Effect of DBR Geometry on Reflectivity and Spectral Linewidth of DBR Lasers *

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Abstract : The linewidths of InGaAs-GaAs-AlGaAs DBR lasers with varied DBR dimensional parameters are measured and analyzed. These lasers were built with different DBR grating lengths and depths in order to explore the effect of the size of the DBR on its coupling coefficient and reflectivity ,and hence on the linewidth of the laser diodes. The linewidths were measured by employing a self heterodyne linewidth measurement system. The experimental and calculated data for DBR reflectivity and spectral linewidth are given. The relationship between these data and the dimensions of the DBR is analyzed. Based on this analysis ,the effect of the DBR geometry on the linewidth of the lasers is explored. The results give useful information related to the design and fabrication of such DBR lasers.

Key words : linewidth ; distributed Bragg reflector ; InGaAs-GaAs-AlGaAs semiconductor lasers
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1 Introduction

Distributed Bragg reflector (DBR) lasers have very important applications in communications, printing, optical remote sensing, and as building blocks for multiwavelength systems. The DBR structure consists of gratings of alternate media with different refractive indices. This causes multiple wave reflections that add up to generate a strong reflection at specific wavelengths. These wavelengths are determined by the spacing and periodicity of the gratings and the variations in the refraction indices. This structure provides very high reflectivity at a selected wavelength, which translates to lower mirror losses and lower current thresholds. The linewidths of DBR lasers are mainly determined by the DBR reflectivities. The dependence of linewidth of DBR lasers on DBR reflectivities ,and thus on coupling coefficients, has been theoretically analyzed[1~3]. The investigation of the relationship between reflectivity (and linewidth) and the geometrical parameters of DBR, however ,has hardly been touched. In this paper we report the results of controlled measurements of linewidths and reflectivities of first order surface DBR lasers with varied DBR geometrical parameters. These results are applicable to the optimum design and fabrication of such DBR lasers.

2 Theory

According to the configuration of our DBR laser ,we can divide it into four independent sections :

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a lossless mirror, a gain section, a DBR, and another lossless mirror. For a wave incident on a DBR structure that has no gain or incoming light and oscillates at the Bragg frequency, the expression that relates the DBR reflectivity to its coupling coefficient κ can be derived using the method of scattering matrices[4]:

$$R = |r|^2 = \tanh^2(\kappa L) \tag{1}$$

where r is the reflection coefficient of the DBR structure, R is the effective power reflectivity, and L is the reflector length. From the above formula we see that the power reflectivity of the DBR can be obtained from the product κL. Then the static linewidth of the DBR laser can be expressed as[2]

$$\Delta\nu = \frac{1}{4\pi P} W E_{cv} F(1+\alpha^2) \tag{2}$$

where W, E_{cv}, and F are defined by

$$W = \frac{h\nu c}{2\bar{n}L_g}\ln(\sqrt{R_1}\,|r|^{-1})\left\{1+\frac{\sqrt{R_1}}{|r|}\times\frac{1-|r|^2}{1-R_1}\right\}^{-1}$$

$$E_{cv} = n_{sp}\frac{c}{n_0 L_g}\{\alpha_0 L + \ln(\sqrt{R_1}\,|r|^{-1})\}$$

$$F = \left\{1 - \frac{c}{2\bar{n}L_g}\times\frac{1}{2\pi}\left[\mathrm{Im}\left(\frac{d}{df}\ln(\sqrt{R_1}\,r)\right) + \alpha\mathrm{Re}\left(\frac{d}{df}\ln(\sqrt{R_1}\,r)\right)\right]\right\}^{-2}$$

where R_1 is the power reflectivity of the right-hand facet (emitting side), $\bar{n}$ is the group index of the laser material, L_g is the active region length, and α is the linewidth enhancement factor. P is the output power from the R_1 mirror. Physically, W corresponds to the ratio of output power P to the photon number in the laser cavity, while E_{cv} is the spontaneous emission rate into the mode. Since the factor F is the only quantity which differs between the above formula and the corresponding expression for a FP laser, it can be interpreted as the ratio of the linewidth of a DBR laser to that of an equivalent "standard" laser with the same active layer parameters operating at the same internal power and with facet reflectivities given by the moduli of the respective DBR reflection coefficients.

3 Experiment

The DBR laser is designed and fabricated to be an asymmetric cladding laser structure as reported in Ref. [5], consisting of an etched ridge waveguide that is 4μm wide with a contact window that is 2μm wide. The first 500μm of the ridge waveguide makes up the gain section followed by the DBR section. The control samples of the DBRs were fabricated with six different lengths and three depths: 50, 100, 150, 200, 250, 300μm (in length), and 0.1, 0.2, 0.3μm (in depth), respectively. The gain peak of the quantum well structure was designed and verified to be 1.045μm, while the gratings were written with a Bragg period corresponding to emission wavelengths of 1.045, 1.050, and 1.055μm. For these wavelengths, the corresponding effective refraction indices are 3.316911, 3.316067, and 3.315233, respectively.

In the experiment, the value of the coupling coefficient can be derived by measuring the ratio of the output power of both the DBR and the facet end of the laser diode (see Ref. [1]). Then we can get the DBR reflectivity from Eq. (1).

The linewidths of the DBR lasers were measured by using a self heterodyne linewidth measurement system[6]. The principle of this method is shown in Fig. 1. The laser output is divided into two branches. The light through one of the bran-

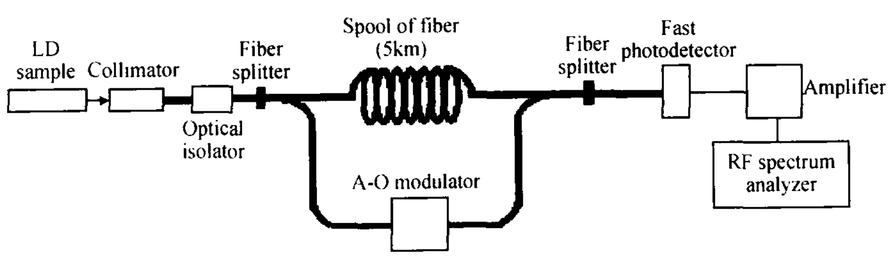

Fig. 1 Schematic of the linewidth measurement setup

ches is delayed by τ_d through a single-mode fiber, and is regarded as the local oscillator power. The light through another branch is frequency-shifted by an RF f_s (80MHz) using an acousto-optic modulator. The beat signals between the modulated and the delayed signals from the laser are mixed on a high-speed photodetector and put into an RF spectrum analyzer. According to the principle of the heterodyne method, the beat waveform measured by the spectrum analyzer will then have twice the spectral width of the original signal[1]. The resolution limit is given as the inverse of the delayed time τ_d[1]. Figure 2 gives an example of the mixer output spectrum.

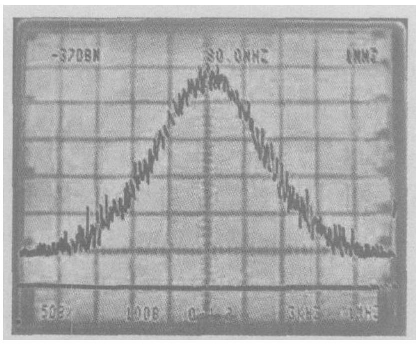

Fig. 2　Example of the mixer output spectrum

4　Results and discussion

The emission wavelengths of the control samples fabricated were intentionally targeted at three nominal values. For some samples with nominal emission wavelengths differing quite largely from the gain peak (that is, the nominal wavelengths being 1.050 and 1.055μm) and with shallow-etched or short gratings (mainly for the 0.1μm deep or for 0.2μm deep but with short DBR), the DBR gratings did not provide enough feedback at the Bragg wavelength, which means that the Fabry-Perot mode may have oscillated, resulting in a passive cavity broadening or multi-mode lasing phenomena. This complicated situation will be discussed elsewhere. In the following, only the data from the samples with a nominal wavelength of 1.045μm (coinciding with the gain peak) are provided. For 0.1μm deep DBR, the emission wavelength was, on average, 1.0475nm (2.5nm longer) with a very narrow spread. For the 0.2μm DBR, the spread around the nominal wavelength was 3nm. For the 0.3μm deep gratings, the emission wavelength was only 1nm longer than the nominal wavelength.

Figure 3 shows the variation of DBR reflectivities with the depths and lengths of the DBR gratings. These data reflect the average of all three targeted wavelengths for all depths and lengths. The reflectivity data include the reflection from the facet at the end of the DBR and the residual reflectivity phase[1]. The average reflectivities are 11.4%, 72.8%, and 84.6% for the 0.1, 0.2, 0.3μm deep DBR structures, respectively. It can be seen that the depth has a much higher impact on the reflectivity of the DBR than the length.

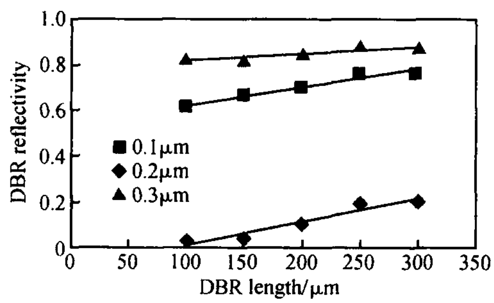

Fig. 3　Variation of DBR reflectivity with respect to the length of the DBR structure for several grating depths

Figure 4 shows the variation of the static linewidths of the DBR lasers with normalized bias currents. All data were derived at 20 ℃ without any modulating. Figure 4(a) shows the linewidth variation for several DBR lengths with the same grating depth, 0.1μm. The range of linewidth variation observed above $1.2I_{th}$ is ~8MHz, while for 0.2 and 0.3μm deep gratings the variation ranges are both below 4MHz (this is not shown in Fig. 4). Comparing these results with Fig. 4(b), we find that this is similar to the reflectivity situation: depth has a much higher impact on the linewidths of the diode lasers than length. This coincides with what we would expect intuitively. In addition, the linewidth distributions over ascending bias current are much smoother for 0.2 and 0.3μm-deep gratings than for 0.1μm deep gratings. On the other hand, the far field characteristic is poorer for deeper gratings than for shallow gratings. According to our observations, the DBR samples with shallow-etched gratings sustain a single mode up to an injection current level of 55mA (~4.7I_{th}), while the samples with 0.3μm-deep and 300μm-long DBR sustain a single mode only up to an injection current level of 15mA (~1.1I_{th}).

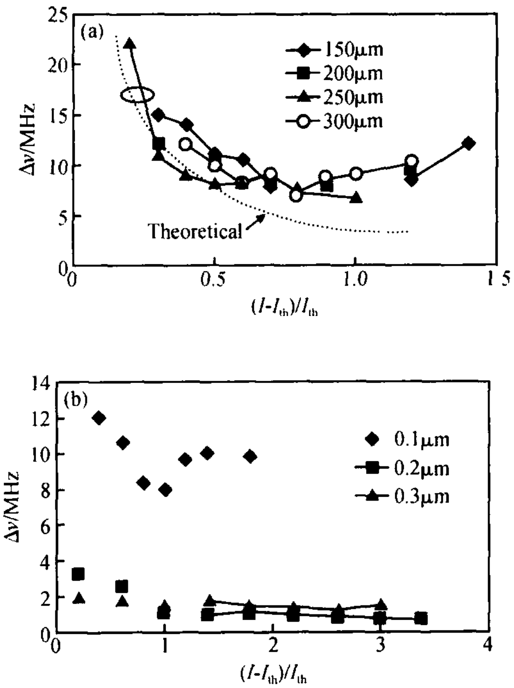

Fig.4 (a) Variation of linewidth with respect to normalized bias current for several lengths of the DBR structures with grating depth of 0.1nm; (b) Variation of linewidth with respect to normalized bias current for several depths of the gratings with DBR length of 200μm

For all three types of the control samples, we also measured the temperature coefficient of wavelength, $\Delta\lambda/\Delta T$, with the temperature ranging from 10 to 70℃. The observed values of $\Delta\lambda/\Delta T$ for these three types of samples were about 0.7~0.9nm/℃. Samples with shallower etching have relatively smaller temperature coefficient. For samples with 0.1μm-deep gratings and a length shorter than 150μm, however, the emitting wavelengths were not able to be measured due to multi-mode or mode-hop phenomena at 1.2I_{th} bias currents and temperatures above 40℃. Thus there is no point in measuring temperature coefficient for samples with too shallowly etched gratings.

From Fig.4, it can be seen that there is apparent linewidth broadening above 1.8I_{th} for 150 and 200μm DBR. We attribute this to the activation of some Fabry-Perot modes for these shallow-etched gratings in this high bias condition. Besides, the linewidths manifest apparent fluctuations along the intermediate current range, which must be caused by the modulation resulting from the reflection off the facet at the end of the DBR and the residual reflectivity phase. A detailed discussion of this will be presented in a forthcoming paper.

From the analysis mentioned above, we conclude that longer and deeper gratings provide more effective feedback at the Bragg wavelength, increasing reflectivity and hence improving linewidth performance of the DBR lasers. On the other hand, this introduces more losses, resulting in higher threshold current and poorer operating conditions, decreasing the beam quality of the laser diode, especially in the large current operating range. It also can be deduced that deeper etching more strongly leads to these two negative effects than longer gratings. Since a main factor of linewidth broadening for this type of DBR laser, as analyzed above, is the residual reflectivity in the facet on the end of the DBR, one possible solution to enhance the affectivity of short (or shallow-etched) DBRs is to coat the end of the laser diode with an antireflective coating to suppress the feedback of the Fabry-Perot modes. This will promote both the improvement of spectral linewidth and the enhanced performance of the diode lasers in a wider operating range.

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DBR几何特性对其反射率和DBR激光器线宽的影响*

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摘要: 对DBR几何参量不同的InGaAs-GaAs-AlGaAs DBR半导体激光器样品的输出线宽进行了测量和分析. 样品激光器DBR光栅取不同的长度和蚀刻深度以考察其几何特性对耦合系数、反射率以及输出线宽的影响. 线宽通过自差频测量系统测量得到. 对实验结果与理论计算结果进行了对比. 对测得的光学特性参数与几何特性参数之间的联系进行了分析. 在此基础上讨论了DBR几何特性对激光器输出线宽的影响. 研究结果为该类型DBR半导体激光器的制造提供了有用的信息.

关键词: 线宽; 分布式布拉格反射器; InGaAs-GaAs-AlGaAs半导体激光器

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