Asymmetric Cladding for Distributed Feedback Lasers at 1.5 μm with High Power and Narrow Linewidth

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Abstract We have prepared a ridge waveguide distributed feedback (DFB) laser emitting at 1.5 μm. To gain maximum output power of the laser, we choose asymmetric cladding layer structure. By simulation, it is found that while the lower cladding is 450 nm, the laser has minimum inner loose coefficient, and first order mode ($m=1$) can has minimum limiting factor. The loose coefficient of prepared tube core is 9.78 cm^{-1}, which matches well with the loose coefficient of simulation 9.3 cm^{-1}. Under the direct current of 600 mA, the maximum power of prepared Fabry-Perot (F-P) cavity laser is greater than 114mW. Under the direct current of 225 mA, the prepared DFB laser with single-wavelength has side-mode suppression ratio of 45dB, output power of 40 mW and spectrum line width smaller than 400 kHz.

Key words lasers; distributed feedback laser; high power; asymmetric cladding

OCIS codes 140.3570; 140.3490; 060.4510

基于非对称波导限制层的高功率窄线宽 1.5 μm 分布反馈激光器

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摘要 报道并制备一种脊波导结构的大功率 1.5 μm 分布反馈(DFB)激光器。为了获取最大的激光器出光功率,采用上下限制层非对称的波导结构。通过模拟仿真发现,当下限制层选择为 450 nm 时,该激光器具有最小的内部损耗系数,同时还能保证一阶模($m=1$)在量子阱区具有最小的限制因子。实际制备的管芯的损耗系数为 9.78 cm^{-1},这与仿真中计算的损耗系数 9.3 cm^{-1} 较为符合。600 mA 直流电流下,制备的法布里-帕罗(F-P)腔激光器最大功率大于 114 mW;255 mA 直流电流下,制备的单波长 DFB 激光器具有 45 dB 的边模抑制比,40 mW 输出功率,和小于 400 kHz 的光谱线宽。

关键词 激光器;分布反馈激光器;高功率;非对称波导盖层

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1 Introdution

High power semiconductor lasers have important applications in analog microwave links for radar systems and free-space laser communication systems. Meanwhile, narrow linewidth characteristics are needed for coherent communication systems[1]. They are also excellent candidates for pumping amplifiers and solid-state lasers[2]. In order to increase the output optical power, the key is to reduce the losses of the

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optical mode. As we know, for 1.5 μm semiconductor laser, the internal losses is mainly derived from the p-doped layers, due to the fact that the free carrier absorption resulted from holes is higher than that from electrons[3]. So reducing the optical overlap between the optical eigenmode and the p-doped layer is an effective method to reduce the internal losses.

By pulling the mode away from the upper p-doped layers so as to reduce the internal losses, asymmetric cladding has been used a lot in the past for high power and narrow linewidth. Using the asymmetric cladding, Price *et al.*[4-5] have worked on distributed Bragg reflector (DBR) lasers for high power and narrow linewidth. Smith obtained lasers emitted at 1010 nm with a slope of 0.3 W/A and 39 kHz spectral linewidth for an output power of 24 mW, whereas Price *et al.* realized a maximum slope efficiency of 0.32 W/A and a minimum linewidth of 30 kHz for a 850 nm DBR laser. Recenetly, Faugeron *et al.*[2] has used an asymmetric cladding to fabricate distributed feedback (DFB) lasers at 1.5 μm. By using a 1.62 μm-thick dilute waveguide as the lower cladding layer including an alternation of thin layers of InP and InGaAsP, impressive results were obtained with a linewidth of less than 500 kHz for 100 mW output power.

The goal of this study is to obtain high power for 1.5 μm lasers using a simple bulk InGaAsP as the asymmetric cladding. In this paper, we present a discussion to design and optimize the asymmetric cladding. The dependences of the internal losses and the overlap with the quantum wells (QWs) (Γ_{QW}) at $m=1$ on the lower-cladding thickness are investigated. Taking into consideration both the lowest internal losses and maintaining the single mode output, asymmetric cladding Fabry-Perot (F-P) lasers are fabricated and the internal loss is calculated. Furthermore, DFB lasers emitting at 1570 nm are fabricated and single-mode output power of 40 mW at 255 mA is obtained for a 1 mm long laser at 25℃. Wavelength tunability of 5.4 nm with 45 dB sidemode suppression ratio is obtained for the temperature ranging from 15℃ to 50℃. Besides, a spectral linewidth of less than 400 kHz is measured.

2 Epilayer structure

Figure 1 shows the schematic of the epitaxial structure of the laser diode, which consists of a 1.8 μm thick n-InP buffer layer, a lower separate confinement heterostructure (SCH) InGaAsP layer, a multiple quantum well (MQW) active region consisting of five 6 nm InGaAsP QWs and six 10 nm InGaAsP barriers, a 120 nm upper SCH InGaAsP layer, a 30 nm i-InP, a 35 nm InGaAsP layer. Above the active part, there is a 1.6 μm p-InP and a 200 nm p^+-InGaAs layer.

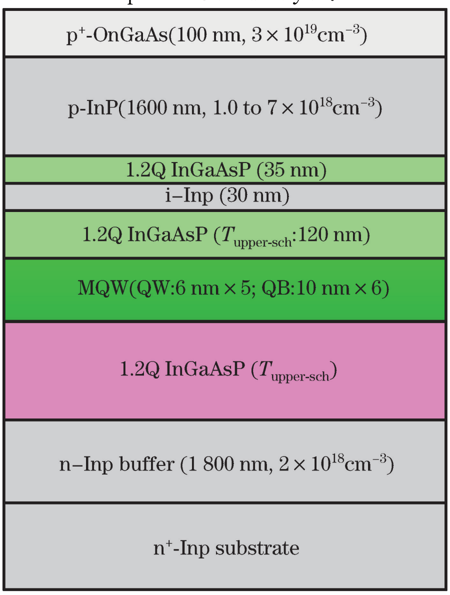

Fig. 1 Schematic of the epitaxial structure of the laser diode

Figure 2(a) shows the simulated optical confinement factor for the QWs, p-cladding layer (Γ_{QWs}, Γ_p, respectively at $m=0$) as a function of the thickness of lower SCH layer ($T_{lower\text{-}SCH}$). It can be seen that as $T_{lower\text{-}SCH}$ increases from 120 nm to 800 nm, the fundamental mode ($m=0$) is pulled into the lower cladding layer, thus reducing the overlap with the p-cladding layer, which will reduce the losses resulting from free carrier absorption. Figure 2(b) shows the calculated internal losses as a function of $T_{lower\text{-}SCH}$, by using $\alpha_i = \Gamma_{QWs} \times k_{MQW} + \Gamma_p \times k_p + k_n \times k_n$, where k_{QW}, k_p and k_n are the absorption coefficients at $\lambda = 1.55$ μm in QWs, in the p- and n-cladding layers, respectively[6]. Taking into consideration for maintaining the fundamental mode lasing (Γ_{QWs} is selected at the lowest value at $m=1$), a 450 nm $T_{lower\text{-}SCH}$ is selected, where the calculated internal loss (α_i) for this structure is 9.3 cm^{-1}.

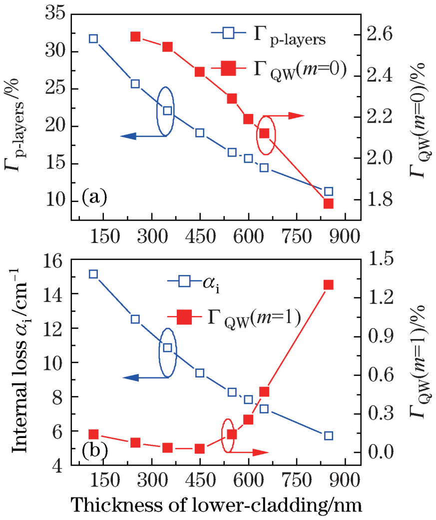

Fig. 2 (a) Calculated optical confinement factor (Γ_{QWs}, Γ_p) under different $T_{lower\text{-}SCH}$; (b) calculated Γ_{QWs} at $m=1$ and internal loss

3 Device fabrication and performance

The device structure is grown by metal organic chemical vapor deposition (MOCVD) on n-InP substrates. A grating is formed in the InGaAsP material ($\lambda_g = 1.2$ μm) layer through holographic lithography and dry etching. A 3 μm ridge-waveguide is formed to preserve lateral single-mode operation. A Ti-Au metal layer is sputtered on the p-InGaAs contact layer to form a p-contact. After the substrate is thinned, Au-Ge-Ni metal is evaporated on the backside. Finally, chips are cleaved with both sides uncoated.

The basic parameters, such as internal quantum efficiency η_i and internal loss α_i of the laser structure, can be extracted by using the standard method. As shown in Figure 3(a), the external parameters of η_i (= 0.91) and α_i (= 9.87 cm^{-1}) are extracted. Figure 3(b) shows the continuous optical power and the efficiency of the F-P cavity laser (on the same wafer as the DFB laser but without grating) at different injection currents at 25℃. As can be seen, an output power of more than 114 mW is obtained at 600 mA.

Figure 4 shows the optical spectra of the 1 mm DFB laser at 255 mA injection current and at various temperatures. As can be seen, the sidemode suppression ratios (SMSR) are better than 45 dB from 15℃ to 50℃. This temperature shift permits to obtain a tunability of 5.4 nm. At 255 mA, a single-mode output power of 40 mW is measured at 25℃. Besides, we use the delayed self-heterodyne method with 5 km single mode fiber (SMF) to characterize the laser linewidth. A Lorentz fitting linewidth of 400 kHz is obtained for the DFB laser under 255 mA injection current at 25℃.

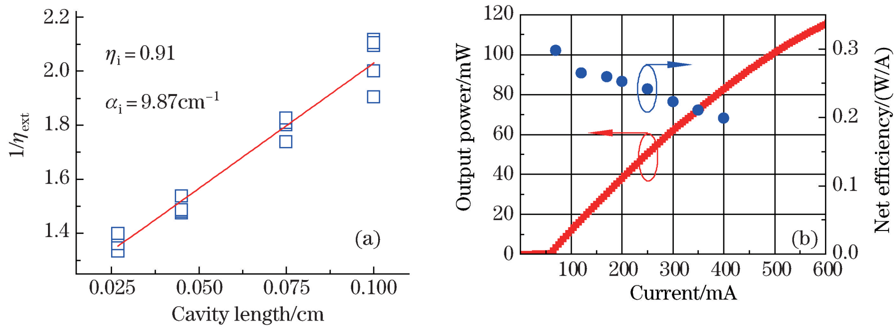

Fig. 3 (a) Inverse external differential quantum efficiency as a function of the cavity length; (b) light-current characteristic of 1 mm uncoated F-P laser at 25℃

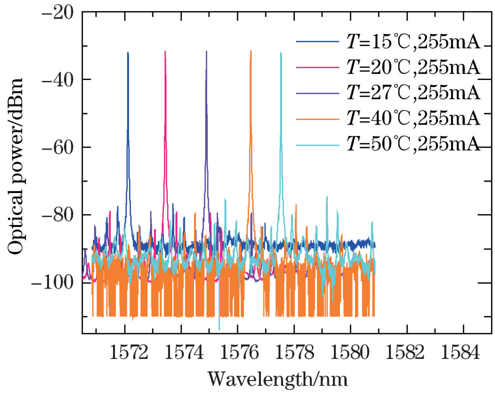

Fig. 4 Optical spectra of a 1 mm DFB laser from 15℃ to 50℃ at 255 mA current

4 Conclusion

A ridge waveguide distributed feedback laser emitting at 1.5 μm with high power and narrow linewidth has been reported. By calculating and optimizing the asymmetric cladding structure, 114 mW F-P laser and 40 mW single-mode DFB laser with Lorentz fitting linewith of 400 kHz are obtained.

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