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Multi-Wavelength InGaAsP Lasers Grown by LP-MOCVD Selective Area Growth Technology*

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Abstract　We have investigated the low pressure metalorganic chemical vapor deposition (LP-MOCVD) selective area growth technology. The relationship between the thickness enhancement factor of InGaAsP and the width of SiO_2 mask (W_m) was obtained. When $W_m = 60\mu m$, growth width $W_g = 10\mu m$, the enhancement factor arrived at 2.5. Multi-wavelength InGaAsP multiquantum well (MQW) laser structure was realized in one step of epitaxy by the selective area growth technology. The lasing wavelength varied from 1.45μm to 1.58μm when W_m changed from 0 to 25μm, and $W_g = 15\mu m$.

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1　Introduction

Selective area growth (SAG) is a potential technology for integration of optoelectronic devices. By taking advantage of growth rate enhancement and composition variation resulted from SiO_2 mask in epitaxy, different growth thickness can be realized in one epitaxy step with different mask pattern. In quantum well devices, the well thickness has direct effect on the energy gap of the device. Thus active layer with different energy gap can be grown in one epitaxy. So SAG has been widely used in integration of laser diode with spot-size-converter[1], distributed feedback (DFB) laser diode with electroabsorption modulator[2] and multi-wavelength laser diode array used in wave division multiplex (WDM)[3]. SAG can automatically offer ideal waveguide coupling between different photonic devices, hence it can not only reduce the cost of production but also improve device reliability.

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There have been extensive studies on SAG, but few in our country. In this paper, we report the SAG technology of InGaAsP, and the growth of multi-wavelength InGaAsP multiquantum well (MQW) laser diode in the same epitaxy procedure by this technology.

2 Experiments

To obtain the growth rate under different SiO_2 mask width, we designed the mask pattern as illustrated in Fig. 1. The length of SiO_2 mask pair was 800μm, while the width (W_m) changed from 5μm to 60μm. The width of growth region (W_g) between the pair of mask was 10μm or 15μm. Before the epitaxy, SiO_2 film of 200nm was deposited by PE-CVD on the InP substrate. The mask pattern of Fig. 1 was formed by standard photolithography process. Then a thick layer of InGaAsP layer was grown by MOCVD. SEM was employed to determine the growth thickness at different positions. When growing the laser diode structure, the same mask pattern was used. The thicknesses of well and barrier for MQW (without any mask) were 6nm and 9nm respectively, both of them were lattice matched to the InP substrate. The center part in W_g of 2μm wide was fabricated into buvied heterostructure (BH) stripe laser diode. The energy gap was determined by lasing wavelength of the laser diode. Reverse pn InP junction was used as the current blocking layer. All epitaxy growth was done on AIXTRON-200 LP-MOCVD. The growth temperature was 650°C. The growth rate for InGaAsP was lower than 1.0μm/h.

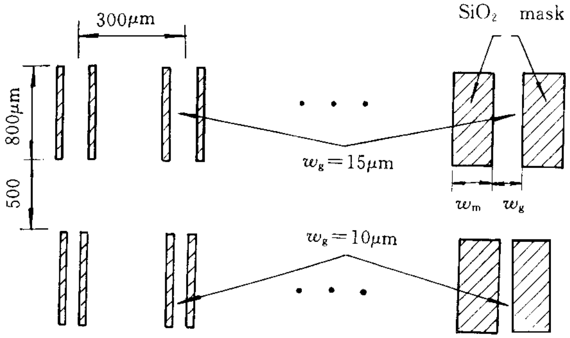

Fig. 1 Schematic diagram of SiO_2 mask for selective area growth.

3 Results and discussions

The dependence of growth rate enhancement factor (defined as the ratio of growth rate with mask pair of W_m to the growth rate without any mask) on W_m is illustrated in Fig. 2. The growth rate enhancement factor shows a linear relationship with W_m and it reaches 2.5 when W_m= 60μm and W_g= 10μm. Growth rate enhancement results from gas phase diffusion of group III species. As is observed in practice, there is no significant deposition of semiconductor on SiO_2 mask. The excess group III species above SiO_2 mask will diffuse to the growth area around the mask. It is well known that the growth rate during MOCVD is determined by the amount of group III species. Thus gas phase diffusion of group III species from SiO_2 mask enhances the growth rate.

Flat epitaxy interface is necessary to obtain high quality MQW active layer and to successfully realize the subsequent technological process such as grating, photolithography and so on. In our former experiments, we found that the excess growth formed high peak around the mask when the growth rate was higher than 2.0μm/h. To obtain flat epitaxy interface, many technologies have been tried, such as: pulse growth technology[6], HCl assisted growth technology.[7] The aim of all these technologies is to reduce growth rate. We found that when the growth rate is lower than 1μm/h, the epitaxy interface keeps flat, as shown in Fig. 3, even when W_m is 60μm.

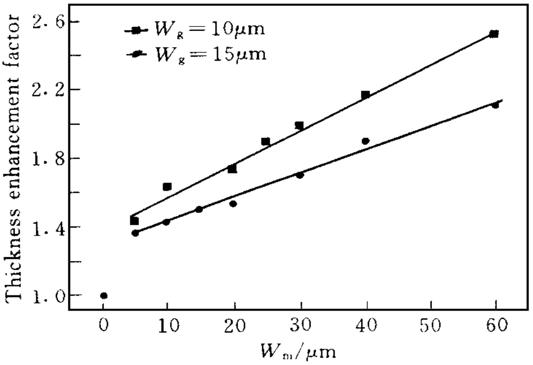

Fig. 2 The dependence of InGaAsP growth rate enhancement factor on W_m, with W_g = 10μm or 15μm.

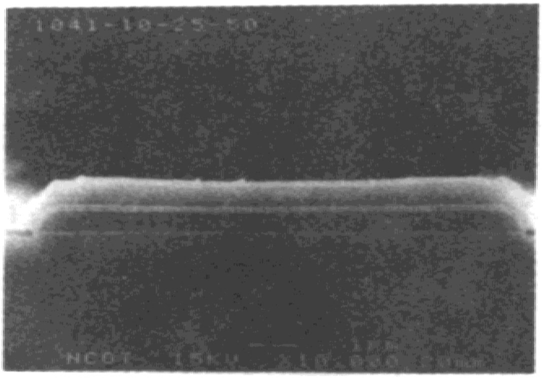

Fig. 3 SEM cross section view after selective area growth, with W_g = 10μm, W_m = 25μm.

Figure 4 shows the dependence of lasing wavelength and slope efficiency (dP/dI) of selectively grown InGaAsP laser diode on W_m. The lasing wavelength without any mask is 1.45μm, while it reaches 1.58μm when W_m = 25μm. The lasing wavelength basically keeps a linear relationship with W_m, and this enables an easy way to obtain the demanded wavelength. The slope efficiency dP/dI decreases gradually as W_m increases. When W_m is larger than 30μm, the laser diode even could not work. This means the wider the mask, the lower the quality of the epitaxy crystal layer. Larger mask width leads to the increase of growth rate and thus to low crystal quality. In addition, Indium and Gallium have different diffusion rates in SAG epitaxy process. It has been reported that the SAG growth region is Indium rich for InGaAs and In-

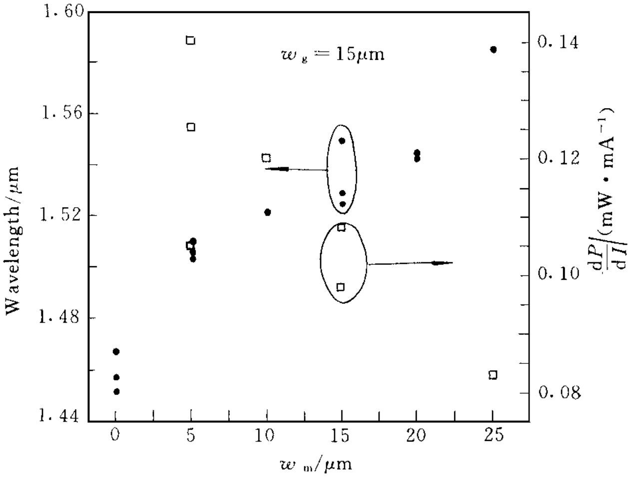

Fig. 4 The dependence of lasing wavelength of MQW InGaAsP laser diode and slope efficiency on W_m, with W_g = 15μm.

GaAsP. So the material changes from lattice-match to compress strained. The larger the mask, the greater the strain, which sometimes reaches several thousandth[4]. The active layer contains dislocations when its thickness exceeds the critical thickness of elastic deformation, which may also lead to the failure of the laser diode.

4 Conclusion

We have discussed the selective area growth (SAG) of InGaAsP by LP-MOCVD. When $W_m = 60\mu m$, $W_g = 10\mu m$, the growth rate enhancement factor reaches 2.5. Multi-wavelength InGaAsP MQW laser structure can be realized in one epitaxy by the SAG technology. The lasing wavelength varies from 1.45μm to 1.58μm when W_m changes from 0 to 25μm, with growth width $W_g = 15\mu m$.

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