Research Paper

A 10-channel Multiple Quantum Well Array Integrated with Selective Area Grown InGaAsP Layers on InP

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Abstract

We present a ten-channel selective area grown multiple quantum well array with a wavelength of 8 nm spacing which can offer the tailored bandgap to each channel for application of monolithically integrated multi-channel devices. Scanning electron microscope images and photoluminescence spectra of the selective area grown layers for all channels are examined and analysed experimentally. We find out that, as a function of opening width, the thickness of selective area grown layers is linearly changed and the photoluminescence peak wavelength of selective area grown multiple quantum well array is varied with a quadratic shape. As a result, it is confirmed that extremely uniform and stable selective area grown layers can be obtained at the opened area between the adjacent mask patterns without significant degradation in spectral quality.

Keywords: Selective area growth, Electro-absorption modulated laser, Multi-wavelength laser, Metal-organic chemical vapor deposition

I. Introduction

The selective area growth (SAG) of III-V compound semiconductors has attracted considerable interest as a powerful tool for monolithically integrated laser diodes such as an electro-absorption modulated laser, a broadband super-luminescent diode, and a multi-wavelength laser array [1-4]. SAG is a growth process on a dielectric mask-patterned semiconductor substrate. Using this technique, the thickness and bandgap can be controlled simply by adjusting the opening width between the mask patterns.

SAG has been widely studied by many groups for different material systems, various growth conditions, and pattern configurations [1-7]. During the SAG process, the epitaxial layer grown on an opened area will undergo a dimensional change caused by the growth-rate enhancement of the group III precursors, as well as a compositional change from the different diffusion characteristics of each precursor, simultaneously. For the SAG layers employing a multiple quantum well (MQW) structure, we previously reported that the photoluminescence (PL) spectrum can be red-shifted by 88 nm for a 1.5- μm QW structure without degradation of the spectral quality [6-8].

In this work, we fabricate a ten-channel SAG MQW array for realizing a ten-channel laser diode array with an 8 nm wavelength grid [3]. The InGaAsP/InP layers are grown on a SiN_x-patterned InP substrate by using a metal-organic chemical vapor deposition (MOCVD) equipment. To examine the physical change of SAG MQW array and evaluate its spectral properties, scanning electron microscope (SEM) images, macro- and micro-PL spectra are analyzed experimentally.

II. Experimental

SAG fabrication: The epitaxial layers were grown using a horizontal type MOCVD. Trimethylindium (TMIn), trimethylgallium (TMGa), PH₃, and 10 % AsH₃ diluted in hydrogen were used as source materials. The configuration of mask pattern structure used for the SAG process was the same as that in the reference of [3]. To realize a ten-channel SAG array with a wavelength interval of 8 nm, the opening width W_o for each array channel was designed to be 165.7- (for ch. 1), 154-, 144-, 135.5-, 128.1-, 121.6-, 115.6-, 110-, 104.5-, and 98.7-nm (for ch.10) with a channel interval of 500 nm and a pattern length of 3 mm. These values were obtained empirically by the calculation taking a SAG characteristics of a dimensional change and a compositional change into account. After the mask-

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Figure 1. SEM images (cross-sectional view) (a) the center and (b) edge of opened area for ch. 10.

patterning, the InGaAsP/InP layers were grown at a temperature of 630 °C and a pressure of 100 mbar. Detailed MQW growth structure for SAG array is as in the following: 7-pair InGaAsP/InGaAsP strained MQW (i.e., 0.6 % compressively strained 6-nm thick wells with a band-gap wavelength of 1.62 μm and 0.45 % tensile-strained 7.5-nm thick barriers of 1.3 μm) with 40-nm thick separate confinement heterostructure layers on both sides of MQW, p-InP clad, InGaAs, and InP cap layer in

Figure 3. Thicknesses at the center and edge for SAG layers with different values W_o . The thickness at the edge is the peak-value.

sequence. After completing the SAG process, the SEM measurements were performed at a center and both edges of the opened area for each channel. Figures 1(a) and 1(b) show cross-sectional SEM images at the center and edge for ch. 10 (i.e., $W_o = 98.7\text{-}\mu\text{m}$), respectively. The SAG layers appear to be extremely uniform and stable at the center for all channels, as shown in Fig. 2, while they become non-uniform with a slight rabbit-ear within the transition length of about 3.5 mm from the boundary of the SiN_x mask. For this result, considering that a minimum opening width (i.e., ch. 10) is about 98 μm in this mask pattern, the uniform SAG array channel of more than 90 μm can be obtained for all channels. To examine the thickness change for each channel quantitatively, we measured them at the center and edge with different values of W_o . As shown in Fig. 3, both thicknesses are increased with the decrease of W_o , and the averaged ratio of edge to center in thickness was about 1.48. The important thing to note here is that the thickness at the center is changed linearly as a function of W_o , and consequently this enables easy-to-control of SAG layers without any change of growth condition.

Figure 2. Cross-sectional SEM images at the center for all channels. The magnification of all pictures was the same.

Figure 4. Normalized macro-PL spectra for 10 channel SAG MQW array. The inset shows micro-PL spectra at room temperature. The dashed line on the inset is a guide for eye about peak position variation.

Figure 5. Macro-PL peak wavelengths for SAG layers with different values of opening width W_o . Peak wavelength obtained from the micro-PL as a function of W_o are denoted by error bars.

III. Results

After the SAG process, room-temperature macro-PL measurements were taken at the centers of the opened areas. Figure 4 shows the normalized PL spectra of ten-channel SAG MQW array. The PL spectra have similar shapes with a full width at half maximum of ~ 35 meV, as well as a significant degradation in optical quality was not observed. As W_o decreases, the peak-wavelength is shifted to a longer wavelength side with a wavelength interval of about 8 nm. It is well known that this red-shift is mainly due to the lowering of the quantum level caused by a growth-rate enhancement and a reduction of the bandgap energy through Indium enrichment. This phenomenon is

also identically shown on micro-PL spectra of the inset in Fig. 4. Figure 5 indicates the variation of the macro-PL peak wavelength for the mask patterns with different W_o values. It shows that, as W_o decreases to 98.7 nm, the peak wavelength is red-shifted with the quadratic shape to 72 nm (± 2 nm). From the comparison of micro-PL peak wavelength displayed by error bars in Fig. 5 with that of macro-PL, mean difference is very small about 0.0375 %. Therefore, it can be concluded that ten-channel SAG MQW array was uniformly grown indeed.

IV. Conclusions

We successfully developed the ten-channel SAG MQW array with an 8 nm wavelength interval using a SAG technique. The measured SEM images and PL spectra show that the extremely uniform and stable SAG layers could be obtained with no significant degradation in spectral quality. It is also confirmed that the SAG-based MQW array with multi-channel wavelength could be simply controlled without any change of growth condition. From these results, we believe that the SAG-based MQW array will be one of the most promising commercially-available methods in realizing the multi-channel laser diode array.

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