Selective Area Growth InGaAsP by MOVPE*

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Abstract: The wide stripe (15μm) selective area growth (SAG) of InGaAsP by low pressure MOVPE is systematically investigated. The characteristics of the growth ratios, thickness enhancement factors, bandgap modulation, and composition modulation vary with the growth conditions such as mask width, growth pressure. Flux of Ⅲ-group precursors are outlined and the rational mechanism behind SAG MOVPE is explained. In addition, the surface spike of the SAG InGaAsP is shown and the course of it is given by the variation of Ⅴ/Ⅲ.

Key words: SAG; MOVPE; InGaAsP; edge spike; Ⅴ/Ⅲ ratio

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1 Introduction

In the future years of the fiber to the home (FTTH), the optical communication networks will be required to offer a huge transmission capacity, and photonic switching will play an important role in such an environment due to the ability to handle over-Gb/s. Besides novel performance, cost reduction is another important issue for these devices. Thus, photonic integrated circuits (PICs) are essential devices for the future fiber transmission systems[1~4]. In PICs, various optical components, such as laser diodes, photodetectors, modulators, semiconductor optical amplifiers, and passive waveguides are monolithically integrated on the same substrate. In general, fabrication of PICs requires various steps of regrowth to realize different bandgap energy regions along the waveguide direction and complicate etching. The increasing demand of PICs has led to the development of advanced growth techniques, among which selective area growth MOVPE is a breakthrough technique which facilitates to restrict growth to laterally defined regions, thereby avoiding complicated etching and regrowth steps. In a multi-quantum well (MQW) layer selectively grown between a pair of mask stripes, the bandgap energy can be modulated by simply changing the width of the masks. Therefore, waveguide layers with different bandgap and thickness can be obtained in one-step growth[5,6].

In this article, selectively grown InGaAsP by MOVPE is systematically investigated, including growth ratios, thickness enhancement factors, bandgap modulation, composition modulation varied with the growth conditions, such as mask width, growth pressure. Flux of Ⅲ-group precursors are outlined and the rational mechanism behind SAG MOVPE is explained. In addition, the surface spike of the SAG InGaAsP is shown and its course is given by the variation of Ⅴ/Ⅲ ratio.

2 Experiment procedure

Selective area growth was performed by low pressure MOVPE. The growth temperature was

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650℃; the pressure was changed from 7 to 13kPa. A SiO_2 dielectric mask was deposited and patterned on the S-doped InP substrates. Trimethylindium (TMI), Trimethylgarium (TMG), phosphine (PH_3), and arsine (ASH_3) were used as precursors. The thickness profile of the selectively grown layer was measured by scan electronic microscope (SEM). The bandgap wavelength was determined by spatial resolved photoluminescence (μ-PL) with a 4μm diameter. The mismatch of the selectively grown layer was measured by X-ray diffraction spectra (XRD).

3 Results and analysis

3.1 Growth ratio and thickness enhancement factors of selectively grown InGaAsP

Figure 1 shows the thickness enhancement factors, which are defined as the ratios of the thickness of selectively grown region to that of the large area region, modulated by the mask widths under various growth pressure. The thickness enhancement factors increase linearly with the increasing of the mask widths, while they decrease with the increasing of the growth pressure with the same mask width.

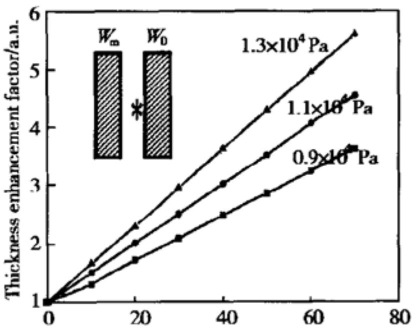

Fig. 1 Mask width dependence of the thickness enhancement factor (ratio of thickness at the center (*) to the mask opening to the thickness in the maskless region) at various growth pressure

The principle mechanism of selective grown MOVPE lies in the lateral vapor phase diffusion the group-Ⅲ precursors[7]. MOVPE can only occur on the surface of the semiconductor. The excess group-Ⅲ precursors above the dielectric masks diffuse to the surface of semiconductor and then the SAG takes places. So the growth ratio in the unmasked region depends largely upon the geometry of the mask. Galeuchet[8] proposed the concept of filling factors, which was defined as the percentage of the unmasked area with respect to the total area, and found that the growth ratio increased with increasing the mask widths. As a result, the thickness enhancement factor increased with the mask width increasing.

According to the results of Fujii *et al*.[9], three parameters dominate the growth ratio distribution: diffusion length on the epilayer, diffusion length on the mask, and the lifetime ratio for the mask and the epilayer regarding desorption and solidification. The lateral diffusion constants defined at mask at the epilayer and the mask surface are found experimentally to be inversely proportional to the growth pressure. So, the thickness enhancement factors decrease with increasing growth pressure.

Figure 2 indicates the TMIn flux dependent thickness enhancement factors and growth ratios. The thickness enhancement factors, i.e. selectivity, increase with the decreasing flux of TMIn, while the growth ratio increases with the increasing flux of TMIn. According to Avishay Katz[10], the MOVPE growth rate of InGaAsP is linearly dependent on the group-Ⅲ partial pressure calculated from the gas flow passed through the source bubble. According to the 2-dimension lateral diffusion model of selective area growth proposed by Gibbon *et al*.[7], the selectivity of SAG can be determined by the effective diffusion factor (D/k). In the case of high group-Ⅲ flux, the value of D/k is small, and the selectivity is small accordingly. On the other hand, when the flux of the group-Ⅲ is lower, the D/k value is large and hence, the selectivity is high, although the absolute growth ratio is low, as indicated in Fig. 2(b).

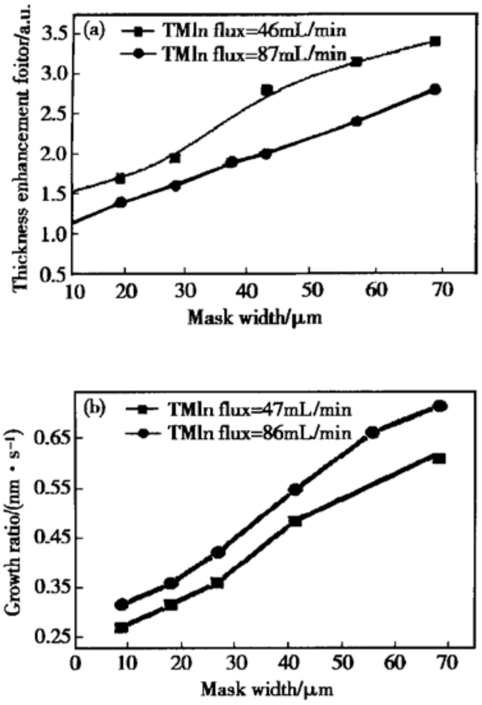

Fig. 2 Group-Ⅲ flux dependent thickness enhancement factors and growth ratios (a) Thickness enhancement factor; (b) Growth ratio

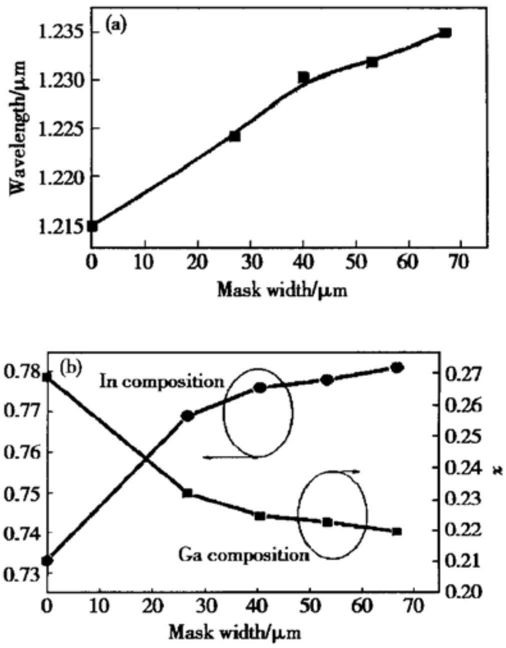

Fig. 3 Modulation of wavelength and group-Ⅲ compositions (a) Modulation of wavelength; (b) Modulation of group-Ⅲ compositions

3.2 Modulation of the bandgap wavelength and the group-Ⅳ compositions

Figure 3 gives the modulation of bandgap wavelength and group-Ⅲ compositions of selectively grown InGaAsP by the mask width. The bandgap wavelength is measured by micro-scope photoluminscence, mismatch between the SAG InGaAsP and the InP substrate is measured by XRD. And the compositions of group-Ⅲ are calculated by Vigard's law[11], assuming the group-Ⅴ compositions can not be modulated by the dielectric mask[12].

The bandgap wavelength of InGaAsP increases with increasing of the mask width, which means the composition of In increased and Ga decreased with the mask width. Selectively grown InGaAsP material reveals In enrichment. This is due to the difference between the D/k of TMIn and TMGa in H_2. In general cases, the parameter D/k of TMIn is larger than that of TMGa, so the TMIn precursor diffuses further than TMGa. Caneau *et al.*[13] referred to the different decomposition temperature of TMI and TMG to explain the larger D/k for TMI and smaller D/k for TMG. It can be found that the half of decomposition temperature in a H_2 ambient for TMI is around 320℃ and approximately 450℃ for TMG. The consequences of the decomposition of the TMI molecule at a lower temperature compared to TMG are twofold: it leads to a greater proportion of decomposed species. It also allows the decomposition of molecules at a greater distance from the mask, where a lower temperature exits than near the mask.

3.3 Investigation of the edge spikes of the selectively grown InGaAsP

Figure 4 reveals the morphologies of selectively grown InGaAsP with different Ⅴ/Ⅲ ratios with various mask widths. As indicated in these figures, the edge spike is more obvious in the SAG InGaAsP with small Ⅴ/Ⅲ ratio of 320 than that of InGaAsP with large Ⅴ/Ⅲ ratio of 390. Many groups[10,14,15] have found the same phenomena. Sugiura *et al.*[14] give a model of dangling surface

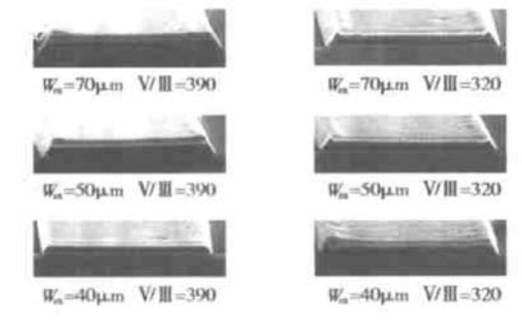

Fig. 4 Morphologies of selectively grown InGaAsP with different V/III ratios with various mask widths

phosphor atoms to explain the facet growth of InP. He assigns a relative dangling bond density per unit area to each substrate orientation, 1.73 for (111) A surface, 1 for (001) surface, and 0.58 for (111) B surface. Group-III reactants will always tend to migrated from plane with lower dangling bong density to plane with higher dangling bond density. This is depicted in Fig. 5 for the situation where the mask stripes are oriented along the

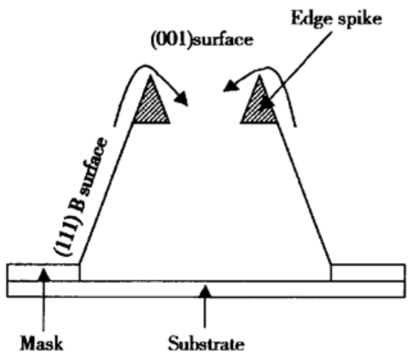

Fig. 5 Schematic of spike

[110] direction, i. e. reversed mesa. If the migration length along the (111) B sidewalls is long enough to exceed the length of the sidewalls, no growth on the (111) B planes will occur. The migration length on the (111) B sidewalls can be controlled by V/III ratio. Kayser[10] pointed out that in the case of lower V/III ratio, the In spices on the (111) B planes with slow growth rate could migrate to the (001) planes with high growth rate, but the migration length is around 2μm and not enough to reach the center of the stripes and form a flat surface. This is the principal mechanism of the edge spike. In the case of high V/III ratio, the migration of In from (111) B planes to (001) planes can be prevented significantly by the high V/III ratio. So it indicates the flat surface of the stripe.

4 Conclusion

The selective area growth of InGaAsP by low pressure MOVPE was systematically investigated in this article. The selectivity increased with the mask widths increasing, or with the growth pressure decreasing. The growth rate increased with the increasing of the flux of group-III precursor, while the selectivity decreased. The selectively grown InGaAsP was In enriched by the influence of mask, and the bandgap wavelength increased due to the lateral diffusion of the group-III precursor. The edge spikes of SAG InGaAsP were obvious with lower V/III ratio, and could be prevent by high V/III ratio.

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利用 MOVPE 选区外延生长 InGaAsP*

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摘要: 研究了利用低压 MOVPE 宽条(15μm)选区外延生长 InGaAsP 的性质.研究了生长速率、厚度增强因子、带隙调制、组分调制随着生长条件如掩模宽度、生长压力、Ⅲ族源流量的变化规律,给出了合理的解释.同时研究了不同Ⅴ/Ⅲ比下选择性生长 InGaAsP 表面尖角的性质.

关键词: 选区外延; MOVPE; InGaAsP; 表面尖角; Ⅴ/Ⅲ比

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