1.55-μm InGaAsP–InP Spot-Size-Converted (SSC) Laser with Simple Technological Process

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***Abstract*—In this letter, we report the realization of a 1.55-μm spot-size-converted (SSC) laser using conventional SCH-MQW active layers and conventional photolithography. The laser consists of a 300-μm-long rectangular gain section, with compensated multiple-quantum-well (MQW) structure, and a 300-μm-long tapered passive waveguide, fabricated on lower SCH layer. The device exhibits a beam divergence of 13° × 18° and 3.5-dB coupling loss with a cleaved single-mode fiber (SMF). The 1-dB alignment tolerance is ±2.3 μm in the vertical direction and ±1.9 μm in the lateral direction, respectively.**

***Index Terms*—Integrated optics, optical couplers, semiconductor junction lasers.**

I. Introduction

The spot-size-converted (SSC) laser, with a large spot size well matched to that of a single-mode optical fiber, is the key element to obtain low-cost packaging with optical fiber for the FTTH (fiber-to-the-home) networks [1]–[7]. However, to fabricate a long-wavelength (1.55 μm) SSC laser, either complicated active layers or technology must be used [5], [6] which reduces substantially the yield and increases the cost of the laser itself.

In a previous letter [7], we reported a SSC laser fabricated with conventional multiple-quantum-well (MQW) layers and conventional technological process. The laser consisted of a gain section, a lateral taper and a passive waveguide. The lower SCH layer was divided into two "layers" to fabricate the taper and the passive waveguide. Although low coupling loss has been realized with a large alignment tolerance, the process was comparatively complicated. At least three steps of photolithography were needed to define the three sections, and difficulties were found in alignment.

In this letter, we report an SSC laser with a less complicated structure which is easy to fabricate using conventional technological process. Conventional MQW active layers have been used. The laser consists of only two sections: a rectangular active section with compensated MQW structure, and a tapered passive waveguide fabricated on the lower SCH layer. The passive waveguide changes its shape from a 2.5-μm starting width to a 0.5-μm-wide narrow waveguide, over a 300-μm distance. Using this structure the SSC laser can be easily fabricated with good reproducibility. Low-beam divergence and large alignment tolerance with cleaved single-mode optical fiber have been obtained.

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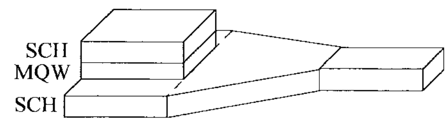

Fig. 1. SSC laser structure.

II. Devices Design and Fabrication

The SSC laser structure, shown in Fig. 1, consists of a gain section, and a laterally tapered passive waveguide. The active layer is grown by MOCVD on (001) Sn-doped InP substrate at a temperature of 660 °C. The MQW stack contains five 9-nm-thick wells of 0.9% compressively strained InGaAsP and six 10-nm-thick barriers of 1.27 μm − 0.8% tensile strained InGaAsP. The whole MQW stack is thus quasi-compensated. The MQW stack is sandwiched between two 120-nm-thick unstrained confining layers with 1.27-μm wavelength.

The spot size of the SSC laser which is required to have a good match with that of the cleaved single-mode fiber (SMF), is mainly determined by the dimensions of the narrow passive waveguide. Fig. 2 shows the calculated coupling loss between an SSC laser and a cleaved SMF. A Gaussian expression has been used to simulate the near field of the fiber, with a 9 μm 1/e FWHM. The near field of the SSC laser is simulated using two-dimensional beam propagation method (BPM) and effective index method (EIM). It is seen that a low coupling loss can be obtained by optimizing both the width and thickness of the passive waveguide of the SSC laser. In the early report [7], a wide (2 μm) and thin (0.05 μm) passive waveguide has been utilized. In that case the whole lower SCH layer (100 nm thick) was divided into "two layers" with equal thickness for the taper and the passive waveguide. However, from Fig. 2, we know a low coupling loss is also possible if a narrow and thick passive waveguide is used. For example, if the width of the passive waveguide is controlled around 0.5 μm, with a 100-nm thickness, the coupling loss can be lower than 3 dB. In this way, the passive waveguide can be fabricated using the whole SCH layer.

For an SSC laser the radiation loss in the passive taper section deteriorates the laser characteristics (i.e., a higher threshold current and a lower quantum efficiency), therefore a low radiation loss taper has been required. The design of the lateral taper in our work is based on a 2-D BPM analysis [7]. It shows that an adiabatic taper has lower radiation loss than a linear taper having the same length. Recently, Wada *et al.* [8] fabricated a 1.3-μm wavelength SSC laser, which consisted of

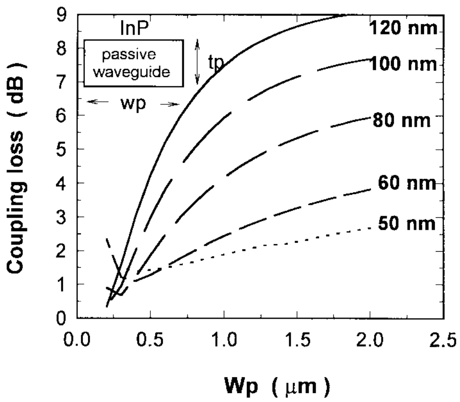

Fig. 2. Simulated laser–fiber coupling loss against passive waveguide width and thickness [7].

a gain section, a taper and a passive waveguide. Based on a 3-D BPM analysis [9], a short nonlinear taper ($100 - 150$ μm) (probably having an adiabatic shape) was used in their work to reduce the SSC laser cavity and thus to increase the yield on a 2-in InP substrate. Although adiabatic taper is effective to suppress the radiation loss, however it requires a complicated mask design. In our structure, we chose a longer linear taper (300 μm) to have a low radiation loss and to simplify the mask design.

The device is fabricated using conventional technological process. A 1.5 μm $\times$ 300 μm rectangular active region is defined and etched down to the interface of the last well and the lower SCH layer, by the use of RIE with CH_4:H_2 as etching gases. Then the 300-μm-long tapered passive waveguide is defined using conventional photolithography and etched down to n:InP buffer layer. During the etching, a 670-nm wavelength He–Ne laser is used to monitor the reflected signal on the etched surface to control *in situ* the etching depth. The SSC laser then is fabricated as described in [7].

III. Device Results

The whole SSC laser is 600 μm long. The lowest threshold current (room temperature) is 18 mA with a quantum efficiency of 0.15 W/A for one mirror.

The far-field pattern of the SSC laser has been measured with 80-mA continuous-wave (CW) injection current (shown in Fig. 3). A FWHM of $13^\circ \times 18^\circ$ has been obtained in lateral and vertical directions compared to a $34^\circ \times 45^\circ$ far-field pattern of the Fabry–Perot laser using the same active structure. The small lobes near the main lobe in Fig. 3(b), in the vertical direction, is related to the radiation fields, and will be reduced by cleaving the SSC laser with a long cavity. However, in that case, the threshold current will be increased.

Coupling experiments of the SSC laser to a cleaved single-mode fiber have been carried out. Both the SSC laser and the fiber are uncoated. Ripples of coupling loss against distance have been observed, due to the reflection between the mirror of the laser and the facet of the cleaved fiber. A minimum 3.5-dB coupling loss has been obtained. Fig. 4 shows the measured coupling loss against the misalignment shift. The

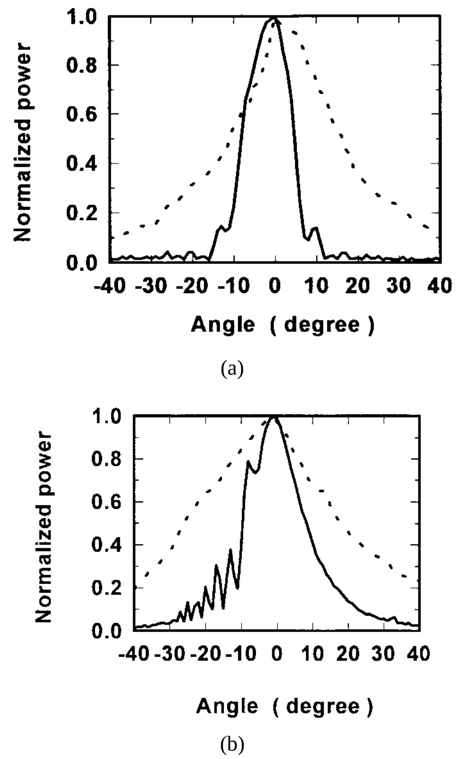

Fig. 3. Measured far-field pattern for a SSC laser (solid line) and a conventional Fabry–Perot laser (dotted line) on the same wafer. (a) Lateral direction. (b) Vertical direction.

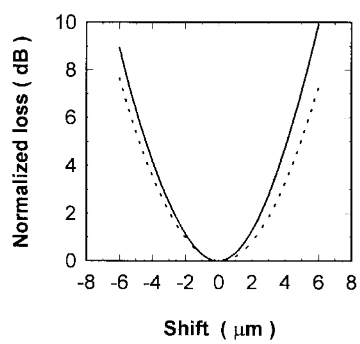

Fig. 4. Measured butt-coupling loss against misalignment between a SSC laser and a cleaved SMF. Dotted line: Lateral direction. Solid line: Vertical direction.

1-dB alignment tolerance is ± 2.3 μm in the vertical direction and ± 1.9 μm in the lateral direction, respectively.

As seen from Fig. 2, the measured coupling loss is determined by the passive waveguide parameters. The comparatively high coupling loss, respect to the results of [7], is due to a thick passive waveguide, about 120 nm. A lower than 3-dB coupling loss is possible by reducing the passive waveguide thickness. For example, if the SCH thickness is 100 nm, the coupling loss will be less than 3 dB; for an 80-nm-thick SCH layer, less than 2-dB loss can be obtained.

In conclusion we have realized a simple SSC laser emitting at 1.55-μm wavelength. The main advantage of this structure is: a) conventional SCH-MQW layers and b) easy technological process. Lower coupling loss will be realized by optimizing the passive waveguide thickness.

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