Broad-Band Superluminescent Diodes Fabricated on a Substrate with Asymmetric Dual Quantum Wells

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Abstract—**Broad-band AlGaAs–GaAs superluminescent diodes are fabricated using asymmetric dual quantum wells. With a proper design of the quantum-well structure, the spectral width of the superluminescent diodes could be engineered. By choosing 40 Å and 75 Å, respectively, for the two quantum wells, the spectrum remains bell-shaped and is broadened to 2 ~ 3 times that of the conventional superluminescent diodes. The measured spectra show that there is no obvious preference on the transition in either well at any pumping current.**

I. INTRODUCTION

SUPERLUMINESCENT diodes (SLD's) are optimum light sources for applications in areas such as optical gyroscopes and sensors, multichannel optical amplifiers, mode-locking semiconductor lasers, and wide-range tunable external-cavity semiconductor lasers. Small spectral modulation and large spectral width are important features for SLD's. Reduction of spectral modulation has been attempted by many efforts, including antireflection coating the facet [1], tilting the stripe [2], polishing [3] or dry-etching [4] the facet at an angle to the pumping stripe, and bending the mesa stripe [5]. Some efforts have also been devoted to broadening the spectral width. Mikami et al. [6] has used stacked twin active layers with different bandgaps, to obtain a broadened spectral width. With the amplification of intrinsic spontaneous emission by $n = 1$ and $n = 2$ transitions simultaneously [5], [7], the spectral width can also be significantly broadened. However, the wide spectrum is only obtained as the device is biased at a large injection current and the spectrum has a dip due to the large separation of the $n = 1$ and $n = 2$ transitions [5]. In this letter, we report that the SLD's fabricated on a substrate with asymmetric dual quantum wells have a wide spectrum. By choosing 40 Å and 75 Å, respectively, for the two quantum wells, a bell-shaped emission spectrum with a spectral width around 2 ~ 3 times that of the conventional SLD's is achieved.

II. LAYER STRUCTURE

According to the quantum mechanics, the ground state energy level is elevated from the bottom of the quantum well, so the emitted photon energy of the semiconductor quantum well increases as the well width decreases. Fig. 1 shows the calculated transition energy versus the well width for the GaAs quantum well bounded by the $Al_{0.18}Ga_{0.82}As$ barrier. By choosing well widths at 40 Å and 75 Å, respectively, for the two quantum wells, their $n = 1$ transitions separate for about 50 meV. This energy difference corresponds to a spectral width of ~300 Å, which is approximately equal to the gain bandwidth of this material. Therefore, the gain profile due to the simultaneous $n = 1$ transitions in both wells shows no dip. In addition, the $n = 2$ transition of the 75-Å well also separates from the $n = 1$ transition of the 40-Å well for ~50 meV. The occurrence of the $n = 2$ transition will then further broaden the spectrum, while the gain profile remains bell-shaped. The quantum-well structure is shown in Fig. 2. The graded index separate confinement heterostructure (GRINSCH) is formed in connection with the wells. Between the two wells is a wide $Al_{0.18}Ga_{0.82}As$ barrier to ensure that those quantized states have no coupling and so the transitions occur at the desired energy levels. MOCVD is applied to grow this quantum-well structure. Although the transition energy can also be altered by different material gradients in the wells, MOCVD epitaxial growth could usually better control the well width than the material gradients.

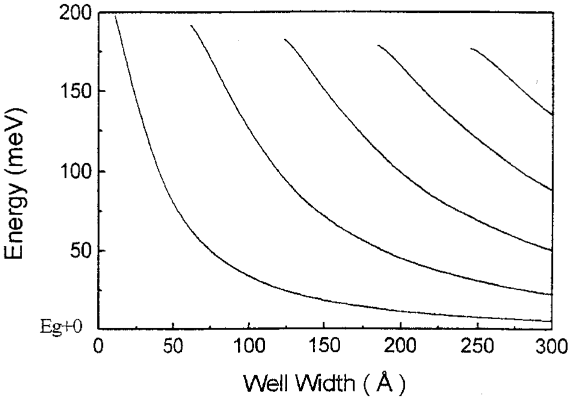

Fig. 1. The calculated transition energy versus the well width for GaAs quantum well bounded by the $Al_{0.18}Ga_{0.82}As$ barrier.

III. FABRICATION AND RESULTS

The tilted-stripe and bent-waveguide SLD's are fabricated on the MOCVD grown substrate with the designed asymmetric dual quantum wells. The same types of SLD's are also fabricated on another substrate with two GaAs quantum wells of the same width for comparison. The tilted-stripe SLD's has a 5-μm-ridge waveguide tilted at 5° from the normal to the cleaved facet. The bent-waveguide SLD's also has a 5-

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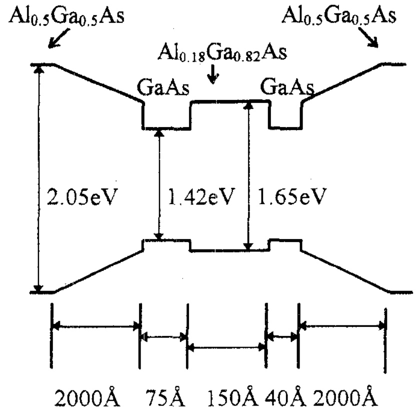

Fig. 2. The designed asymmetric dual-quantum-well structure.

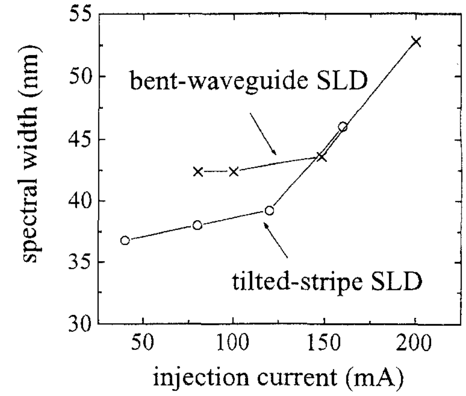

Fig. 3. The measured spectral width versus the injection current for: (a) tilted-stripe SLD, (b) bent-waveguide SLD.

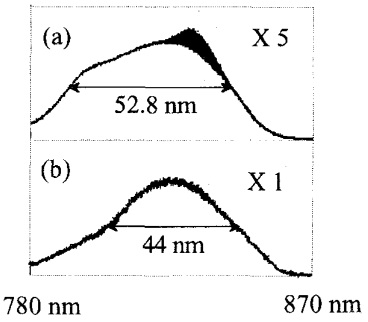

Fig. 4. Spectra of SLD: (a) with and (b) without the $n = 2$ transition in the 75-Å well.

μm-ridge waveguide, but with a 300-μm bent part [8]. The waveguide nearest to the output facet is oriented at several angles, which are found to have little influence on the emission spectrum as the angle is more than 5°. Both types of SLD's are about 500 μm long. The ridge waveguide is created by wet-etching. Etching is stopped at ~200 nm above the GRINSCH layer. The fabrication is completed by n-contact metallization and then the devices are cleaved apart. No facet coatings were applied to both types of devices.

The L–I curves and the spectra of SLD's are measured. The L–I curves are similar to those measured from other types of SLD's. The bent-waveguide SLD's has a slightly larger spectral ripple than the stited-stripe ones due to the large reflectivity at the straight-waveguide facet [8]. However, the spectral ripples are less than 10% even when the device is pumped at 200 mA and the output power is 5 mW. The spectral widths are 2 ~ 3 times broader than that of the conventional SLD's fabricated on the two quantum wells of the same width. The bell-shaped spectra show that the $n = 1$ transitions in both wells occur simultaneously, indicating no preference on the transition in either well. The spectral width also varies with the injection current. Fig. 3 shows the spectral width versus the injection current for the two types of SLD's. The two curves in the figure show that the spectral width is significantly increased for the injection current more than 150 mA. This is due to the occurrence of $n = 2$ transition in the 75-Å quantum well at a large pumping current [5]. Because the $n = 2$ transition in the 75-Å well separates from the $n = 1$ transition in the 40-Å well at a spectral distance of 300 Å, the spectral curve is still bell-shaped. Fig. 4(a) and (b) shows the measured spectra of the SLD with and without the addiotnal $n = 2$ transition in the 75-Å well, respectively.

To see if the spectrum is still broadened even at low injection current, the spontaneous emission spectrum of Fabry–Perot laser diodes fabricated on the asymmetric quantum-well substrate is measured below threshold. The spontaneous emission spectrum has a spectral width as wide as ~600 Å. The doubled spectral width, compared to conventional ones, indicates that both the 40-Å and 75-Å wells have the $n = 1$ transition at the low injection level and confirms that the grown substrate meets the expectation of the design. Because no amplification due to the stimulated emission occurs below the threshold, the spontaneous emission spectrum should have a shape very similar to the gain profile and is much broader than the amplified spontaneous emission spectrum. In the latter one, the output power is amplified approximately according to

$$p(\lambda) \propto e^{g(\lambda)l}$$

where $g(\lambda)$ is the gain profile and l is the device length. The exponential growth of the amplified emission makes its FWHM width narrow.

Spectra at different temperatures are also measured. The temperature variation basically changes the bandgap energy, but has no obvious influences on the quantized energy levels of the asymmetric quantum wells. Therefore, the peak wavelength is observed to be red-shifted and the measured spectral width is only slightly broadened as the temperature increases. For the temperature ranging from 10 °C to 70°C , the spectral measurements show that the $n = 1$ transition occurs simultaneously in both wells for the low and high injection currents.

IV. CONCLUSION

Broad-band SLD's are fabricated using asymmetric dual quantum wells. The spectral width of the SLD's could be engineered by the proper design of the quantum-well structure. With the widths 40 Å and 75 Å, respectively, for the two

GaAs quantum wells bounded by the the $Al_{0.18}Ga_{0.82}As$ barrier, the spectral width is increased $2 \sim 3$ times that of the conventional SLD's. The broadened spectral width is observed for both the tilted-stripe and the bent-waveguide SLD's. The measured spectra show that there is no obvious preference on the transition in either wells at any pumping current. In addition, the occurrence of $n = 2$ transition in the wider quantum well at a large pumping current could further increase the spectral width. An even wider spectral width should be expected as additional quantum wells of different widths are added.

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