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2004 Chinese Phys. Lett. 21 963

(http://iopscience.iop.org/0256-307X/21/5/056)

Enhancement of the Spectral Width of High-Power 1.5 μm Integrated Superluminescent Light Source by Quantum Well Intermixing Process *

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(Received 10 November 2003)

A novel type of integrated InGaAsP superluminescent light source was fabricated based on the tilted ridge-waveguide structure with selective-area quantum well (QW) intermixing. The bandgap structure along the length of the device was modified by impurity free vacancy diffusion QW intermixing. The spectral width was broadened from the 16 nm of the normal devices to 37 nm of the QW intermixing enhanced devices at the same output power level. High superluminescent power (210 mW) was obtained under pulsed conditions with a spectral width of 37 nm.

PACS: 78.67.De, 85.60.Jb

Superluminescent diodes (SLDs) are required as fibre gyroscopes and sensors, and wavelength division multiplexing systems. High output power, large spectral width and small spectral width are important features for SLDs. Various device structures and techniques, such as antireflection coating of the facet, unpumped absorption regions, and tilting of the stripe, have been proposed to reduce the spectral modulation. Some efforts have also been made to broaden the spectral width, such as stacked twin active layers,[1] tandem active layers,[2] selective area epitaxy [3] and asymmetric dual quantum wells.[4] In this Letter, we present a novel method to broaden the spectral width of high-power integrated SLDs. We modify the bandgap structure in a SLD along the length of the device by impurity free vacancy diffusion quantum well (QW) intermixing which has been used to fabricate photonic integrated circuits.[5] High amplified spontaneous emission (ASE) power at 1.5 μm with a broad spectrum was obtained by selective-area QW intermixing.

The integrated superluminescent diodes were fabricated in multiple QW InGaAsP material grown by metalorganic vapour phase epitaxy. From the n-InP substrate up, the layer specifications were as follows: a 0.4 μm InP layer Si doped, an intrinsic 0.34 μm waveguide core, a 1.5 μm Zn-doped InP upper cladding layer, and finally a Zn-doped p+-InGaAs cap layer. The waveguide core contained five 6 nm InGaAsP ($\lambda_G = 1.6\,\mu$m) QWs and six 10 nm InGaAsP ($\lambda_G = 1.3\,\mu$m) barriers surrounded in both directions by a step graded index region of 60 nm InGaAsP ($\lambda_G = 1.3\,\mu$m) and 60 nm InGaAsP ($\lambda_G = 1.15\,\mu$m). Different bandgap regions in the wafer were realized by selective-area QW intermixing. The QW intermixing was implemented using SiO_2 capping. A 200-nm-thick SiO_2 layer was deposited on the wafer at 300°C by plasma enhanced chemical vapour deposition (PECVD). Then the silica on the QW intermixing suppressing region was removed by wet chemical etching. The wafer was annealed for 30 s at 720°C. The photoluminescence (PL) peaks of the silica-covered region and the uncovered region were blue-shifted by 41 nm and 11 nm, respectively, resulting in a PL shift of 30 nm between the two regions. After annealing, the silica on the wafer was removed. Photoresist was then used to define the ridge waveguide, which was wet-etched to 150 nm above the SCH layer. Then SiO_2 was deposited on the wafer. The SiO_2 on the top of the ridge waveguide was removed by wet chemical etching. After thinning and metallization, the device was cleaved. No AR-coating was deposited on the output facets. The device was mounted substrate-side down on the copper heat sink. Figure 1 shows a schematic diagram of the integrated SLD device. The device consisted of two regions, the stripe SLD region and the tapered SOA region, which could be electrically pumped separately. The SLD region was the QW intermixing suppressed region. The SOA region was the QW intermixing enhanced region. The narrow SLD region was about 300 μm long and 3 μm wide. The tapered SOA section was about 1500 μm long. The full angle of the taper was 5°. The central axis of the device was tilted 6° in order to eliminate the facet

* Supported by the Major State Basic Research Programme of China under Grant No G2000036605, the National Natural Science Foundation of China under Grant No 60107002, and the National High-Tech Research and Development programme of China under Grant No 2003AA311080.

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reflectivity. In order to compare with the QW intermixed device, we also fabricated a normal integrated SLD with the same wafer not QW intermixed. The dimension of the normal integrated device was the same as that of the QW intermixed one.

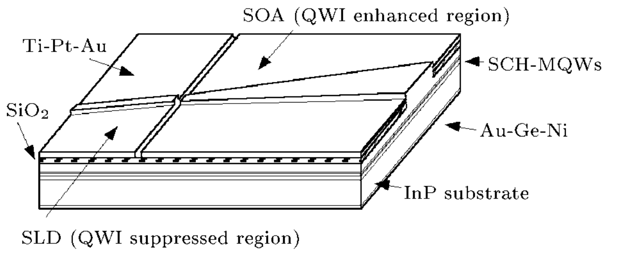

Fig. 1. Schematic structure of integrated superluminescent light source.

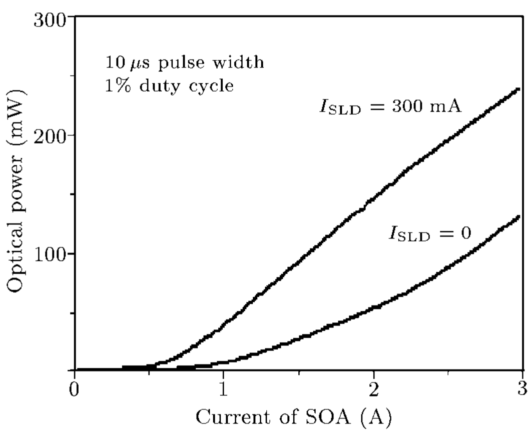

Fig. 2. *L–I* curves of the normal integrated superluminescent light source.

The performance of the integrated device was measured under a pulsed condition (10 μs pulse width, 1% duty cycle). Figure 2 shows the typical light power-injected current (*L–I*) characteristics of the normal integrated device. The output efficiency when the two regions worked simultaneously was much higher than when only one region was pumped, which is a benefit of an integrated device.[6] The output power was 240 mW when I_{SOA} = 3A and I_{SLD} = 300 mA. Figure 3 shows the output spectra of the normal integrated device with two regions pumped and with only the SOA region pumped. The spectral width decreased from 26 nm to 17 nm when the SLD was pumped. This should be due to the same QW structures of the two regions. The SLD section and the SOA section have the same gain spectrum and spontaneous emission spectrum (neglecting the influence of the waveguide) since the two sections were fabricated in the same wafer. When the two regions of the integrated device pumped simultaneously, photons of different wavelength from the SLD section obtained different gain in the SOA section. The photons near the peak wavelength of the SLD's spontaneous emission obtained more gain than that of other wavelengths. The output ASE of the integrated device was mainly attributed to photons near the peak wavelength. Thus, the spectral width of the integrated device decreased when the SLD region was pumped.

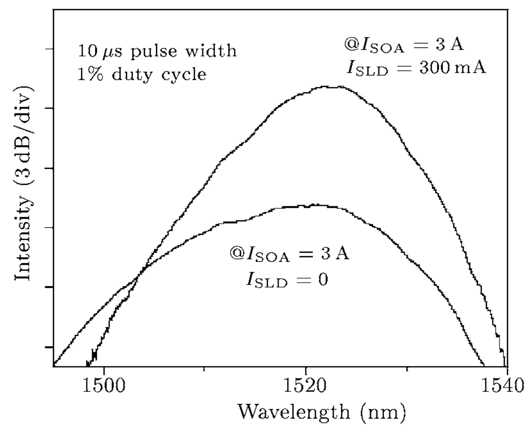

Fig. 3. Spectra of the normal SLD under different conditions.

Figure 4 shows the *L–I* curves of the QW intermixed integrated device. The output power was also much higher when the two regions were pumped simultaneously than when only the SOA section was pumped. The output power reached 210 mW under the condition of I_{SOA} = 3A and I_{SLD} = 300 mA. This was a small decrease compared with that of the normal integrated device. Figure 5 shows the spectra of the QW intermixed integrated device of the two regions pumped separately. The peaks of the SOA region and SLD region were 1501 nm at I_{SOA} = 3A and 1528 nm at I_{SLD} = 300 mA, respectively. The two regions had different peak wavelengths because the SOA region was blue-shifted due to QW intermixing. The spectral width was 27 nm by pumping the SOA region alone at I_{SOA} = 3A. Figure 6 shows the output spectrum of the QW intermixed integrated device at I_{SOA} = 3A and I_{SLD} = 300 mA. According to Fig. 5, the gain peak of SOA was blue-shifted in relation to the SLD's spontaneous emission. In the wavelength region from the peak of the SOA's gain to the peak of the SLD's spontaneous emission, the spontaneous emission in the SLD decreased as the gain in the SOA increased. The gain of the SOA compensated the spontaneous emission of SLD in that region. Hence, the spectrum was expanded after amplification in the SOA. A broadband emission with FWHM of 37 nm was obtained at I_{SOA} = 3A and I_{SLD} = 300 mA. It is shown that the QW intermixing enhanced integrated SLD was very effective to broaden the output spectrum. Figure 7 shows the measured far-field patterns along the horizontal and vertical directions to the QW plane from the wide end at I_{SOA} = 3A and I_{SLD} = 300 mA. Both horizontal and vertical output profiles were single peak patterns. The peak of the horizontal far-field pattern was centred at about 20° to the facet normal, due to the tilted output axis.

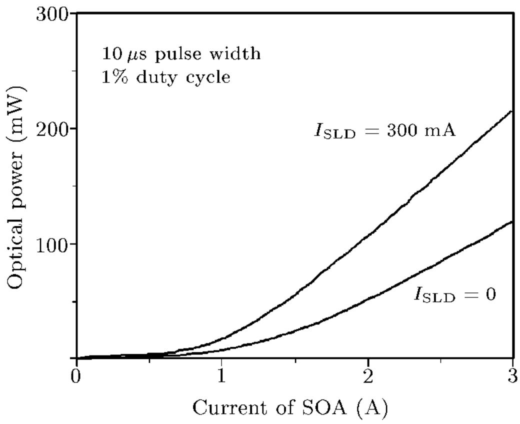

Fig. 4. *L–I* curves of the QW intermixing enhanced integrated superluminescent light source.

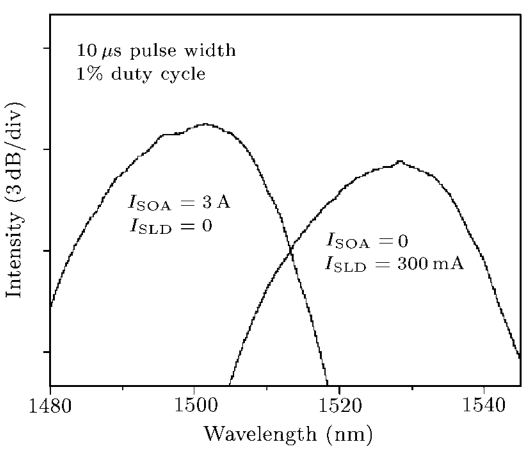

Fig. 5. Spectra of the QW intermixed device when the two regions were pumped separately.

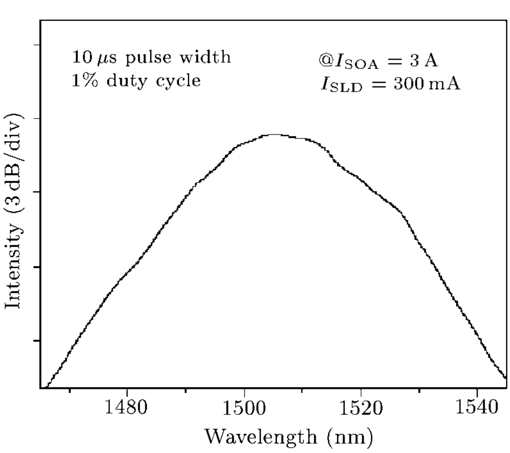

Fig. 6. Spectrum of the QW intermixed SLD when the two regions were pumped simultaneously.

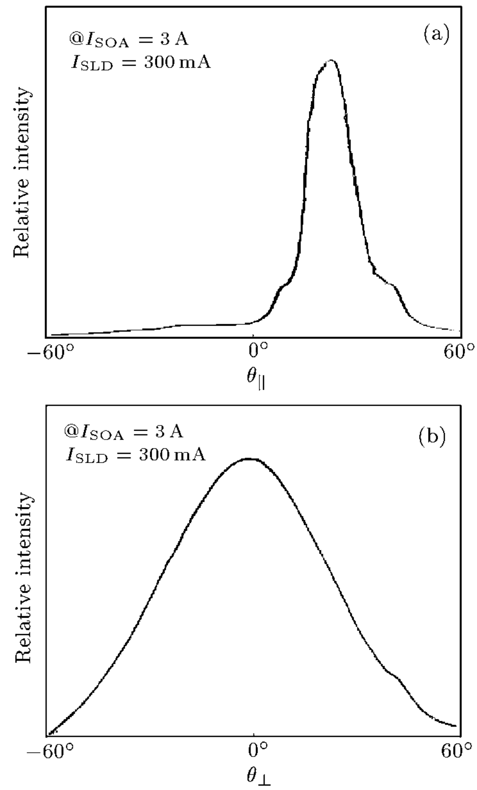

Fig. 7. Far-field patterns along the horizontal and vertical directions to the QW plane.

In conclusion, a broadband high-power 1.5 μm integrated superluminescent light source was fabricated with a selective-area QW intermixing process. A high superluminescent power of 210 mW was obtained under pulsed conditions. The spectral FWHM was 37 nm. The spectral width of the intermixed device was much broader than that of the normal device. However, the output power was slightly decreased compared with that of normal integrated devices. It is shown that the QW intermixing enhanced integrated SLD was very effective in broadening the output spectrum.

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