Narrow-beam divergence 1.55 μm laser diodes with integrated self-aligned spotsize converter

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This paper describes the high performance of narrow-beam divergence spot size converter (SSC) integrated separately confined heterostructure (SCH) LD. The upper optical confinement layer (OCL) and the butt-coupled tapered thickness waveguide were regrown simultaneously, which not only offered the separated optimization of the active region and the integrated spotsize converter, but also reduced the difficulty of the butt-joint selective regrowth. The threshold current was as low as 5.4 mA, the output power at 55 mA was 10.1 mW, the vertical and horizontal far field divergence angles were as low as 9° and 15°, and the 1-dB misalignment tolerances were 3.6 and 3.4 μm, respectively.

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A cost reduction in the optical module is required to realize optical access networks, such as fiber to the home (FTTH) or fiber to the curb (FTTC). The assembling and packaging costs account for the most of the module cost because a large difference in the optical spot size of the laser chip and fiber requires lenses aligned in a sophisticated way. A laser diode with optical fiber matched spotsize is an attractive device providing low-loss coupling to the optical fiber and waveguide without a lens and offering alignment tolerance during assembling optical modules. This leads to a cost reduction in optical modules. Furthermore, large-area wafer processing is essential for the reduction of laser cost.

There are two kinds of methods for achieving vertically tapered waveguide monolithically integrated lasers[1−3]. The first method is the all-selective MOVPE grown buried heterostructure (ASM-BH) LDs, in which the active region and the waveguide are selectively grown simultaneously[1]. The advantage of this type LD is the simplicity of selective growth, but the disadvantage lies in the lack of the separated optimization of the active region and the waveguide, which can induce excess absorption loss in the waveguide. The other kind of method is the butt-joint spotsize converter integrated LDs[2,3]. The advantage of this method is the separated optimization of the active region and the waveguide, but its difficulty in selectively regrowth is obvious.

In this paper, we propose the self-aligned selective area growth technique to fabricate the SSC integrated DFB, where the upper optical confinement layer and the integrated vertically tapered waveguide are selectively grown simultaneously by using a twin-mask. The active region and the integrated waveguide can be separately optimized, and the difficulty of selective growth of the butt-joint integration between the waveguide and the active region is reduced significantly. Furthermore, the buried heterostructure is proposed, and both the lateral and the vertical far field divergence angles can be improved.

The integrated device is schematically shown in Fig. 1, where the SSC region is composed of a bulk taper which is butt-joint to the MQW active region. We choose the tapered waveguide changing thickness along the output direction, which is thick at the butt-joint section in order to reduce the coupling loss between the active region and the SSC region, and the output tip of the SSC is thin to insure the narrow far field pattern.

The device was fabricated by four steps MOVPE. The n-InP buffer layer, lower optical confinement layer, and strained multi-quantum well layer were grown in the first step epitaxy. The active MQW in SSC region was etched down, two SiO_2 pads shown in Fig. 2 were patterned on the wafer in the vicinity of the active region.

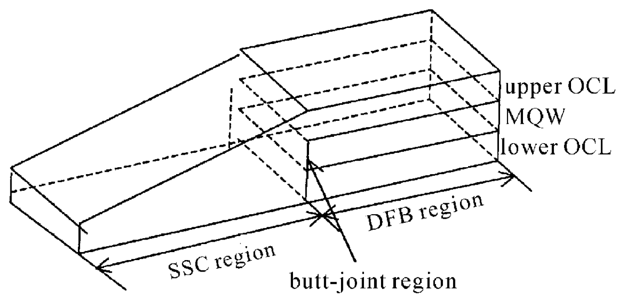

Fig. 1. The schematic structure of the integrated device.

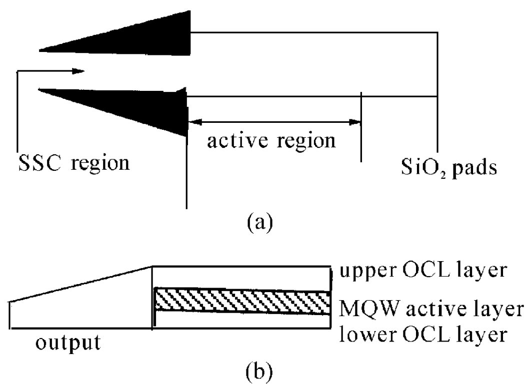

Fig. 2. (a) The mask shape of the SSC integrated DFB. (b) The lateral view of the schematic structure of the device.

The SiO_2 pads caused an enhancement of the growth rate and an increase of the bandgap wavelength of the InGaAsP waveguide in the middle of the gap between the SiO_2 pads. The bulk waveguide and the upper optical confinement layer were selectively grown simultaneously. Figure 2(b) showed the schematic thickness profile along the propagation axis. The advantage of this structure was that the waveguide was thick in the butt-jointed region to reduce the coupling loss, the output tip was thin to obtain narrow far field divergence angles. A uniform stripe was formed by wet etching. PNPN current-blocking layer was grown in the third step MOVPE. Finally, 1.5 μm p-InP cladding layer and 0.2 μm p^+-InGaAs contact layer were grown.

Figure 3 showed the bandgap wavelength and the width of the photoluminous (PL) spectra peak profiles of the InGaAsP waveguide in the selectively grown SSC region measured by micro-region photoluminescence. The wavelength was long at the thick section and short at the thin section due to the lateral diffusion of the In and Ga species[4]. The PL peak width was wide in thick waveguide region and narrow in the thin region. The crystal quality in thick region was poorer than that in the thin region, which would cause excess loss of absorption and scattering[5].

Typical *P-I* characteristics were shown in Fig. 4. The threshold current was 5.4 mA at room temperature, and the output power was 10.1 mW at the current of 55 mA. No degradation of the threshold current characteristics was observed with and without SSC region because of the low absorption in the SSC region buried by the PNPN current-blocking layer. Figure 5 showed the 3-D view of the spot size of the SSC integrated DFB. The vertical and horizontal far field patterns were given in Fig. 6.

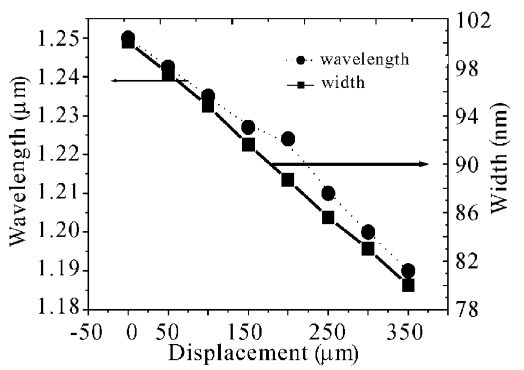

Fig. 3. The profile of PL peak and the width in the SSC region.

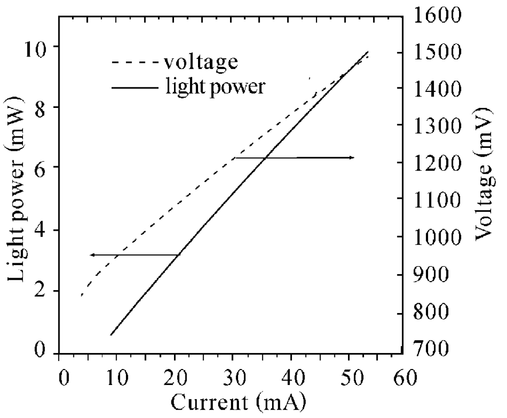

Fig. 4. *P-I* characteristics of the device.

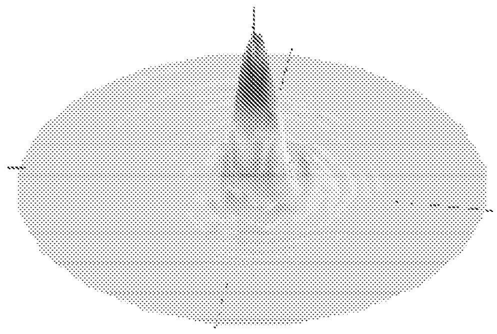

Fig. 5. The 3-D view of the far field spot of the SSC integrated laser.

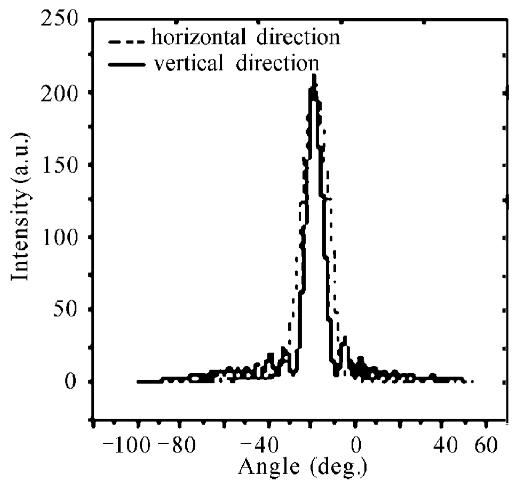

Fig. 6. The far field divergence pattern in vertical and horizontal direction.

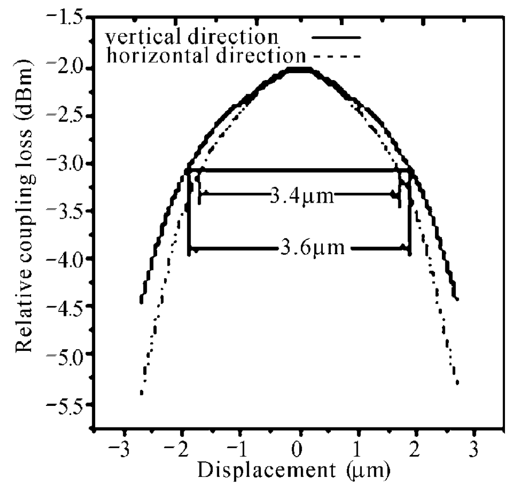

Fig. 7. The 1-dB misalignment tolerance in vertical and horizontal direction.

The FWHM of the vertical and the horizontal angles of the device were as low as 9° and 15°, respectively. The characteristics of direct coupling to a cleaved single mode fiber were given in Fig. 7, and the 1-dB misalignment tolerances were 3.6 and 3.4 μm in vertical and horizontal direction, respectively.

The self-aligned spotsize converter integrated laser was fabricated by selective LP-MOVPE. The FWHM of the vertical and horizontal divergence angles were 9° and 15°, and the 1-dB misalignment tolerances in vertical and horizontal direction were 3.6 and 3.4 μm, respectively. The threshold current was as low as 5.4 mA, the output power was 10.1 mW at 55 mA.

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