1.55μm Laser Diode Monolithically Integrated with Spot-Size Converter Using Conventional Process*

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Abstract: A novel 1.55μm laser diode with spot-size converter is designed and fabricated using conventional photolithography and chemical wet etching process. For the laser diode, a ridge double-core structure is employed. For the spot-size converter, a buried ridge double-core structure is incorporated. The laterally tapered active core is designed and optically combined with the thin and wide passive core to control the size of mode. The laser diode threshold current is measured to be 40mA together with high slop efficiency of 0.35W/A. The beam divergence angles in the horizontal and vertical directions are as small as 14.89°×18.18°, respectively, resulting in low-coupling losses with a cleaved optical fiber (3dB loss).

Key words: laser diode; spot-size converters; integrated optoelectronics; optical coupling
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1 Introduction

In recent year, an optical device integrated with a spot-size converter (SSC) has been paid much attention for its direct coupling to an optical fiber with low-loss, large alignment tolerances, and simple packaging schemes without using a micro-lens or tapered fiber[1~6]. In particular, a laser diode (LD) integrated with an SSC (LD-SSC) is much more attractive for low-cost packaging due to its large spot size which is well matched to that of a single-mode fiber (SMF)[7].

To achieve low-loss, alignment-tolerant coupling, the small elliptical beam from the laser has to be mode-matched to the larger circular beam in the fiber. So far, there are three main classes of SSC that have been developed to expand the laser optical mode. The first one is the vertical SSC in which the waveguide thickness is decreased along the output direction[8]. In the second one, the active region is laterally tapered, which is formed by decreasing the waveguide width[9]. The third one is the so-called double-core taper in which the active waveguide is laterally tapered and combined with an underlying passive waveguide[10]. So far, most of them were based on buried structure[11] with or without selective area growth[12]. Moreover, many

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of these structures use very narrow waveguides (below 0.5μm), which require special lithography[11] and may be sensitive to the width of the taper tip[13]. In addition, most of them involve complex growth steps, excessive processing steps, strict process tolerance, and poor device performance. Our research group has demonstrated the first and third classes of SSC[14,15]. In the first case, the LD active and SSC waveguide were butt-joint fabricated with four steps LP-MOVPE growth in which the interface between LD and SSC was too difficult to deal with for the post-regrowth. In the third case, the waveguide is vertically tapered and combined with an underlying passive waveguide in which the device had to be fabricated with three steps LP-MOVPE growth. Furthermore, its beam divergence angles are not so small (20°×30° in the horizontal and vertical directions respectively) to get high coupling efficiency. In this letter, a 1.55μm novel LD-SSC is fabricated by simple process in which the active waveguide is laterally tapered and combined with an underlying passive waveguide. The taper shape and the passive waveguide can be optimized independently which allows to easily controlling the beam divergence at the output facet[16]. For the laser diode, a ridge double-core structure is employed. For the spot-size converter, a buried ridge double-core structure (BRS) is incorporated. The combination of ridge and BRS structure can take advantage of both easy processing of ridge structure and the excellent mode characteristic of BRS. Furthermore, the novel LD-SSC fabricated only uses two steps LP-MOVPE growth. The laser threshold current is measured to be 40mA together with high slop efficiency of 0.35W/A. The beam divergence angles in the horizontal and vertical directions are as small as 14.89°×18.18°, respectively, resulting in low-coupling losses with a cleaved optical fiber (3dB loss).

2 Device structure

The schematic diagram of the LD-SSC is shown in Fig.1. The device is constructed with the double-waveguide structure: one is the deep ridge shape laser section and another is SSC section which is in a buried-taper shape active stripe. The LD and the SSC are both 200μm-long. The total length of the device is only 400μm. The active waveguide is formed in two parts: a straight active region (laser section) in which the width of the active waveguide is 3μm, and the SSC section is lineally tapered from 3 to 0μm. Since the width of the whole passive waveguide under the two sections is 8μm and its thickness is sufficiently thin (50nm), so in the laser section the most optical power is confined in it. However, in the SSC section, the optical power is gradually transferred to the passive waveguide along with the active region becoming narrow. Eventually, at the output facet of SSC, the optical mode is determined only by the thin passive waveguide. So when the beam propagates from the LD section to the SSC section, the mode size is gradually expanded and eventually matched that of a cleaved SMF.

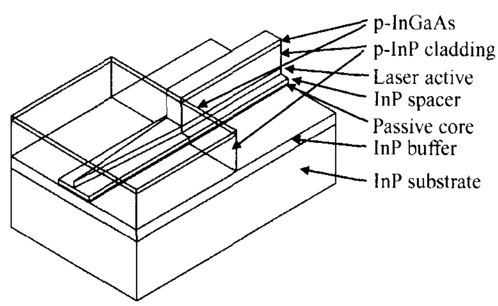

Fig.1 Schematic of LD-SSC

Compared with double-core SSC reported previously, our structure does not rely on multilayer waveguides[17,18], so that growth is easier and conventional chemical wet etching can be performed straightforwardly by using the guiding layer as a stop etch one.

The LD-SSC is fabricated by only two steps LP-MOVPE. The n-InP buffer, passive guiding layer (50nm, λ=1.125μm), 0.2μm InP spacer, the active layer which is optimized to the laser performance are grown successively in the first LP-

MOVPE. The active layer contained eight compressively strained (0. 6 %) InGaAsP quantum wells , SCH layers (70nm , λ = 1. 125μm) on both sides of the MQW-layer.

The chemical wet etching method is used to make the active and passive waveguide mesa. It is found that a sharp taper tip with 0. 3μm or less at SSC section tip is easily achieved by normal photolithography combined with an undercut etching. So , there is no need for a submicron pattering using expensive and time-consuming e-beam lithography.

After mesa etching , p-InP and contact layers are grown successively in the second LP-MOVPE. Hereafter the SSC segment is masked by SiO_2 , and the laser segments is etched to form a ridge shape.

Finally the samples are thinned to 100μm and p-side (TiPtAu) and n-side (AuGeNi) ohmic contacts are deposited.

3 Results

The lasing wavelength of LD-SSC is around at 1. 55μm , and the chips have extremely small leakage current at - 4V. The device reproducibility and stability are excellent.

Figure 2 shows mode profiles calculated by beam propagation method. The mode size expanded from 2. 52μm (lateral) ×1. 08μm (vertical) at the laser section to 5. 31μm (lateral) ×4. 1μm (vertical) at the SSC facet. In this work , the full width of the spot-size is defined as the distance from one side to the other of the waveguide , where the intensity is 1/ e of its maximum value (or the power intensity is $1/e^2$) .

The CW light-current characteristics were measured at both sides of the devices and a typical result is shown in Fig. 3. The threshold current is 40mA. An obvious asymmetric feature of the slope efficiency at both sides is observed for all the devices. The slope efficiency from the SSC facet is as large as 0. 35W/ A while that from laser back facet is around 0. 24W/ A. It is demonstrated that the transmittance at SSC facet is larger than that at the laser back facet.

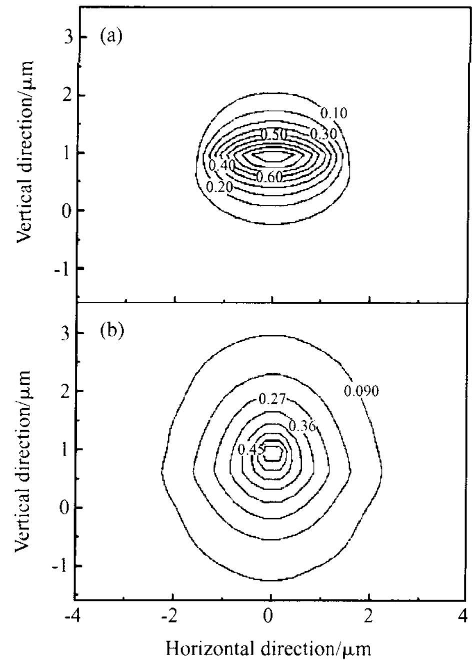

Fig. 2 Intensity distribution of waveguide modes in the laser section (a) and at the output facet of SSC section (b) The digital data represent the ratio of intensity.

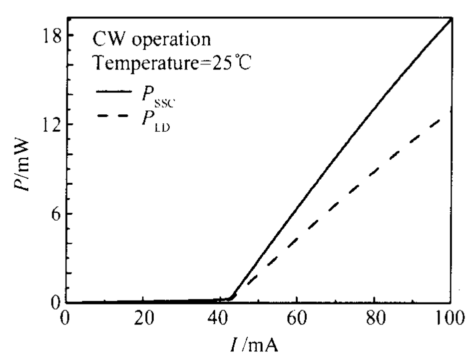

Fig. 3 *P-I* characteristics at SSC and LD facets

Figure 4 shows the far field pattern observed from SSC facet and laser back facet. The divergence angles from SSC facet are as small as 14. 8°× 18. 18°in the horizontal and vertical directions , respectively. On the other hand , those from the laser facet are 28°and 34. 8°. When coupled to a cleaved SMF , coupling loss and - 1dB align tolerance for LD with SSC are about 3dB , ±3. 0μm ×±2. 64μm for horizontal and vertical directions , respectively. However , those from the laser facet are about 9dB , ±2. 0μm ×±1. 7μm[10] .

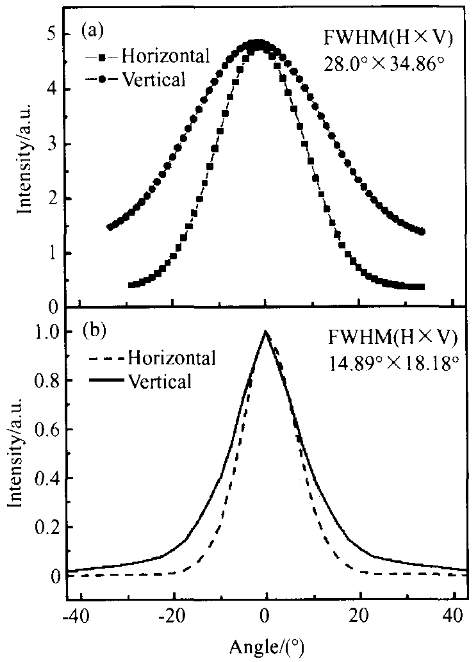

Fig.4 Far-field pattern from the laser facet (a) and SSC facet (b)

4 Conclusion

A novel 1.55μm LD monolithically integrated with SSC is designed and fabricated. The threshold current is measured to be 40mA together with high slop efficiency of 0.35W/A. The beam divergence angles in the horizontal and vertical directions are as small as 14.8°×18.18°, in the horizontal and vertical directions respectively. Simple fabrication procedure and excellent performance of the device proves that it would be reasonable as a low cost and mass-production light source for optical access network.

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使用传统工艺实现 1. 55μm 激光器与模斑转换器的单片集成 *

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摘要: 采用传统的光刻和湿法腐蚀工艺制作了 1. 55μm 波长的新型半导体激光器和模斑转换器的单片集成器件. 其中激光器采用脊型双波导 ,模斑转换器采用掩埋双波导结构 ,水平楔型的有源波导和宽而薄的无源波导同时控制光斑模式大小. 实验测得器件的阈值电流为 40mA ,斜率效率为 0. 35W/ A ,水平和垂直方向的远场发散角分别为 14. 89°和 18. 18 °,与单模光纤的耦合损耗为 3dB.

关键词: 激光器; 模斑转换器; 光电子集成; 光耦合

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