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Effect of In content of the buffer layer on crystalline quality and electrical property of $In_{0.82}Ga_{0.18}As/InP$ grown by LP-MOCVD

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Abstract

The $In_{0.82}Ga_{0.18}As$ grown on InP (1 0 0) substrates by low pressure metalorganic chemical vapor deposition (LP-MOCVD) with two-step growth method was investigated. It was analyzed that the effect of In content of buffer layer on the crystalline quality and electrical property of the $In_{0.82}Ga_{0.18}As$ eplialyers, which were characterized by X-ray diffraction, scanning electron microscopy, and Hall effect. The experiments show that the crystalline quality and the electrical property of the $In_{0.82}Ga_{0.18}As$ eplialyers have close relation to the In content of buffer layer and will be optimum when the In content of buffer layer is same as that of the epilayer.

Keywords: $In_{0.82}Ga_{0.18}As$; Buffer layer; MOCVD

1. Introduction

The $In_xGa_{1-x}As$ material is very important for uncooled infrared detector of near-infrared region. They may replace the commercially available cadmium mercury telluride detectors. In recent years, there are growing needs for high In composition $In_xGa_{1-x}As$ ($x > 0.53$) detectors, the most important applications are aerospace imaging including earth observation, remote sensing and environmental monitoring, etc. [1] and spectroscopy. One of the goals of growing $In_{0.82}Ga_{0.18}As$ materials is the extension of the response wavelength of the InGaAs infrared detector. The lattice and thermal mismatches are the primary challenges to heteroepitaxy. In order to overcome this limitation, many schemes have been developed. Buffer layer is the most widespread technique used in the heteroepitaxy [2–6]. Two-step growth method has often been adopted in growing extremely highly mismatched heteroepitaxy layers, in which low-temperature growth of thin buffer layers is followed by annealing and growth of thick epilayers at higher temperatures [7]. The low-temperature deposited buffer layer is believed to act as a template for succeeding high-temperature grown epilayers and to accommodate lattice strain caused by both lattice mismatch and thermal one. In the two-step growth method, the buffer layer is an important issue and an actively investigated subject. Two-step growth methods of SiGe [8], AlGaN [9], GaN [10], and InAs [11] have been reported, but there are few reports on the effect of buffer layer In content on $In_{0.82}Ga_{0.18}As$ materials with two-step growth method. The crystalline quality and electrical property are essential for semiconductor material, which decide the device performance. In this paper, we report low pressure metalorganic chemical vapor deposition (LP-MOCVD) growth of the $In_{0.82}Ga_{0.18}As/InP$ with the two-step growth method, and the effect of In content of buffer layer on the crystalline quality and electrical property of $In_{0.82}Ga_{0.18}As$. The X-ray diffraction (XRD), scanning electron microscopy (SEM), and Hall effect are used to evaluate the quality of materials.

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2. Experiment

All the samples were grown on semi-insulating (1 0 0) Fe-doped InP substrates by LP-MOCVD. The growth was performed using trimethylindium (TMIn), trimethylgallium (TMGa), 10% arsine (AsH_3) in H_2 as precursors and palladium-diffused hydrogen was used as carrier gas. The substrates on a graphite susceptor were heated by inductively coupling RF power, their temperatures were detected by a thermocouple, and the reactor pressure was kept at 10 000 Pa. At first, $In_xGa_{1-x}As$ buffer layer of 300 nm was deposited on InP substrates at 450 °C, then followed by the deposition of the $In_{0.82}Ga_{0.18}As$ epilayer of 1 μm at 530 °C. The growth rate of buffer layer and epilayers was kept 0.6 and 0.8 μm/h, respectively. In our experiment, the buffer layer's In content of 0.28, 0.53, 0.82, and 0.88 was selected and referred to as sample A, B, C, and D, respectively. The crystalline quality of the $In_{0.82}Ga_{0.18}As$ was characterized by XRD and SEM. The standard Hall measurements were performed to determine the electrical properties of the $In_{0.82}Ga_{0.18}As$.

3. Result and discussion

The $In_{0.82}Ga_{0.18}As$ epilayers grown on the buffer layer with different In content were investigated by XRD. The alloy composition was estimated from XRD peak position of the alloy using Vegard's law [12]. The results of XRD measurements are shown in Fig. 1. For the In content of buffer layer $x = 0.28$, it can be found that FWHM of the epilayers is 2146 s and the widest among the four samples. It shows that sample A is the poorest crystalline quality. FWHM is 1685 s when the In content of buffer layer is 0.53. It indicates that the crystalline quality of the sample B is improved. When the In content of buffer layer is 0.82, FWHM reaches a minimum of 1303 s. However, for the buffer In content of 0.88, FWHM is 1408 s and wider than that of sample C, that means the crystalline quality of sample D is degraded. In our experiments, the growth conditions, such as thickness, V/III ratio, growth temperature, and pressure are fixed, but only the In content of buffer layer is different. It is reasonable to speculate that the change of the FWHM of the XRD of $In_{0.82}Ga_{0.18}As$ epilayer is related to the In content of buffer layer. The selection of appropriate In content of buffer layer can improve the crystalline quality of $In_{0.82}Ga_{0.18}As$ epilayer. D'Hondt et al. [13] have reported the $In_{0.82}Ga_{0.18}As$ 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. The buffer layer in two-step growth method is different from the linear or step compositional graded buffer layer [that is quite thick layer, and the In content gradually gets coincidence from its substrates to its epilayers].

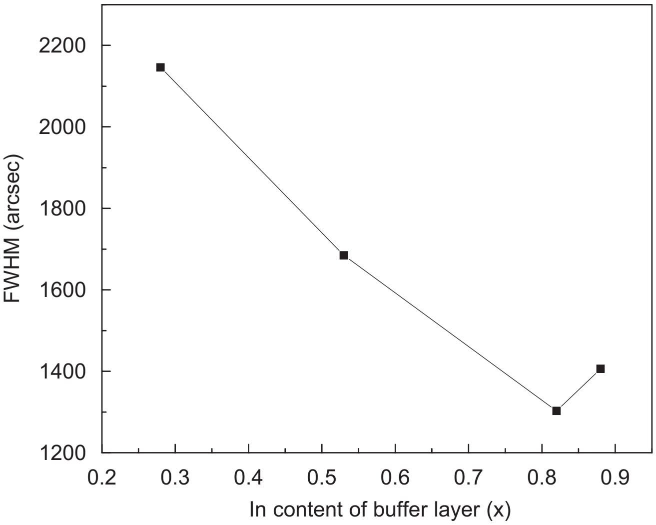

Fig. 1. The dependence of FWHM of the X-ray diffraction of the epilayers on In content of the buffer layer.

SEM is used to study the surface morphology. Figs. 2(a)–(d) show the surface morphology of $In_{0.82}Ga_{0.18}As$ epilayers grown on $In_xGa_{1-x}As/InP$ with $x = 0.28$, 0.53, 0.82, and 0.88, respectively. For $x = 0.28$ (Fig. 2(a)), the surface with the cross-hatched patterns appears. There is a large positive lattice mismatch between epilayer and buffer layer, so the relaxation of strain generates cross-hatched patterns. For $x = 0.53$ (Fig. 2(b)), the cross-hatched patterns disappear, but the pits appear, where a positive lattice mismatch between epilayers and buffer layer is in existence, but the degree of mismatching is decreased. For $x = 0.82$ (Fig. 2(c)), both the cross-hatched patterns and the pits disappear, the surface morphology is improved further. But the surface with some cracks can be observed, it might be caused by the existence of stress. It seems that the stress can be reduce or eliminate through some growth technology, that will be discussed in the future paper. For $x = 0.88$ (Fig. 2(d)), the surface morphology is similar to that of $x = 0.82$, but a rough surface is developed. This indicates that 3D growth mode takes place when $x > 0.82$. At this time, there is a negative lattice mismatch between epilayers and buffer layer. The SEM images of samples show that the surface morphology is improved when In content of the buffer layer is same as that of the epilayer.

The electrical property is measured using the Hall effect. The results are shown in Fig. 3. The carrier concentration of samples decreases from 1.53×10^{17} to $5.64 \times 10^{16}\,cm^{-3}$ with increasing In content of buffer layer from 0.28 to 0.82, and it increases from 5.64×10^{16} to $7.28 \times 10^{16}\,cm^{-3}$ with increasing In content of buffer layer from 0.82 to 0.88. On the other hand, the mobility of samples increases from 1760 to 4046 $cm^2/V\,s$ with increasing the buffer layer's In content from 0.28 to 0.82, and it decreases from 4046 to 3050 $cm^2/V\,s$ with the buffer layer In content from 0.82 to 0.88. The change of carrier concentration and mobility of the samples may relate to the mismatching between epilayers and buffer layer. The misfit dislocations caused

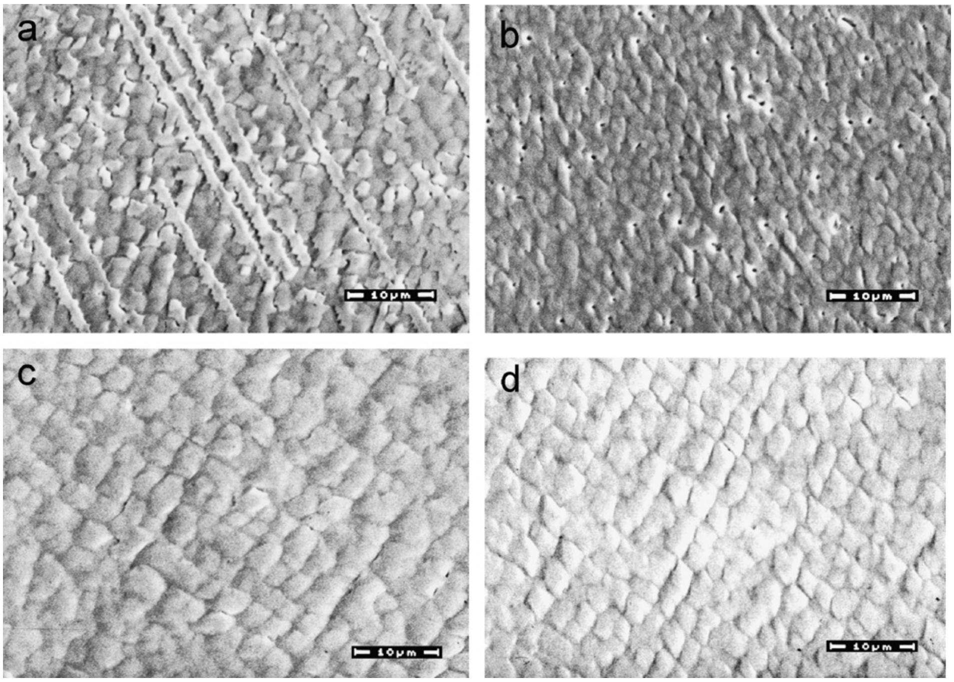

Fig. 2. Surface morphology of $In_{0.82}Ga_{0.18}As$ epilayers grown on $In_xGa_{1-x}As/InP$ substrates for (a) $x = 0.28$, (b) $x = 0.53$, (c) $x = 0.82$, and (d) $x = 0.88$, respectively.

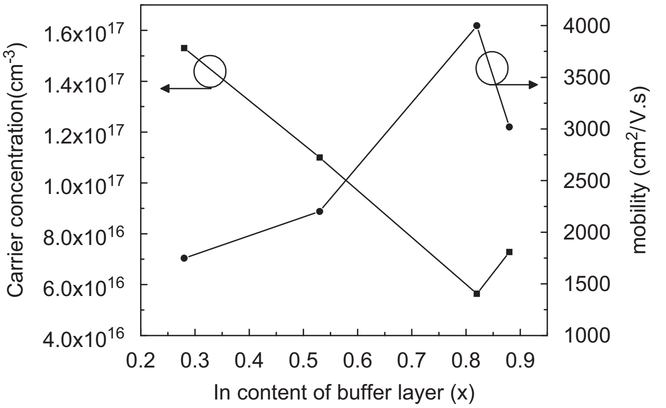

Fig. 3. The dependences of carrier concentration and mobility for $In_{0.82}Ga_{0.18}As$ epilayers on In content of buffer layer.

by a large lattice mismatch will serve as scatting centers for electrons and limit the electron mobility.

4. Conclusions

In summary, in order to investigate the optimum In content of buffer layer, the $In_{0.82}Ga_{0.18}As$ was grown on $In_xGa_{1-x}As$ buffer layer with In content of $x = 0.28$, 0.53, 0.82, and 0.88, respectively. The results from XRD, SEM and Hall measurements show that the crystalline quality and electrical property of the epilayers can be improved by employing an appropriate In content of buffer layer. In particular, the epilayer quality is optimum when the In content of buffer layer is same as that of its epilayer. Our work shows a useful way how to design for the suitable buffer layer in the heteroepitaxy of InGaAs on InP.

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