Broadband Flat-top Superluminescent Diode with Low Spectral Modulation at 850 nm

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***Abstract-* The broadest bandwidth (80 nm) superluminescent diode (SLD) with center wavelength at 850 nm fabricated on GaAs/AlGaAs double quantum-well structure is characterized and analyzed. The broadband flat-top like spectrum and a 0.3 dB spectral modulation enable this device to produce an axial resolution of 4 μm in optical coherence tomography systems.**

I. INTRODUCTION

Superluminescent diode (SLD) producing broad emission spectrum at high power is the key component for high resolution sensor and tomography systems based on low coherence interferometry principle [1]. Several techniques have been employed to broaden the emission bandwidth of SLDs include: multiple-width quantum wells (QWs) or chirped QWs [2], quantum well intermixing (QWI) [3, 4] or selective area epitaxy (SAE) [5]. These approaches often involve pre-wafer fabrication or complex processing steps.. In addition to the wafer level design, a multiple electrodes scheme has been introduced to increase the injection versatility and to simultaneously excite multi-state emission from the QW [6]. In order to minimize facet reflectance and to suppress lasing, several schemes have been implemented, these include: (i) incorporation of angled waveguide structure to support only single pass photons [7], (ii) incorporation of an etched angled facet to minimize back reflectance [8], (iii) integration of an optical amplifier [9] and (iv) having an un-pumped absorber region [10].

In this work, a two-section device design scheme is implemented on a GaAs/AlGaAs double quantum-well (DQW) emitter structure to produce an SLD with an emission wavelength peak at 850 nm. The device consists of two sections namely a photon absorber (PA), and an emitter (gain) section. The un-pumped photon absorber is used to restrain the Fabry-Perot oscillations from the rear facet. The multiple-section design increases the injection flexibility, and helps to extend thermal roll-off to high injection current. With these design features, SLDs with low spectral ripple and broadband emission from simultaneous emission of ground and excited states from the quantum well can be obtained.

II. EXPERIMENTS

The wafer structure used in this experiment was grown by metal-organic vapor phase epitaxy (MOVPE) on a GaAs substrate. The active region consists of two 10 nm wide GaAs quantum wells, separated by an undoped 10 nm $Al_{0.2}Ga_{0.8}As$ barrier, and based on a separate confinement heterostructure (SCH) configuration. Both the upper and lower cladding $Al_{0.4}Ga_{0.6}As$ layers are 1.5 μm thick and doped at a concentration of $5x10^{17}$ cm^{-3} using Zn and Si respectively. The top contact epitaxial layer is a 0.1 μm GaAs layer doped with Zn at $5x10^{18}$ cm^{-3}. The photoluminescence (PL) measurements were performed using a diode-pumped solid state laser at 532 nm as the excitation source. The room temperature (RT) PL spectrum shows a peak emission wavelength at 860 nm and a shoulder at ~830 nm with a full-width-half-maximum (FWHM) of 31 nm (Fig. 1). From a Gaussian curve fit calculation, the 860 nm peak corresponds to the first electronic subband (e1) to heavy-hole (hh) transition (e1-hh), and the high energy shoulder at ~830 nm corresponds to the second electronic subband (e2) to heavy-hole transition (e2-hh). Spectra showing similar features were observed from PL measurements performed at 4K and 77K as given in the inset of Fig. 1.

The SLDs were fabricated using the standard ridge-waveguide fabrication process. First, the inter-electrode separation was defined by removing the highly doped contact layer using selective chemical etching. Plasma etching of the cladding layer resulted in 1.1 μm deep ridge sections. A 200 nm thick SiO_2 layer, deposited using plasma enhanced chemical vapor deposition method, was patterned and wet

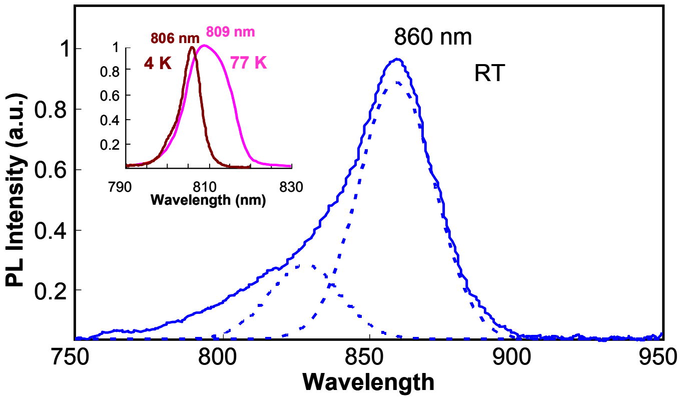

Fig. 1. Normalized photoluminescence spectra for the GaAs/AlGaAs double QW structure at 77 K and 4 K.

etched to open the electrode contact. The final steps of the fabrication involve p-contact (Ti/Pt/Au) evaporation, metal lift-off for electrode definition, substrate thinning, n-contact (Au/Ge/Au/Ni/Au) evaporation and thermal annealing for metal alloying. Anti-reflection (AR) coating, comprised of a multilayer of ZrO/SiO_2 with reflectivity of 1%-2%, was applied on the emitter facet to further suppress the feedback oscillation.

The emitter section is a 4 µm wide, 1.1 µm deep index guided ridge waveguide. The advantage of such a design over the angled facet or angled rib scheme is an improved ease of coupling between the device and fiber. The PA section is in the form of a 50 µm wide broad area slab-guide to spatially distribute the beam and to prevent optical feedback, thus suppressing lasing action. The maximum electrode lengths of the PA and emitter sections are 1 mm and 350 µm, respectively. The width of the electrode isolation, formed by removing the highly p-doped GaAs contact layer, is 25 µm. These devices were placed p-side up on a temperature-controlled heatsink and characterized under continuous wave (CW) operation at 20 °C.

III. RESULTS & DISCUSSION

The broadest emission is obtained from an SLD with a floating 850 µm PA section and a 200 µm active emitter section. Fig. 2 depicts the expected current-voltage (I-V) curve and superlinear light-current (L-I) curve with thermal roll-off begin to happen at 70 mA. The maximum amplified spontaneous emission (ASE) power is 0.56 mW. The spectrum shown in Fig. 3 reveals the flat-top and Gaussian-like shape of the emission with a FWHM of 80 nm and a spectral ripple of 0.3 dB. The spectral ripple corresponds to the amplitude of the Fabry-Perot oscillations, which were measured at a wavelength span of 10 nm at the center wavelength with the resolution of the optical spectrum analyzer set to 0.05 nm. The low ripple was achieved due to the sufficient absorption efficiency of the PA.

The evolution of the spectrum with varying emitter injection current is graphed in Fig. 4. At 20 mA (green dataset), there is a prominent peak (ground state) at 860 nm, correlating directly to the RT PL data in Fig. 1. As current increases, the ground state peak red shifts to 872 nm and a shoulder at 840 nm becomes apparent. This high energy shoulder can be correlated to the emission from the first excited state for the material structure used [11]. As a result of the band filling effect, this short wavelength peak exhibits a blueshift to 830 nm under high injection current. Multiple state emission from multiple-section SLDs has been achieved previously [6] with prominent spectral dips and 25% less FWHM. The SLDs described in the paper, however, have the unique flat-top like shape that is favorable for low coherence interferometric applications.

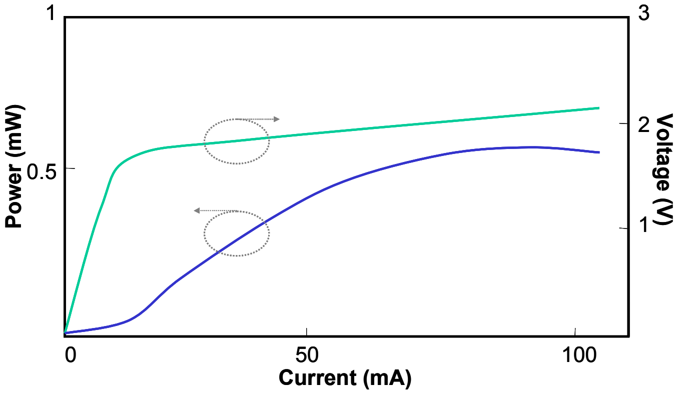

Fig. 2. The optical power and voltage versus injection current to the emitter section of the 2-section SLD.

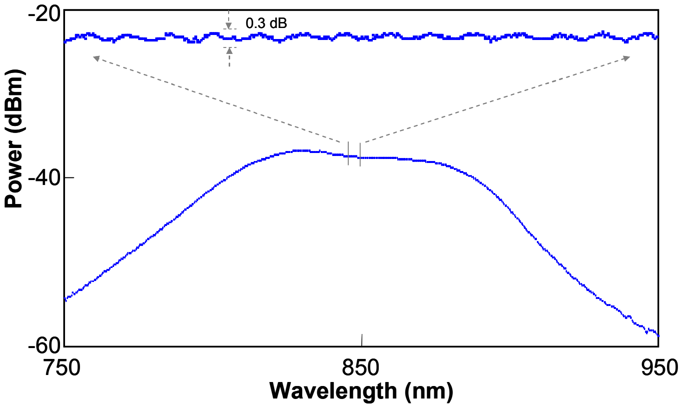

Fig. 3. The spectrum and ripple for the 2-section SLD measured using a spectrum analyzer with a resolution of 2 nm and 0.05 nm respectively. The wavelength span for the ripple spectrum is 10 nm (from 845 nm to 855 nm).

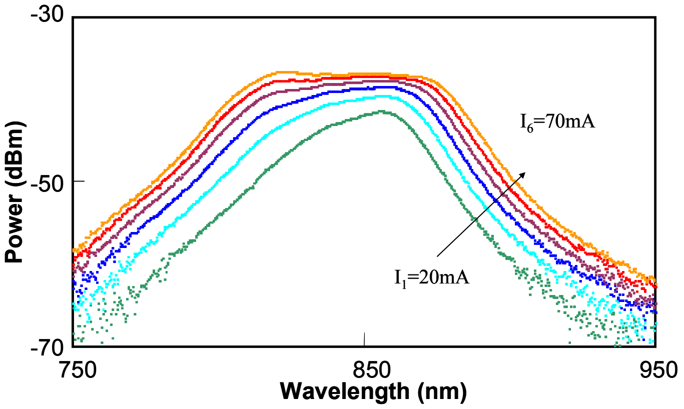

Fig. 4. The spectrum of the 2-section SLD with increasing injection current in increments of 10 mA

IV. CONCLUSION

In summary, a broadband 2-section SLD with unique flat-top spectral-free emission is achieved without anti-reflective coating. The device is fabricated on GaAs/AlGaAs DQW structure. An emission bandwidth as broad as 80 nm at a center wavelength at 850 nm, and an output power of 0.5 mW have been measured. This broad emission bandwidth will yield a high axial resolution of 4 µm in low coherence interferometric applications.

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REFERENCES

[1] G. O. Young, T. Ko, D. Adler, J. Fujimoto, D. Mamedov, V. Prokhorov, V. Shidlovski, and S. Yakubovich, "Ultrahigh resolution optical coherence tomography imaging with a broadband superluminescent diode light source," Opt. Express, vol. 12, pp. 2112-2119, 2004

[2] C. F. Lin and B. L. Lee, “Extremely broadband AlGaAs/GaAs superluminescent diodes,” Appl. Phys. Lett. vol. 71, pp. 1598-1600, 1997

[3] B. S. Ooi, K. McIlvaney, M. W. Street, A. Helmy, S. G. Ayling, A. C. Bryce, J. H. Marsh, and J. S. Roberts, “Selective quantum well intermixing in GaAs/AlGaAs structures using impurity-free vacancy diffusion,” IEEE J. Quant. Electron., vol. 33, pp. 1784–1793, 1997.

[4] P. J. Poole, M. Davies, M. Dion, Y. Feng, S. Charbonneau, R. D. Goldberg, and I. V. Mitchell, “The fabrication of a broad-spectrum light-emitting diode using high-energy ion implantation,” IEEE Photon. Technol. Lett., vol. 8, no. 9, pp. 1145–1147, 1996.

[5] M. L. Osowski, T. M. Cockerill, R. M. Lammert, D. V. Forbes, D. E. Ackley, and J. J. Coleman, “A strained layer InGaAs-GaAs-AlGaAs single quantum well broad spectrum LED by selective-area metalorganic chemical vapour deposition,” IEEE Photon. Technol. Lett., vol. 6, pp. 1289–1291, 1994

[6] A. T. Semenov, V. R. Shidlovski, D. A. Jackson, R. Willsch, W. Ecke, “Spectral control in multisection AlGaAs SQW superluminescent diodes at 800 nm,” Electron. Lett., vol. 32, pp. 255-256, 1996

[7] G.A. Alphonse, D. B. Gilbert, M. G. Harvey, and M. Ettenberg, “High power superluminescent diodes,” IEEE J. Quantum Electron., vol. 24, pp. 2454-2457, 1988

[8] C. F. Lin and C. S. Juang, “Superluminescent diodes at .8 μm with bent optical waveguide,” Electron. Lett. vol. 29, pp. 854-856, 1993

[9] Y. Zhaoy, G. Devanez, Z. Suny, K. Stairz, Y. Liuy, G. Duy and R Changzx, "The embryonic form of the integrated superluminescent diode," Semicond. Sci. Technol., vol. 12, pp. 576–579, 1997

[10] T. P. Lee, C. A. Burrus, and B. I. Miller, “A stripe geometry double heterostructure amplified-spontaneous-emission (Superluminescent) diode,” IEEE J. Quantum Electron., vol. 9, pp. 820-828, 1973

[11] I. Gontijo, T. Krauss, J. H. Marsh, and R. M. De La Rue, “Postgrowth control of GaAs/AlGaAs quantum well shapes by impurity-free vacancy diffusion,” IEEE J. Quantum Electron. vol. 30, pp. 1189-1195, 1994