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Short Note

High-Power 1.5 μm InGaAsP/InP Strained Quantum Wells Integrated Superluminescent Light Source with Tilted Structure

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Based on our original idea about monolithic integration of the superluminescent diode (SLD) with a semiconductor optical amplifier (SOA), the axis of the current injection area was tilted. High superluminescent power (more than 200 mW) at 1.5 μm was obtained by optimizing the tilted device structure. No lasing mode was discovered within the range of measurement. In addition, it was discovered that the tilted integrated device had the function of lasing suppression, to some extent.

KEYWORDS: superluminescent diode, semiconductor optical amplifier, monolithic integration, spectrum slicing, multiwavelength light source, wavelength division multiplexing

Multiwavelength light sources are the key components in wavelength division multiplexing(WDM) systems, particularly in the future dense WDM (DWDM) system. To date, distributed-feedback (DFB) laser arrays or discrete DFB-lasers have been used for this purpose. As another approach, broadband light sources have been employed to obtain the multiwavelength lights using the spectrum slicing technique.[1–3] This technique is attractive because it can avoid the need for laser diodes. However, the performance of the spectrum-sliced system has been severely limited by the available low output power of the broadband sources, such as light-emitting diodes (LEDs) and conventional superluminescent diodes (SLDs). To obtain high broadband optical power, many schemes, such as spontaneous emission from an erbium-doped fiber amplifier (EDFA),[4] a tandem combination of SLD and EDFA,[5] the cascade connection of SLD[6] or LED[7] and semiconductor optical amplifier (SOA), a high power SLD with tapered active region[8] (its superluminescent power reached 1 W with pulsed 10 A current) and monolithic integration of SLD with tapered SOA[9] have been proposed for the purpose.

In this study, based on our original idea[9] about monolithic integration of the SLD with a SOA, an integrated superluminescent light source with a tilted structure was fabricated. High amplified spontaneous emission (ASE) power was obtained at a relative low current injection.

Figure 1 shows a schematic diagram of the integrated superluminescent device. The device consists of two regions, the stripe SLD region and the tapered SOA region, which can be electrically pumped separately. The angle of tapering is 5°. To eliminate the facet reflection, the axis was tilted by 6° with respect to the facet normal. The active area consists of five compressively strained InGaAsP quantum wells (5 nm thick) with InGaAsP barriers (10 nm thick), which were defined by SiO_2 windows. The wafer was grown by MOCVD on n-InP substrate. The typical device dimensions were as follows. The lengths of the SLD and SOA regions were 300 μm and 1500 μm, respectively. The stripe width of the SLD region was 3 μm. The output end width of the SOA was 130 μm. The AR-coating was not deposited on the output facet.

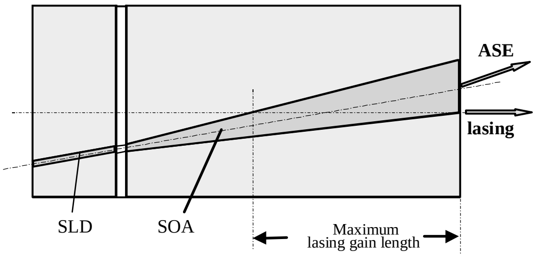

Fig. 1. Schematic structure of integrated superluminescent light source (top view).

The performance of the integrated superluminescent devices was measured under a pulsed condition (10 μs pulse width, 1% duty cycle). The superluminescent power (less than 80 mW) was obtained at a low pumping level. Higher power was limited to be obtained because the lasing modes appeared with increasing current for the SOA. A beneficial discovery was that the lasing modes, to some extent, can be suppressed by injecting the current into the SLD region. The entire process was investigated not only spectrally [Fig. 2(a)] but also spatially. Figure 2(b) shows the corresponding far field patterns (FFPs) parallel to the junction plane. The main output beam was centered at about 20° to the facet normal, due to the tilted output axis. Another small peak which appeared at 0° was attributed to lasing lights, which was confirmed from the corresponding spectrum under the same pumping conditions. Moreover, we can also confirm (from the peak at 0°) that the lasing was due to the Fabry–Perot oscillations. That is to say, although the light was attenuated in the unpumped region, the lasing could be established if the lasing gain length is long enough (as Fig. 1).

We consider that the process of lasing supression was attributed to the stimulated emitting competition between the superluminescent photons that propagated along the tilted axis and the F–P oscillation photons. With the increased incident light power from the SLD region, the incident photons gradually dominated the stimulated emission process and depleted the inverted carriers that previously participated in the lasing actions. As the gain of lasing modes decreased, the lasing was gradually suppressed.

However, the lasing would not be suppressed if the lasing level was high enough because the high-intensity lasing photons dominated the stimulated emission process. We think the failure of lasing suppression is due to the easily lasing structure in the SOA region, in which the lasing gain length (Fig. 1) was too long (900 μm and 50% of the total length).

In order to further suppress the lasing and increase the su-

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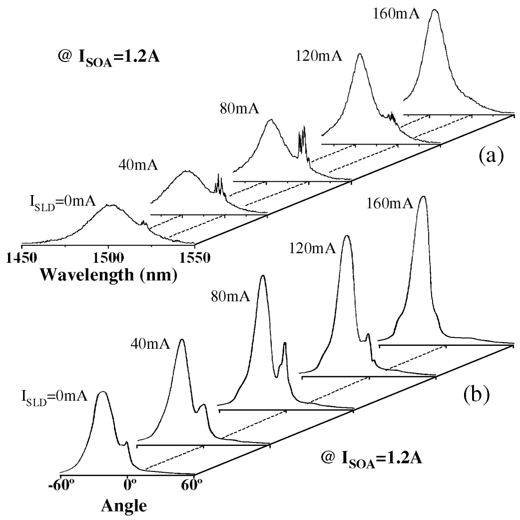

Fig. 2. Lasing suppression process: corresponding (a) spectrum and (b) far-field pattern parallel to the junction plane at different SLD currents when $I_{\mathrm{SOA}} = 1.2$ A.

perluminescent power, the device structure should be optimized by adjusting the SOA taper angle and the angle of the tilted axis which determine the lasing gain length. Considering the photon injection efficiency of the SOA (because of emitting divergence from the SLD) and the light output angle (governed by Snell's Law), 3° and 7° were chosen for the taper angle and the tilted angle, respectively. The calculated longest lasing gain length in the SOA region is about 550 μm, only 30% of the total length if the length of the SLD and SOA are 300 μm and 1500 μm, respectively.

The optimized devices have the same dimensions as the previous one except for the different angles. Figure 3 shows, simultaneously, the spectrum and the far-field pattern parallel to the junction plane at a higher pumping level, which indicates that no lasing mode appeared within the range of measurement. Although the reflection between the cleaved facets still exists, the oscillation will not easily be established at a higher pumping level because of the shorter gain length in the SOA and the competition effect in the stimulated emission process.

Figure 4 shows the output power versus current for the SOA (I_{SOA}) at different pumped conditions for the SLD region (I_{SLD}). It is evident that the device presented the "soft" current threshold characteristics, which is a typical feature of the superluminescent device. Relatively low power was obtained when only the SOA region was pumped (when $I_{\mathrm{SLD}} = 0$ A). The output ASE power increased significantly when current was injected into the SLD section. That is to say the power increased with the appearance of the incident light. High ASE power was obtained, compared with the case in which only the SOA region was pumped. This shows the superiority of the integrated device from the view point of increasing optical power.

The maximum superluminescent output power is 220 mW at 3.5 A for the SOA and 400 mA for the SLD, respectively. To our knowledge, this is the maximum ASE power which has been obtained at the same pumping level. The full with at half maximum (FWHM) of spectrum and the full angle at half maximum (FAHM) of the FFP parallel and perpendicular to the junction plane are 26 nm, 10° and 64°, respectively.

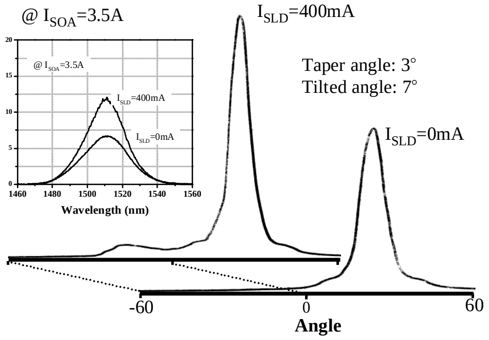

Fig. 3. Spectrum and corresponding far-field pattern of the optimized integrated device at a higher pumping level.

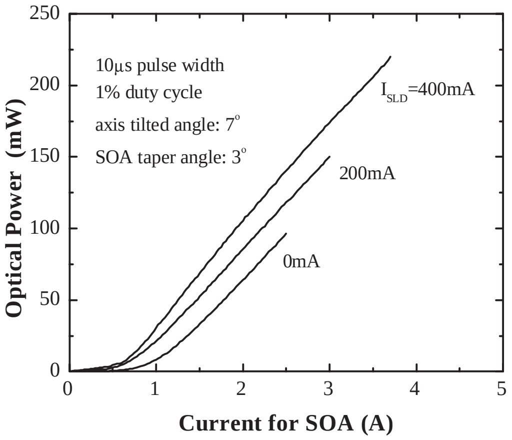

Fig. 4. Optical output power of the optimized device versus current injection of the SOA at different currents for the SLD.

In summary, a 1.5 μm InGaAsP/InP integrated superluminescent light source with a tilted structure was fabricated. High superluminescent power (more than 200 mW) was obtained by integration and optimization of the tilted device structure. No lasing mode was discovered within the range of measurement. In addition, it was discovered that the lasing can be suppressed, to some extent, by pumping the SLD section. Although this function cannot be used to suppress lasing independently for a device with an easy lasing structure, it does work if the structure is optimized properly.

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