 shows the room temperature PL spectra of samples *a*, *b*, and *c*. The characteristics of PL are listed in Table 1. It can be seen that just one peak appears from each sample, and the peak wavelengths of three samples are all at 641 nm. It means that the peak energy of MQWs does not vary with Si doping. The normalized intensities of samples *a*, *b*, and *c* are 1.0, 0.92, 0.95, respectively. It indicated that the peak intensity of MQWs do not change obviously with Si doping. This phenomenon is quite different from the effect of Si doping on InGaN/GaN MQWs. The PL intensity of InGaN:Si/GaN:Si MQW structures was obviously higher than that of undoped MQW structures [9]. The PL intensity of MQWs with Si-doped barriers was approximately 2500 times stronger than that of undoped MQWs [11]. From Table 1, the PL FWHM values of samples *a*, *b* and *c* are 11.6, 14.2,

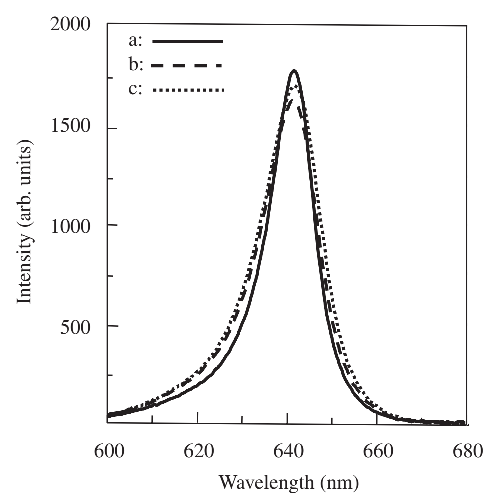

Fig. 3. The room temperature PL spectra of three $(Al_{0.3}Ga_{0.7})_{0.5}In_{0.5}P/Ga_{0.5}In_{0.5}P$ MQW structures with different Si doping.

Table 1
The characteristics of PL of three $(Al_{0.3}Ga_{0.7})_{0.5}In_{0.5}P/Ga_{0.5}In_{0.5}P$ MQW structures with different Si doping

Samples	*a*	*b*	*c*
Wavelength (nm)	641	641	641
Normalized PL intensity	1.0	0.92	0.95
PL FWHM	11.6	14.2	16.0