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Novel Quantum Dot 3-section Super-luminescent Diode

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1. Introduction

Super-luminescent diodes (SLDs) with a spectral bandwidth greater than 150nm are desirable for use in optical coherence tomography (OCT) [1], where a center wavelength of 1.3 µm is important for medical applications due to the minimal absorption in human tissue. In quantum well (QW) SLDs, many approaches have been applied to achieve these features including post-growth quantum well intermixing [2], SLDs integrated with a tapered semiconductor optical amplifier [3], and chirped multiple quantum wells (MQWs) [4]. However, these techniques have one or several problems such as large spectral modulation, low output power, limited bandwidth, or complex growth techniques. Recently, QD active regions have attracted attention for SLDs because of the wide inhomogeneously broadened spectrum, made possible by controlling the dot composition and geometry [5-7]. These QD approaches compare favorably with quantum well versions, but simultaneously wide spectral bandwidth (> 150 nm) and reasonable power (>1 mW) in a QD SLD have been elusive.

In this paper, a novel ridge-waveguide QD SLD that emits near 1.3µm is reported. The multi-section device configuration enables the realization of ultra-wide 3-dB bandwidth (> 150 nm) and an output power greater than 1 mW with a uniform multi-stack QD structure. The new SLD allows a high flexibility in the design and can be reconfigured to adjust independently the power and the spectral bandwidth relative to the ground state (GS) and the excited state (ES) of the QD. The other advantage is that it doesn't require complex growth techniques.

2. Device structure and fabrication

The SLD devices were fabricated from two uniform multi-stack QDs structures, un-doped QDs with ultra-wide spontaneous emission and p-doped QDs. The photon luminance spectra of the un-doped QDs have a full width half maximum (FWHM) over 80nm with a ground state emission at 1.25 µm. The wide inhomogeneous line broadening of un-doped quantum dot spontaneous emission is caused by large fluctuation in self-assembled quantum dot sizes. The p-doped SLD active region is made of 6 p-doped InAs/GaAs QD layers. Both structures have been grown by molecular beam epitaxy [8]. Broad area light emitters fabricated from the material showed emission at 1.25 µm on the ground state with a FWHM of 50 nm and 1.19 µm for the excited state. The wafers were processed into multi-section devices following standard ridge waveguide laser processing. The samples were etched to form a 3.5-µm wide ridge waveguide by inductively coupled plasma (ICP) etching. The ridges are etched down to 0.2 µm above the active region for improved optical field confinement. Ion implantation was used to isolate the adjacent sections. A final multi-section device is composed of 16 segmented-contact sections. Each section is 0.5-mm and the total optical cavity length is 8-mm. The devices were mounted p-side up on a copper heatsink. A TE cooler was used to control temperature. A reverse voltage of -7V was applied on the absorber to eliminate the reflected light from the back facet. By changing the bonding configuration, we can vary the section lengths in the same device.

3. Basic principles of a multi-section SLD

A multi-section SLD consists of a single-mode ridge waveguide divided into three electrically-isolated sections as shown in Fig.1. The absorber section, Abs, located at the rear facet, is reverse-biased to eliminate the back reflections. The two gain sections, A1 and A2, amplify the spontaneous emission. The optical gain and the spectral bandwidth of the amplifiers are tuned through the current densities and the section lengths, L1 and L2. The intensity of the amplified spontaneous emission (ASE) changes with transmission length and the optical gain.

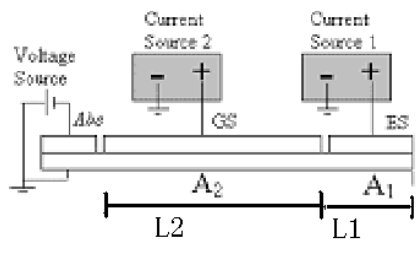

Fig. 1 Structure of multi-section SLDs

4. Results and Discussion

During the testing, the gain section A1 works at the ES and tsection A2 works at the GS. Both of the two gain sections amplified the output ASE at the ground state and the first gain section amplified ASE at the excited state. Increasing the length of the amplifiers results in increasing the power but also in a narrowing of the spectral bandwidth. By changing the configuration of the SLD devices, we optimized the device to provide wider spectral bandwidth or higher output power.

The un-doped QDs SLD has super wide bandwidth. Figure 2 illustrates the evolution of the FWHM versus the total current in pulsed operation with L1 = 0.5 mm and L2 = 2.5 mm. The ratio between the current I_1/I_{total} equals 60%, 55% and 50%. The inset shows the spectrum when current applied on section A1, I_1, is 300mA and total current is 500mA. The FWHM is as much as 220nm with an output power of 0.15mW. The dip between the GS and the ES is less than 1.5 dB. However, the small gain and characteristic temperature at the ES limits the output power of un-doped QDs SLD.

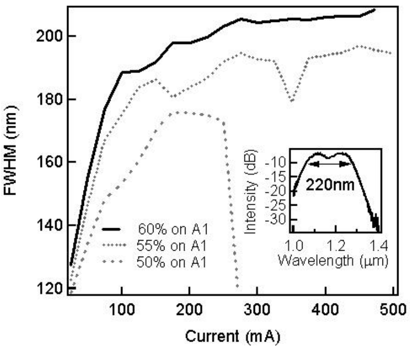

Fig. 2 The FWHM of a QD SLD versus total pump current in pulsed mode at 25°C. The inset shows the spectrum when current applied on section A1 is 300mA and total current is 500mA.

The p-doped QDs structures have higher optical gain and higher characteristic temperature than the un-doped QDs. We successfully achieved p-doped QD SLDs with both high output power and wide bandwidth.

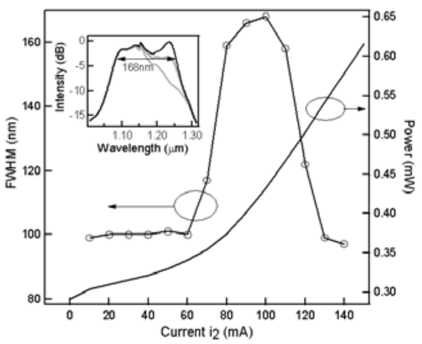

Fig. 3. L-I curve and FWHM of the p-doped QD SLD versus current I_2 in CW mode at 10°C. L1=1.5 mm and I_1=700 mA, L2=5 mm. The inset shows the spectra for I_2=10, 80, 100 mA

The FWHM and the CW output power at 10 °C are plotted versus I_2 for L1 = 1.5 mm and L2 = 5 mm in the Fig. 3. The FWHM stays constant (~100 nm) until 60mA, and then increases strongly with I_2 to reach a maximum value of 168nm for I_2 = 100mA. The corresponding CW output power is 0.43mW. By increasing L1 to 2 mm and keeping L2 = 5 mm, a higher CW power of 1.25mW can be obtained, but a lower FWHM of 123 nm for I_1 = 700mA and I_2 = 140mA is observe.

With the multi-section SLD, the high resolution OCT picture was obtained. The SLD achieved a FWHM of 90nm at 1225nm. Total light power is 0.10~0.12mW through fiber coupling. The measured spatial (axial) resolution was 7.8 um, compared to the theoretical value of 7.3 um.

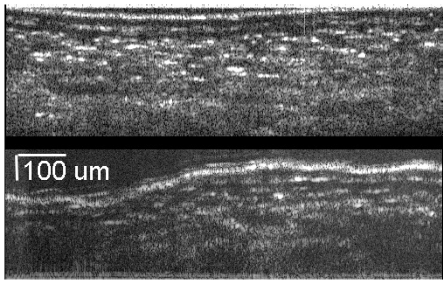

Fig. 4 OCT picture with the multi-section SLD as the optical source

3. Conclusions

A novel ridge-waveguide 1.3μm QD SLD with super wide bandwidth and useful power is reported. The high resolution OCT picture was obtained with the multi-section SLD.

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