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Citation: Applied Physics Letters **57**, 1640 (1990); doi: 10.1063/1.104073
View online: http://dx.doi.org/10.1063/1.104073
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Influence of indium doping on AlGaAs layers grown by molecular beam epitaxy

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(Received 2 May 1990; accepted for publication 24 July 1990)

Influence of indium doping on the qualities of AlGaAs layers grown by molecular beam epitaxy has been studied. It was found that a proper amount of In doping can increase the photoluminescence intensity drastically by a factor greater than 10 indicating an improvement in the optical quality of AlGaAs epilayers. The improvement in the material quality is attributed to a higher surface migration rate of In atoms than those of Ga and Al atoms leading to a reduction of group III vacancies. However, too great a concentration of In atoms leads to effects that may degrade the film quality.

GaAs/$Al_xGa_{1-x}As$ heterostructures grown by molecular beam epitaxy (MBE) are widely used in high-speed and optoelectronic devices. The performance of these devices depends on the quality of AlGaAs, which is strongly influenced by the growth conditions, such as growth rate, growth temperature, Al concentration, V/III flux ratio, source quality, furnace temperature stability, background pressure, and even the run time after opening the growth chamber. Because of the presence of Al, which has lower surface migration rate than that of Ga, vacancies are more easily formed than in GaAs resulting in poorer material quality. Higher growth temperatures,[1] hydrogen passivation,[2] very slow growth rates,[3] and migration-enhanced epitaxy[4] have been used to improve the quality of AlGaAs. In this letter we report a different method which uses In doping during MBE growth and can very effectively improve the AlGaAs quality.

It is well known that In doping in bulk GaAs growth increases material strength and reduces dislocation density.[5] Recently, it has also been observed that the optical property of MBE-grown GaAs could be improved with In doping.[6,7] In this letter we have studied the influence of In doping on the quality of AlGaAs using low-temperature photoluminescence (PL) measurement. Growth was carried out on undoped semi-insulating GaAs (100) substrates in a Varian GEN II MBE system. The samples consisted of a 0.6 μm AlGaAs layer on top of a 0.5 μm GaAs buffer layer. These epilayers were doped with In to a concentration range between 0 and 4×10^{19} cm^{-3} (0 and 0.18% with respect to GaAs mole concentration). During growth, all conditions were carefully kept unchanged except the In-doping concentration. The growth temperature was 610 °C, and the V/III beam equivalent pressure was around 15. The intended growth rate was 1 $\mu m/h$. The Al content of the $Al_xGa_{1-x}As$ layers, determined by x-ray rocking curve and the position of the bound exciton in the PL spectrum, was found to be 42%. The In concentration was determined from the logarithmic plot of In growth rate versus reciprocal temperature of the In furnace. PL was measured at 4 K and the excitation source was the 5145 Å line of an Ar laser. The excitation power was about 0.3 W/cm^2. The PL spectra were analyzed by a Spex 1404 double grating spectrometer coupled to a cooled GaAs photomultiplier tube.

The measured PL spectra for $Al_{0.42}Ga_{0.58}As$ with different In-doping concentration are shown in Fig. 1. The main peak is due to the bound exciton, and the side peak is due to the combination of defect exciton (d,x), carbon acceptor (e,C^0), silicon acceptor (e,Si^0), silicon donor to carbon acceptor (Si^0,C^0), defect complex (d), and phonon replica.[8] Since the Al composition is very high, a large amount of defects and impurities were incorporated during epitaxial growth. These defect- and impurity-related peaks cannot be well resolved. The results of the PL measurement are summarized in Table I. Figure 2 shows the bound exciton linewidth, the bound exciton intensity, and the intensity ratio of the main peak to the side peak against In concentration.

From the results presented above, it is clear that a small

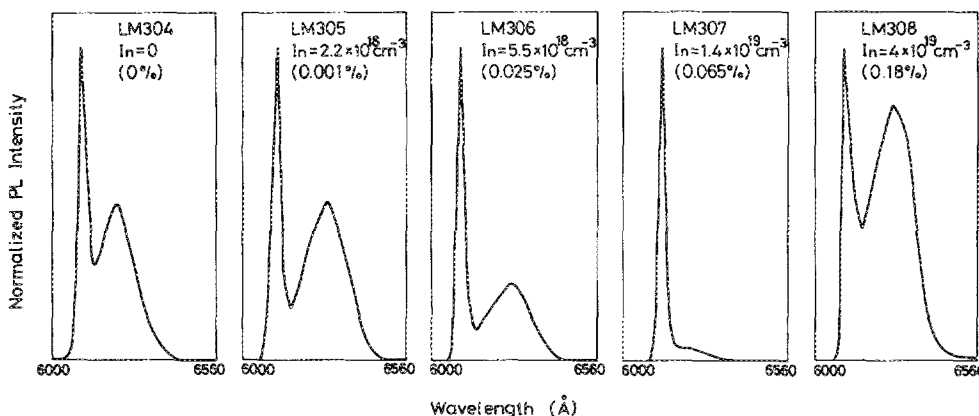

FIG. 1. PL spectra of $Al_{0.42}Ga_{0.58}As$ with and without In doping at 4 K. The intensity is normalized against the peak intensity of the bound exciton.

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TABLE I. PL measurement results (4 K).

Run No.	Indium concentrtion (10^{19} cm^{-3})	Bound exciton peak position (eV)	FWHM[a] bound exciton (meV)	Relative intensity of bound exciton	Relative intensity of side peak	Main peak intensity / Side peak intensity
LM304	0	2.03	12.2	1	1	1.97
LM305	0.22	2.026	10.9	1.24	1.26	1.94
LM306	0.55	2.033	9.0	2.8	1.34	4.12
LM307	1.4	2.022	7.6	10.9	0.92	23.4
LM308	4.0	2.028	16.2	1.47	2.45	1.18

[a] FWHM—Full width at half maximum.

amount of In greatly improves the optical property of AlGaAs yielding higher PL intensity and narrower PL linewidth. The linewidth of the bound exciton reaches a minimum and the intensity reaches a maximum when the In concentration is 1.4×10^{19} cm^{-3} or 0.065% in group III mole fraction. However, when the In concentration reaches 4×10^{19} cm^{-3} or 0.18%, the PL intensity drops and the linewidth widens. The narrowest linewidth obtained is 7.6 meV. To our knowledge, the best PL linewidth reported for MBE-grown AlGaAs with comparable Al composition and similar growth temperature is 4 meV.[3] But that was obtained with a very slow growth rate (0.14 μm/h). With a "faster" growth rate, 1.4 μm/h, the same reference reported a linewidth of 44 meV, which is much wider than our result. The fact that our result was obtained with a low growth temperature and a relatively fast growth condition (1 μm/h) shows that In doping indeed greatly improves the quality of AlGaAs. It should be pointed out that the small and random shift of the bound exciton peak position among those samples is due to the fluctuation of Al flux, not contributed from In doping.

Ga or Al vacancies have been shown to be the source of deep traps in MBE-grown AlGaAs,[9,10] and the PL intensity drops as the density of deep traps increases.[10] Past efforts in improving the AlGaAs quality such as higher growth temperatures, growth interruption, migration-enhanced epitaxy, and hydrogenation, can be, at least partially, attributed to the reduction of the vacancies by either increasing the surface migration rate of group III atoms or passivating the defects associated with the vacancies. In this study, the increase of the PL intensity due to In doping can be explained by the In atoms occupying the Ga or Al vacancies due to higher surface migration rate, decreasing the paths for defect-related nonradiative transitions. The decrease of PL intensity and the increase of the linewidth for heavily In-doped samples are probably attributed to the new impurities associated with the In source and the strain-induced defects in the epilayers due to a small amount of lattice mismatch between the In-doped AlGaAs layer and the underlying GaAs. Studies for GaAs/InGaAs quantum wells have also shown decreased PL intensity due to misfit dislocations in the strained InGaAs.[11]

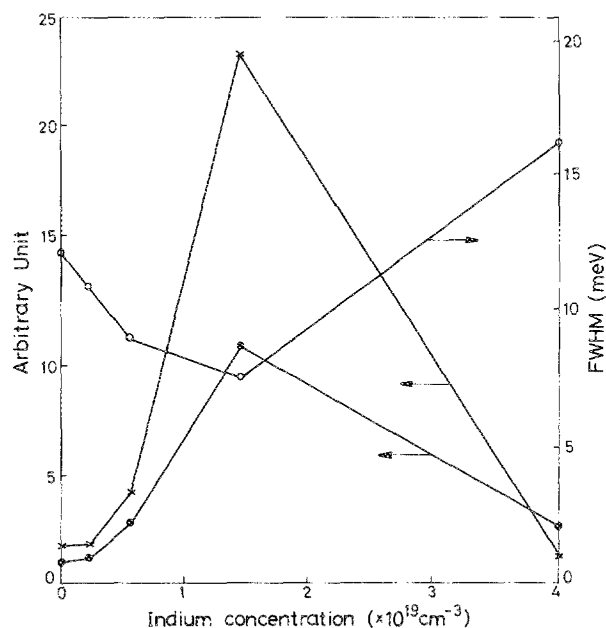

FIG. 2. Bound exciton linewidth (O), main peak to side peak ratio (×), and bound exciton PL intensity (⊗) against indium concentration.

From Table I, one may notice that the PL intensity of the side peak in the spectra does not increase proportionally as the main peak due to In doping. This is probably because the reduction of vacancy concentration resulting in reduced defect complex emission as In concentration increases. The intensity ratio of the main peak to the side peak for the In-free sample is 12.2 but goes up to a maximum value of 23.4 for the sample with an In concentration of 1.4×10^{19} cm^{-3}, then drops to 1.18 for the sample with an In concentration of 4×10^{19} cm^{-3}. It should be pointed out that the relative intensities of the main peak and the side peak strongly depend on the laser pumping power[12] and are difficult to compare with other reported results. The results presented here were based on measurements performed at the same time with the same pumping power. The increase of the intensity ratio is a good indication of the improvement of the material quality.

In conclusion, we have found that the quality of MBE-grown AlGaAs can be greatly improved by proper In doping. The improvement is attributed to the reduction of vacancy concentration of group III atoms due to higher surface migration rate of In atoms. The optimum In concentration for $Al_{0.42}Ga_{0.58}As$ was found to be around 1.4×10^{19} cm^{-3}, or 0.065% in mole fraction, where more than a ten times increase in PL intensity was observed.

The authors would like to thank Professor M. K. Lee of National Sun Yat-Sen University for helpful discussion. The work is supported by the National Science Council of the Republic of China.

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[1]J. E. Cunningham, W. T. Tsang, T. H. Chiu, E. F. Schubert, and J. A. Ditzenberger, J. Vac. Sci. Technol. B **5**, 761 (1987).
[2]L. Pavesi, D. Martin, and F. K. Reinhart, Appl. Phys. Lett. **55**, 475 (1989).
[3]M. Heiblum, E. E. Mendez, and L. Osterling, J. Appl. Phys. **54**, 6982 (1983).
[4]Y. Horikoshi, M. Kawashima, and H. Yamaguchi, Jpn. J. Appl. Phys. **27**, 168 (1988).
[5]H. Ehrenreich and J. P. Hirth, Appl. Phys. Lett. **46**, 668 (1985).
[6]J. P. Laurenti, P. Roentgen, K. Wolter, K. Seibert, and H. Kurz, Phys. Rev. B **37**, 4155 (1988).
[7]M. K. Lee, T. H. Chiu, A. Dayem, and E. Agyekum, Appl. Phys. Lett. **53**, 2653 (1988).
[8]M. Mihara, Y. Nomura, M. Maunoh, K. Yamauaka, S. Naritsuka, K. Shiuozaki, T. Yuasi, and M. Ishii, J. Appl. Phys. **55**, 3760 (1984).
[9]R. A. Puechuer, D. A. Johuson, and G. N. Maracas, Appl. Phys. Lett. **53**, 1952 (1988).
[10]M. J. Lin, E. C. Larkins, Y. C. Pao, D. Liu, G. Yoffe, T. K. Ma, and J. S. Harris, J. Vac. Sci. Technol. B **6**, 631 (1988).
[11]M. J. Joyce, M. Gal, and J. Tann, J. Appl. Phys. **65**, 1377 (1989).
[12]T. Hayakawa, T. Suyama, M. Kondo, K. Takahashi, S. Yamamoto, S. Yano, and T. Hijikata, J. Appl. Phys. **58**, 4452 (1985).

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