Materials Science in Semiconductor Processing 12 (2009) 156–160

Contents lists available at ScienceDirect

Materials Science in Semiconductor Processing

journal homepage: www.elsevier.com/locate/mssp

# A study of two-step growth and properties of $In_{0.82}Ga_{0.18}As$ on InP

Tiemin Zhang [a,*], Guoqing Miao [b], Yixin Jin [b], Shuzhen Yu [b], Hong Jiang [b], Zhiming Li [a], Hang Song [a]

[a] *College of Physics and Electronic Engineering, HaiNan Normal University, Haikou 571158, China*
[b] *Key Laboratory of Excited State Processes, Changchun Institute of Optics, Fine Mechanics and Physics, The Chinese Academy of Sciences, Changchun 130033, China*

ARTICLE INFO

*Keywords:*
InGaAs
MOCVD
Growth temperature

ABSTRACT

$In_{0.82}Ga_{0.18}As$ was grown by LP-MOCVD on InP substrates with the two-step growth technique. It was analyzed that epilayer's growth temperature affected on the crystalline quality, surface morphology, carrier concentration, and mobility of the $In_{0.82}Ga_{0.18}As$, which was characterized by X-ray diffraction, scanning electron microscopy, and Hall measurements. The evaluation of stress in $In_{0.82}Ga_{0.18}As$ was made from frequency shift of the GaAs-like LO phonon of the Raman spectrum.

## 1. Introduction

$In_xGa_{1-x}As$ material is very important for light emitters, field-effect transistors, thermophotovoltaic devices, detectors [1–4], etc. In recent years, there is a great need for 1–3 μm infrared detectors, and the most important applications are space imaging (including Earth observation, remote sensing, environmental monitoring, etc. [5]) and spectroscopy. The goal of growing $In_{0.82}Ga_{0.18}As$ is the extension of the response wavelength of the InGaAs infrared detectors. However, the large mismatch between epilayer and substrate results in poor material quality. In order to overcome this limitation, many schemes [6–8] have been developed. The two-step growth technique has often been adopted in growing highly mismatched heteroepitaxy layers, in which the low-temperature growth of thin buffer layer is followed by annealing and then growth of thick epilayer at higher temperatures [9]. Two-step growth techniques of SiGe, AlGaN, InAs, and GaN [10–13] have been reported. In the two-step growth method, the buffer layer is an important issue and an actively investigated subject. The effects of In content of the buffer layer [14] and buffer growth temperature [15] on $In_{0.82}Ga_{0.18}As$ with the two-step growth methods have been reported. However, the effect of epilayer's growth temperature on $In_{0.82}Ga_{0.18}As$ with this growth technique is rarely studied. Because growth temperature is one of the important condition for preparation material, the study of epilayer's growth temperature is essential, and it is a useful help to design for the large lattice mismatch of InGaAs on InP. In this paper, we report on the effect of the epilayer's growth temperature on the properties of $In_{0.82}Ga_{0.18}As$. X-ray diffraction (XRD), scanning electron microscopy (SEM), Hall measurements, and Raman scattering are used to characterize the properties of $In_{0.82}Ga_{0.18}As$.

## 2. Experiment

All samples were grown on semi-insulating (1 0 0) InP substrates by low-pressure metalorganic chemical vapor deposition (LP-MOCVD). The growth was performed using trimethylindium (TMI), trimethylgallium (TMG), and 10% arsine ($AsH_3$) in $H_2$ as precursors. Palladium-diffused hydrogen was used for carrier gas. The substrates on a

---

[*] Corresponding author. Tel.: +86 898 65882863; fax: +86 898 65882863.
*E-mail address:* zhangtiemin@sohu.com (T. Zhang).

1369-8001/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.mssp.2009.09.009

graphite susceptor were heated by inductively coupling radio-frequency power. Temperature was detected by a thermocouple, and the reactor pressure was kept at 10000 Pa. The $In_{0.82}Ga_{0.18}As$ buffer growth temperature of all samples was at 450 °C, and thickness was fixed 100 nm. However, the epilayer's growth temperature was selected from 490 to 550 °C, thickness was fixed at 0.8 μm, and samples were named A, B, C, and D. Since the In–As bond energy is less than that of Ga–As [16], it is difficult to grow the $In_xGa_{1-x}As$ layer with high In content at high temperature. In the experiments, the flux of TMG was fixed; the flux of TMI was increased with increase in epilayer's growth temperature, and In content of samples was always kept around $x$=0.82. After InGaAs buffer deposition, annealing took place during the temperature ramping from 450 °C to the epilayer's growth temperature at a rate of 25 °C/min in $AsH_3$ ambience. Then TMI and TMG were switched for the growth of InGaAs epilayer. The alloy composition was estimated from X-ray diffraction peak position using Vegard's law [17]. Thickness of samples was measured with SEM. Crystalline quality of $In_{0.82}Ga_{0.18}As$ was characterized by XRD. Surface morphology was observed with SEM. Carrier concentration and mobility were measured using van der Pauw technique at room temperature. Stress in $In_{0.82}Ga_{0.18}As$ was studied by Raman scattering. The Raman measurements were performed at room temperature in backscattering geometry, in which the 514 nm line of an $Ar^+$ laser was used for the exciting light and the incident light on samples was kept to the same intensity.

## 3. Result and discussion

$In_{0.82}Ga_{0.18}As$ results in a lattice mismatch $\Delta a/a = 2.0 \times 10^{-2}$ with InP. In order to reduce the effects of mismatch on properties of material, many schemes [18–20] have been developed. D'Hondt et al. [19] have reported the 2 μm thick $In_{0.82}Ga_{0.18}As$ films grown on different buffer layer. In their studies, the X-ray FWHM value was 1217 s for the linear compositional graded InGaAs buffer, and it was 1356 s for the step compositional graded InGaAs buffer. However, the buffer layer in the two-step growth technique is different from the linear or step compositional graded buffer layer (i.e. quite thick layer, and the In content gradually coincide with its substrates of its epilayers). The growth technique is employed to accommodate the mismatch dislocation in thin buffer layer. Comparing with an InGaAs grown on a buffer consisting of a graded layer and superlattice [20], its structure is very simple in the two-step growth technique.

The results of XRD measurements are shown in Fig. 1. For sample A, in which the epilayer's growth temperature is 490 °C, its full-width at half-maximum (FWHM) of the XRD is 1915 s. However, the FWHM is 1685 s when the epilayer's growth temperature is at 510 °C. It indicates that the crystalline quality of the sample B is improved. When the epilayer's growth temperature is at 530 °C, the FWHM reaches a minimum of 1303 s. But for the epilayer's growth temperature of 550 °C, its FWHM is 1991 s. This value is wider than that of the sample C, which means that

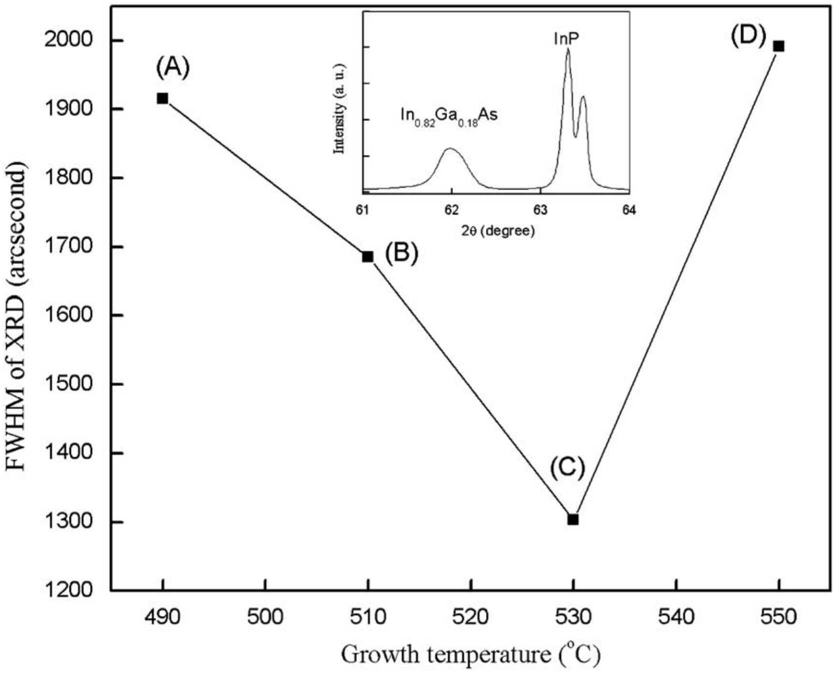

**Fig. 1.** Dependence of the FWHM of the X-ray diffraction of $In_{0.82}Ga_{0.18}As$ on epilayer's growth temperature. The inset shows the X-ray diffraction of the sample C.

the crystalline quality of sample D is degraded. In our experiments the growth conditions such as thickness, In content, and pressure are fixed but the epilayer's growth temperature is varied. It means that the changes of the FWHM of the XRD of $In_{0.82}Ga_{0.18}As$ are related to the epilayer's growth temperature. The selection of epilayer's growth temperature can improve the crystalline quality of $In_{0.82}Ga_{0.18}As$.

Figs. 2(A)–(D) show surface morphology of sample A, B, C, and D. It is evident that surfaces of the four samples do not appear as three-dimensional (3D) islands, indicating that $In_{0.82}Ga_{0.18}As$ is in the growth mode of the two-dimensional (2D) characteristic. However, sample C, when the epilayer's growth temperature is at 530 °C, shows that its surface morphology is better than those of samples A, B, and D. The dramatic improvement of its surface morphology indicates that the epilayer's growth temperature is optimized. It is well-known that the surface-diffusion kinetics plays an important role in the transition from 2D to 3D growth [21]. When the growth temperature of epilayer is less than the optimum temperature, such as 490 °C, the surface atom migration is significantly restricted. Therefore, large-density cross-hatched patterns appear in epilayer, which means that it

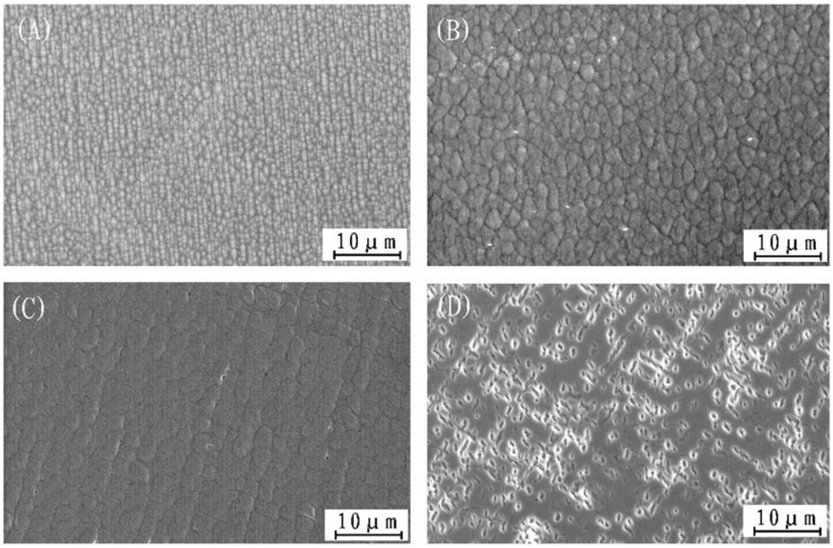

**Fig. 2.** SEM images of $In_{0.82}Ga_{0.18}As$ on InP with epilayer's growth temperature at (A) 490 °C, (B) 510 °C, (C) 530 °C, and (D) 550 °C.

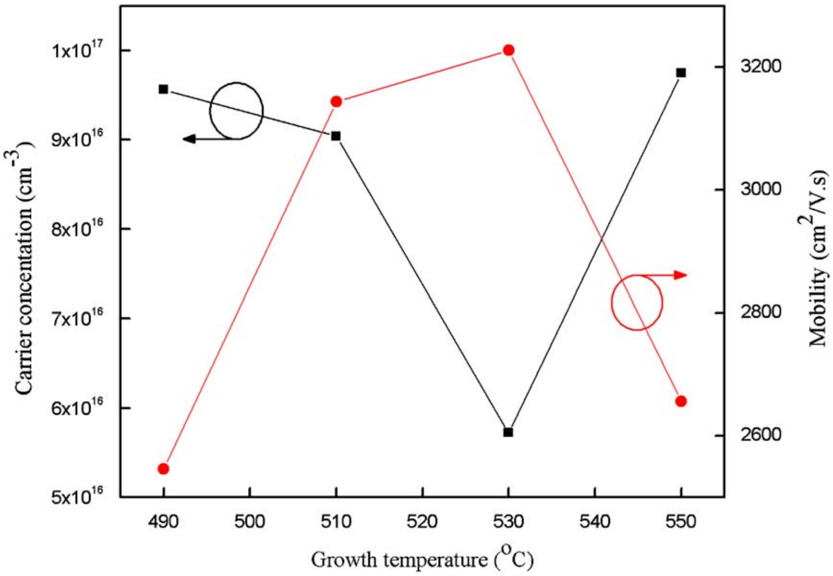

**Fig. 3.** Dependence of carrier concentration and mobility for $In_{0.82}Ga_{0.18}As$ on different epilayer's growth temperatures.

cannot obtain good surface morphology at a low epilayer's growth temperature. However, the surface morphology is improved with increase in growth temperature from 490 to 530 °C. When temperature is higher than the optimum temperature, such as 550 °C, many pits appear in epilayer, which means that the surface morphology of sample D is degraded. It might be caused by 3D growth enhancement when $x$=0.82 in $In_xGa_{1-x}As$ epilayer at 550 °C and buffer layer is not enough to accumulate these defects. It indicates that it is not beneficial to grow high In content of $In_xGa_{1-x}As$ at higher temperature with the two-step growth technique.

The results of Hall measurements are shown in Fig. 3. The carrier concentration of samples changes with increase in growth temperature of epilayer from 490 to 550 °C, and it reaches the lowest value at 530 °C. On the other hand, mobility of samples increases from 2546 to 3228 $cm^2/V\,s$ with epilayer's growth temperature from 490 to 530 °C, and it decreases from 3228 to 2656 $cm^2/V\,s$ with epilayer's growth temperature from 530 to 550 °C. It is obvious that changes of carrier concentration and mobility of the samples are related to epilayer's growth temperature. From the above results on XRD and SEM, it is known that the better the crystalline quality, the higher the mobility of the material and the lower the carrier concentration of the material. This is because some defects in material will serve as scattering centers for the carrier and limit the mobility.

Raman scattering [22] is an indirect way to characterize the crystalline quality of material. Fig. 4 shows Raman spectra of the four samples. There are two Raman peaks in each spectrum, which are at around 234 and 252 $cm^{-1}$, corresponding to LO-phonon modes of InAs and GaAs, respectively. The inset of Fig. 4 shows that Raman frequency shift ($\Delta\Omega$) of GaAs-like LO of samples decreases from 3.12 to 1.08 $cm^{-1}$ with epilayer's growth temperature from 490 to 530 °C and then increases from 1.08 to 5.90 $cm^{-1}$ with epilayer's growth temperature from 530 to 550 °C. The stress in $In_{0.82}Ga_{0.18}As$ can be calculated from a frequency shift of the GaAs-like LO phonon. Since the compressive stress shifts the phonon to high energy [23], the GaAs-like LO-phonon frequency of samples should have frequency shift. Following the formulas and definition [24], using measured result $\Delta\Omega_{LO}$, it can obtain the stress in InGaAs. For sample C, its $\Delta\Omega_{LO}$ reaches a minimum, and its stress in InGaAs is also a minimum. This indicates that the optimum growth temperature of epilayer is at 530 °C.

## 4. Conclusions

In summary, $In_{0.82}Ga_{0.18}As$ has been grown using $In_{0.82}Ga_{0.18}As$ buffer layer on InP substrate with the two-step growth technique. In order to investigate effect of epilayer's temperature on $In_{0.82}Ga_{0.18}As$, several epilayer's growth temperatures are selected. The results of experiments show that the crystalline quality, surface morphology, carrier concentration and mobility, and stress could be improved by employing an appropriate epilayer's growth temperature. When the epilayer's temperature of

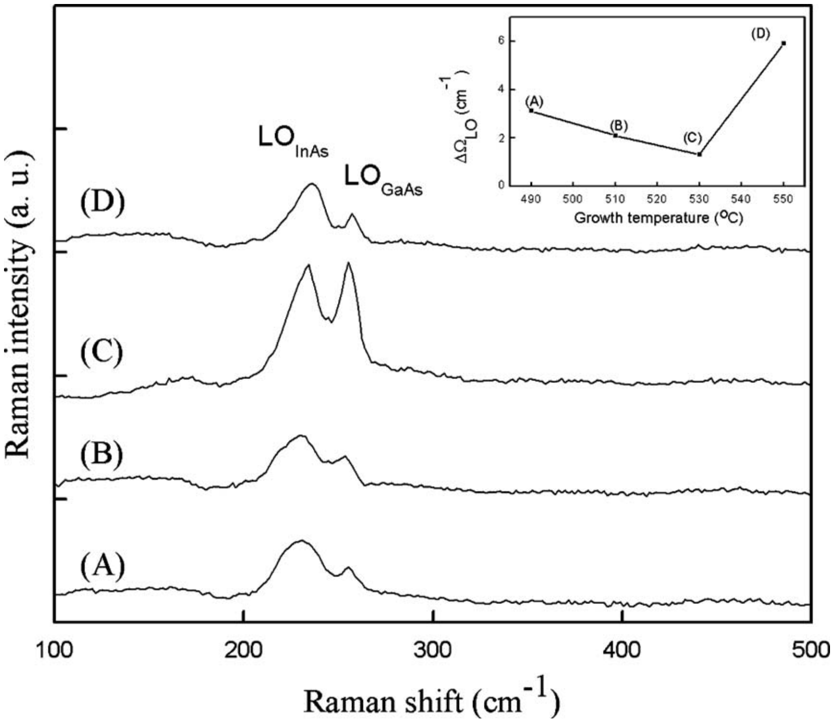

**Fig. 4.** Raman spectra of the samples with epilayer's growth temperature at (A) 490 °C, (B) 510 °C, (C) 530 °C, and (D) 550 °C. The inset shows the dependence of the $\Delta\Omega_{LO}$ of GaAs-like on epilayer's growth temperature.

a sample was at 530 °C its FWHM of XRD was 1303 s, stress reached a minimum, carrier concentration was $5.72\times10^{16}\,\mathrm{cm}^{-3}$, and mobility was $3228\,\mathrm{cm}^2/\mathrm{V\,s}$.

## Acknowledgements

This work is supported by the Projects of National Natural Science Foundation of China under Grant no. 50632060 and Science Research Item of Doctor of HaiNan Normal University.

## References

[1] Nagai H, Noguchi Y. Appl Phys Lett 1976;29:740.
[2] Bandy S, Nishimoto C, Hyder S, Hooper C. Appl Phys Lett 1981;38:817.
[3] Murray SL, Newman FD, Murray CS, Wilt DM, Wanlass MW, Ahrenkiel P, et al. Semicond Sci Tech 2003;18:s202.
[4] Bachmann KJ, Shay JL. Appl Phys Lett 1978;32:446.
[5] Hoogeveen RWM, van der A RJ, Goede APH. Infrared Phys Technol. 2001;42:1.
[6] S. Durel, J. Caulet, M. Gauneau, B. Lambert, A. Le Corre, A. Poudoulec, et al, Second international conference on indium phosphide and related materials. 1990, p. 139–43.
[7] Chai YG, Chow R. J Appl Phys 1982;53:1229.
[8] Wada M, Hosomatsu H. Appl Phys Lett 1994;64:1265.
[9] Ko HJ, Chen YF, Ko JM, Hanada T, Zhu Z, Fukuda T, et al. J Cryst Growth 1999;207:87.
[10] Chen H, Guo LW, Cui Q, Hu Q, Huang Q, Zhou JM. J Appl Phys 1996;79:1167.
[11] Shih CF, Chen NC, Lin SY, Liu KS. Appl Phys Lett 2005;86:211103_1.
[12] Yuan H-R, Chua S-J, Miao Z-L, Dong J, Wang Y. J Cryst Growth 2004;273:63.
[13] Akasaki I. J Cryst Growth 2002;237–239:905.
[14] Zhang T, Miao G, Jin Y, Xie J, Jiang H, Li Z, et al. Microelectron J 2007;38:398.
[15] Zhang T, Miao G, Jin Y, Jiang H, Li Z, Song H. Compd 2008;458:363.
[16] Chang S-Z, Chang T-C, Lee S-C. J Appl Phys 1993;73:4916.
[17] Gao W, Berger PR, Ervin MH, Pamulapati J, Lareau RT, Schauer S. J Appl Phys 1996;80:7094.
[18] Wang SM, Karlsson C, Rorsman N, Bergh M, Olsson E, Andersson TG, et al. J Cryst Growth 1997;175/176:1016.
[19] D'Hondt M, Moerman I, Van Daele P, Demeester P. IEE Proc Optoelectron 1997;144:277.
[20] di Forte-Poisson MA, Brylinski C, di Persio J, Hugon X, Vilotitch B, Noble CLe. J Cryst Growth 2006;124:782.
[21] Snyder CW, Mansfield JF, Orr BG. Phys Rev B 1992;46:9551.
[22] Xiu F, Yang Z, Zhao D, Liu J, Alim KA, Balandin AA, et al. J Cryst Growth 2006;286:61.
[23] Burns Gerald, Wie CR, Dacol FH, Pettit GD, Woodall JM. Appl Phys Lett 1987;51:1919.
[24] Jusserand B, Voisin P, Voos M, Chang LL, Mendez EE, Esaki L. Appl Phys Lett 1985;46:678.