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Liquid-phase epitaxial growth of InAsPSb/InAs heterostructure

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Abstract

Quaternary InAsPSb epitaxial layers have been directly grown on InAs substrate without buffer layer using both the supercooling and step-cooling liquid-phase epitaxy (LPE) techniques. Some properties of InAsPSb/InAs layers were investigated. The quaternary layer is lattice matched to InAs by about 1.6×10^{-3}. X-ray diffraction spectra half-width maximum of the quaternary epilayer is about 200 s. *I–V* characteristics of the p–n junction formed between p-InAsPSb and n-InAs substrate was measured at 300 and 77 K. The laser emission with wavelength of 3.09 μm was observed at 12 K from the p–n junction of the p-$InAs_{0.82}P_{0.12}Sb_{0.06}$ epilayers and the n-InAs substrate. © 1998 Elsevier Science B.V. All rights reserved.

1. Introduction

In this paper, we describe the characteristics of the InAsPSb layers directly grown by liquid-phase epitaxy and of the p–n junction made between the InAsPSb layers and the InAs substrate. The purpose of this paper is to study the properties of the InAsPSb/InAs system grown using both supercooling and step-cooling liquid-phase epitaxial methods. Laser emission has been observed in the 2–4 μm wavelength region using quaternary InAsPSb double heterostructures [1,2].

InGaAsSb and InAsPSb quaternary alloys are two of the most important semiconductor material among the III–V compounds used for optical sources with wavelength in the range 2–4 μm. The former has several disadvantages: a miscibility gap is present around 2.5 μm, which causes problems for liquid-phase epitaxy, the same alloy cannot be used for confinement layers because the refractive index increases with increasing band gap [3–6]. The latter alloy has none of these drawbacks. There is also a miscibility gap, but at a smaller wavelength, outside the range of interest for emission and the same alloy can simultaneously be used both as active layer and confinement layer. High-quality Zn-doped quaternary InAsPSb epitaxial layers have been directly grown on InAs substrate without buffer layer using both the supercooling and step-cooling liquid-phase epitaxial techniques.

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2. Experiment

InAsPSb alloys were grown by supercooling and step-cooling liquid-phase epitaxy in a conventional horizontal graphite slider boat at a temperature of 530–600°C under a purified H_2 flow. An n-type S-doped (1 0 0)InAs substrate was used. Undoped InP as a P source, undoped InAs as a As source, and Sb were dissolved in In at a temperature of 670°C. Prior to growth, the undersaturated quaternary melt was held on an undoped InAs source wafer for an hour to achieve saturation at a given temperature. The epitaxial layers were grown at a temperature of 530°C. The quaternary epilayers were grown by the supercooling LPE method at a rate of 0.2°C/min, and by the step-cooling method under 5–8°C the saturation level. The surface morphology of epitaxial layers grown in different growth conditions were observed by means of SEM and optical microscope. The lattice-mismatch ratio $\Delta a/a = (a_{\mathrm{InAs}} - a_{\mathrm{Epi}})/a_{\mathrm{InAs}}$ was estimated from (0 0 4) X-ray diffraction pattern of Cu $K_{\alpha 1}$ line and solid compositions were determined by EPMA.

3. Results and discussions

Both methods yielded very smooth epitaxial layer surfaces. It was found that the morphology of InAsPSb epitaxial layers strongly depends upon the supersaturation level and growth temperature. The interface between the InAsPSb epilayer and InAs substrate is very flat. The epitaxial layers were lattice matched to InAs about 1.6×10^{-3}. Fig. 1 shows a SEM photograph of a cross-section of single heterostructure made from quaternary $InAs_{0.82}P_{0.12}Sb_{0.06}$ and InAs substrate. The interface between the InAsPSb epitaxial layer and InAs substrate is very flat, and it is suggested that there was no interface problem.

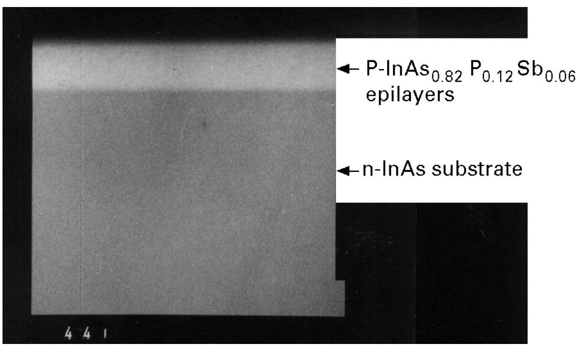

Fig. 1. An SEM photograph of a cross-section of the InAsPSb/InAs SH wafer.

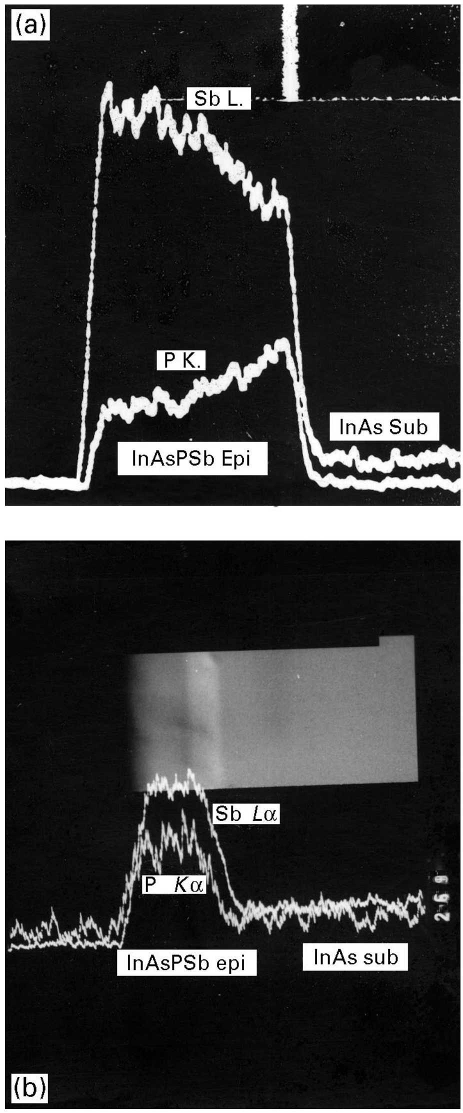

Fig. 2. P and Sb compositional profiles of InAsPSb epilayer: (a) grown by supercooling LPE method; (b) grown by step-cooling LPE method.

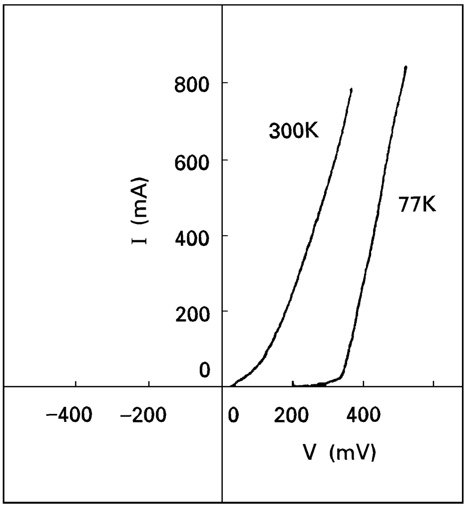

Fig. 3. I–V characteristic of the p–n junction formed between p-InAsPSb and n-InAs Sub at 77 and 300 K.

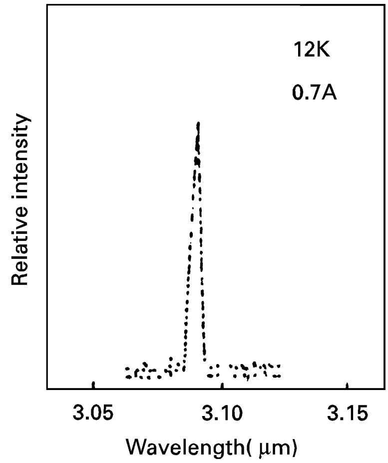

Fig. 4. Typical lasing spectrum of the SH laser excited at pulse at 12 K.

Phosphorus and antimony compositional profile across InAsPSb epitaxial layers grown by the methods mentioned above are shown in Fig. 2. From these results, it can be seen that the phosphorus content has a maximum value at the interface, and decreases gradually along the growth direction [7]. On the contrary, antimony content increases gradually for the epilayer grown by the supercooling LPE method. But both the phosphorus and antimony content have almost a constant value for the epilayer grown by the step-cooling LPE method. This result is in good agreement with that reported by Kobyashi et al. [8]. It can be explained by the distribution coefficient of P and Sb temperature dependence.

The typical I–V characteristics of the p–n junction consists of Zn-doped p-type InAsPSb epilayer and n-type InAs substrate is shown in Fig. 3 at 300 and 77 K, respectively. It is shown that the slope of the I–V relationship depends on the temperature. From these different slopes, we can see that the forward current is mainly due to the generation-recombination mechanism at 300 K and the diffusion mechanism is predominant for temperature 77 K. A $200 \times 350\ \mu m^2$ diode chip was formed. The diodes were driven by current pulses of 10 μs duration at 500Hz–5Hz. The laser emission with wavelength 3.09 μm was observed from single heterojunction made of p-$InAs_{0.82}P_{0.12}Sb_{0.06}$ and n-InAs substrate at 12 K. Typical lasing spectrum of the SH laser at 12 K is shown in Fig. 4. The threshold current of this laser is 0.7 A and the half-width is about 48 Å.

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