Study on Optical Properties and Waveguide Structure Optimization of Semiconductor Lasers with InGaAs Quantum Well

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Abstract. InGaAs quantum wells (QWs) are grown on GaAs substrates by metal-organic chemical vapor deposition (MOCVD). Sample grown on substrates (100) oriented 2° off towards <111> exhibits relatively high photoluminescence (PL) intensity and narrow full-width at half-maximum (FWHM). Increasing growth rate leads to the enhancement of PL intensity and decrease of FWHM. Asymmetric waveguide layers are applied to reduce the confinement factor of base mode and increase the loss of higher-order mode.

1. Introduction
In the application of optoelectronic devices, InGaAs quantum well structure is one of the research hotspots, and it has been widely concerned. However, a large amount of In needs to be incorporated into the InGaAs active layer in the long-wavelength band, and the mismatch between In and GaAs is large, which makes the strain layer form a mismatch dislocation. In general, by studying substrates with off angles, growth rate and other methods, we can inhibit the growth mode from two-dimensional to three-dimensional transformation, and optimize the growth quality of quantum wells [1]. With the development of semiconductor optoelectronic technology, the performance of semiconductor laser has reached a relatively high level. Long-wavelength semiconductor laser has very important applications in civil and military fields, such as fiber communication, laser welding, laser guidance and so on. In these applications, high output power of laser is often needed. At present, in order to improve the output power of semiconductor lasers, the research institutions at home and abroad mostly adopt large cavity structure or super large cavity structure. Although this structure can improve the cavity catastrophic damage (COD) threshold of laser, the excessive thickness of waveguide layer leads to serious carrier leakage and high-order mode generation, which limits the further improvement of device power [2-3]. Use italic for emphasizing a word or phrase. Do not use boldface typing or capital letters except for section headings (cf. remarks on section headings, below). Use a laser printer, not a matrix dot printer.

In this paper, MOCVD is used to study substrate bias angle and growth rate to improve the luminescent properties of quantum well materials. At the same time, the asymmetric waveguide layer is used to optimize the waveguide structure of the semiconductor laser, which reduces the output of high-order mode and improves the output power of the laser.
2. Experiment

1) Substrates with off angles

In epitaxial growth, the substrates with off angles have a great influence on the quality of epitaxial materials. Cheng Tien Wan et al. [4] have grown GaAssb/GaAs quantum wells on GaAs (100) bias <011> 0°, 2°, 6° and 15° substrates. The experimental results show that with the increase of substrates with off angles, the interface between GaAssb and GaAs is steeper, the crystal quality is improved faster, and the luminescent properties are better. In this experiment, we compared the PL spectra of InGaAs / GaAs single quantum wells grown on substrates with GaAs (100) surface deflection <111> 0°, 2°, 4° and 10° and analyzed the influence of substrates with off angles on the luminescence characteristics of the quantum well.

![Figure 1. PL spectra of S1 samples at different offcut angles](image)

As shown in Figure 1, the emission peaks of four groups of samples S1-0°, S1-2°, S1-4°, S1-10° are 0.56mV, 0.63mV, 0.32mV and 0.33mV, respectively. The emission peaks of S1-0° samples are higher than those of S1-2° samples, and the emission peaks of S1-2° samples are twice of S1-4°, while the emission peaks of S1-10° samples are only slightly larger than those of S1-4° samples, still about half of S1-2° samples. The FWHM of the four groups of samples were 38.2nm, 37.6nm, 51.5nm and 65.8nm, respectively, indicating that the FWHM of the samples increased with the increase of substrate deflection angle.

2) Growth rate

The growth rate has an important influence on the growth mode of quantum wells [5]. By optimizing the experimental conditions, the gas ratio of In was set to be 33.71%, and two samples of S2 and S3 were grown. Similar to the first group of experiments, the growth rates of the samples were changed to 1.15 μm / h and 0.95 μm / h respectively. As shown in Figure 2, it is the normal temperature PL of the two samples.

![Figure 2. Normal temperature PL of S2 and S3 samples](image)

It can be seen from Figure 2 that the FWHM of the sample decreases, the luminescence wavelength appears blue shift with the increase of growth rate, and the crystal quality is improved. At this time, the incorporation of In is affected by the growth rate [6].

The results show that increasing the growth rate can increase the luminescent intensity, decrease the FWHM and improve the growth quality. The incorporation of In is decreased with the increase of growth rate.
3) Optimization of waveguide structure of laser

Because the thickness of the quantum well directly affects the COD phenomenon of the device, and then affects the output characteristics. The greater the thickness, the higher the maximum output power. However, when the equivalent quantum well component is fixed, the lasing wavelength increases with the increase of the quantum well thickness. According to Matthews Blakeslee’s critical thickness theory, the thickness of quantum wells cannot be increased indefinitely, otherwise stress release will occur and defects will occur in quantum wells. The thickness of InGaAs quantum well is 7nm, and the In component is about 0.29.

In symmetric waveguide structure, when the thickness of waveguide layer increases to a certain value, the corresponding first-order and second-order modes will appear, and the corresponding transverse mode limiting factors can also be compared with the limiting factors of the basic mode gradually, but the three are gradually reduced with the increase of the thickness of waveguide layer. However, the limiting factors of the second-order mode and the fundamental mode are close. In the actual operation of the device, the threshold currents of the two modes are similar, and there is mode competition between them, which is not conducive to the high power output of the device and the improvement of the beam quality [7-8]. In order to solve this problem, the epitaxial structure of asymmetric waveguide can be used. As shown in Fig. 3, in this structure, the position of the quantum well is no longer in the center of the whole waveguide, but as mentioned before, because the distribution of the optical field is mainly determined by the waveguide layer, the change of the optical field is very small when the thickness of the waveguide layer is unchanged. This causes the quantum well to deviate from the center of the light field, thus changing its limiting factor for a certain mode [9-10].
Set the waveguide thickness to 1.6 μm, we calculated the limiting factors of three modes in symmetric waveguide structure and asymmetric waveguide structure, as shown in the table below:

|                      | Fundamental mode limiting factor ($10^{-2}$) | 1 order mode limiting factor ($10^{-2}$) | 2 order mode limiting factor ($10^{-2}$) |
|----------------------|----------------------------------------------|------------------------------------------|------------------------------------------|
| Symmetrical          | 0.9365                                       | 0.00876                                  | 0.8092                                   |
| waveguide structure  |                                              |                                          |                                          |
| Asymmetric            | 0.8378                                       | 0.3083                                   | 0.1693                                   |
| waveguide structure  |                                              |                                          |                                          |

It can be seen from the data in the table that in the symmetric waveguide structure, the difference between the limiting factors of the basic mode and the second-order mode is very small. In the optimized asymmetric waveguide structure [11], although the limiting factors of the first-order mode increase significantly, their values are still about 2.6 times smaller than the limiting factors of the basic mode. The limiting factor of the second-order module is reduced to about 1/5 of the limiting factor of the basic module. Therefore, in the asymmetric waveguide structure, the loss of the first mode and the second mode will increase, the threshold current will also be greatly increased, and the mode characteristics of the device will be significantly improved.

3. Summary

The InGaAs quantum well structure was grown on GaAs (100) < 111 > substrate by MOCVD. The effects of substrates with off angles and growth rate on the luminescence characteristics of the variable InGaAs quantum well were studied. When the substrate bias angle is small, the PL intensity of the sample is large, and the FWHM is narrow. The incorporation of in decreased with the increase of growth rate, and the wavelength shifted blue. With the increase of growth rate, the luminescent intensity of the sample increases, FWHM decreases, and the growth quality is improved. The results show that the optimized asymmetric waveguide structure can reduce the limiting factor of the fundamental mode and increase the loss of the higher-order mode.
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