Characterization of Three-Section AlGaInAs Multiple Quantum-Well Mode-locked Lasers for Space Applications

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Abstract: We report a quantum-well-intermixing-free three-section mode-locked laser diode at 1580nm, featuring 1.70 psec pulse width. The fixed-point frequency analysis shows four different laser parameters conducive for compensating repetition rate and carrier frequency variations in space environment.

1. Introduction

High repetition rate monolithic mode locked laser diodes, (MLLDs) based on III-V Multi-quantum-well (MQW) material have attracted significant attention in space application due to their high speed, compactness, high stability, excellent efficiency, and wide wavelength coverage when they are operated under passive mode-locked (PML) and hybrid mode-locked (HML) conditions. Various approaches have been reported, including two-section structures [1] and a three-section design with a phase section whose bandgap is blue shifted from the gain using the selective quantum well intermixing process (QWI) [2]. However, QWI introduces additional loss to the laser, potentially compromising its performance. We present our approach utilizing a QWI-free three-section design for space applications. This design comprises a saturable absorber (SA) section, a gain section, and a modulation section. Our approach not only provides greater tunability of the laser's repetition rate (f_{rep}) but also addresses the issue of high loss. To examine the behavior of MLLDs, fixed-point frequency analysis helps measure changes in the pulse train repetition rate, f_{rep} and central carrier frequency f_0 in response to variations in MLLD temperature, current injection in the gain and modulation sections, and reversed bias voltage on the SA section [3]. This analysis is crucial for compensating for changes in f_{rep} and f_0 that may occur after prolonged use in a space environment, and for f_{rep} and f_0 control in coherent optical inter-satellite links (OISL). Additionally, fixed-point frequency analysis is essential for understanding alterations in the refractive index and dispersion, enabling optimal device control.

2. Device Fabrication and Test Setup

The three-section MLLD is fabricated from a commercially available AlGaInAs-InP multiple quantum well (MQW) wafer. The three-section MLLD comprises a 1.85mm gain section, a 70 µm saturable absorber (SA) section and a 100 µm modulation section. Figure.1 illustrates a schematic of the characterization setup for the MLLD under PML conditions. The laser diode is mounted on a gold-coated copper stud with a TEC temperature controller attached. The light from the SA side is coupled to fiber using a tapered fiber lens and directed to the diagnostic setup. The optical signal is amplified using a semiconductor optical amplifier (SOA). The diagnostics consist of an optical spectrum analyzer (OSA), an InGaAs PIN photodiode (20GHz bandwidth), an RF spectrum analyzer (RFSA) and a second harmonic generation (SHG) autocorrelator (AC). The optical pulses are compressed with a 4-f grating compressor under HML conditions. An Erbium doped fiber amplifier boosts the optical power of the pulses before guiding it to the SHG autocorrelator.

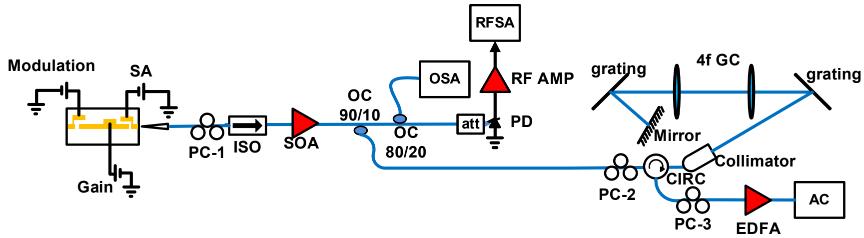

Fig. 1: Schematic of characteristic setup

3. Result and Discussion

Standard characterization methods are employed for the three-section MLLD. Under PML operation, the output characteristics are depicted in Fig. 2(a) and (c). Stable PML is achieved by forward biasing the gain section and modulation section at I_{Gain}=200.43 mA and I_{mod}=12.9 mA, and reverse biasing the SA section at V_{SA}= -2.83 V. The output pulse train was passed through a bandpass filter (Δλ= 7.3 nm @ 1580) and dispersion compensator (D=0.093 ps/nm) resulting in a pulse with duration of 1.7 psec, spectral width of 3.97 nm, with a corresponding time bandwidth product of 0.85. Fig. 2(b) shows, after photodetection, the RF spectrum, which has a peak frequency at 20.3254 GHz, equivalent to the cavity round-trip frequency.

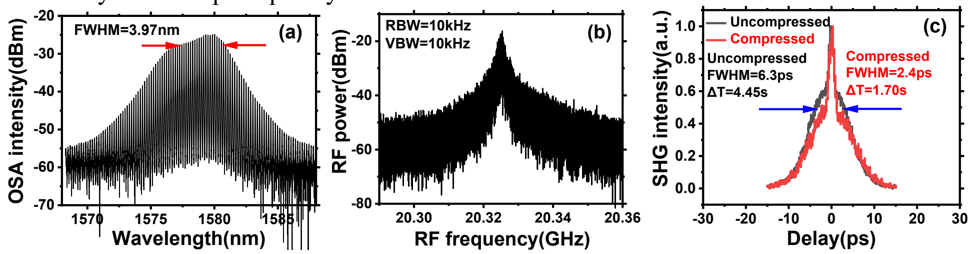

Fig. 2: (a) optical spectrum (b) RF Spectrum (c) SHG autocorrelation trace (Black line: uncompressed; Red line: After compressed with D=0.093ps/nm and band pass filtered with pass band of 7.3nm center at 1579.81nm)

Changing any of the MLLD's driving parameters will influence the MLLD's optical comb-line frequencies ν_0, and their mode spacing f_{rep}. By individually adjusting each of the MLLD's driving parameters and monitoring the changes in the comb-line frequency ν_0, as well as the cavity repetition rate f_{rep}, one can compute the fixed-point frequency by utilizing .

$$\nu_{fix} = -\frac{\partial \nu_o/\partial X}{\partial f_{rep}/\partial X} \cdot f_{rep} + \nu_o$$

The results of the fixed-point measurements are presented. The calculated frequency is given in each frame, and attention must be directed to the slope of each curve. It should be noted that in OISL applications, several factors can influence the pulse repetition rate, including Doppler effects due to orbiting, laser aging effect from prolong operation and radiation induced degradation of the laser. Our results indicate that the slopes of the changes in carrier frequency and pulse repetition rate would have sufficient sensitivity and range for compensating potential alterations.

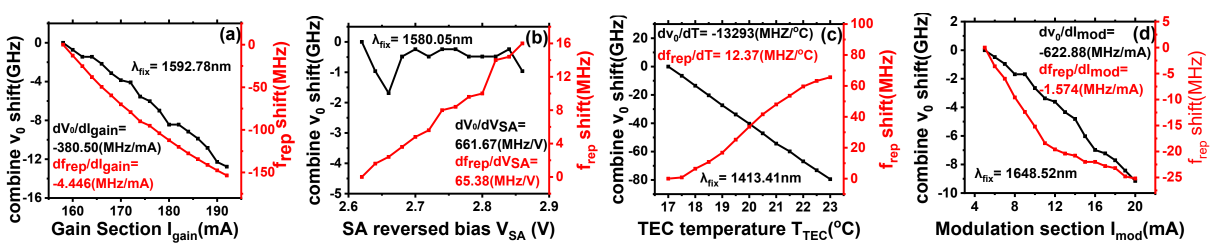

Fig. 3: Fixed point analysis for (a) Gain section current changes: λ_{fix}= 1592.78nm (b) SA reversed bias voltage changes: λ_{fix}= 1580.05nm (c) Temperature changes: λ_{fix}= 1413.41nm (d) Modulation section current changes: λ_{fix}= 1648.52nm

4. Conclusion

We successfully generated 1.70ps pulses with 0.85 time-bandwidth product at 20.3254GHz under passive mode-locking conditions in a three-section MQW MLLD. Employing a 4-f grating compressor and band pass filtered it at 1579.81nm facilitated this achievement. Our investigation into fixed-point frequencies for four parameters in a monolithic MLLD under passive mode-locking conditions revealed that each laser operating parameter can effectively compensate for both repetition rate and carrier frequency changes making our device robust for long-term with agile flexibility for use in space-based applications.

5. References

[1] Sarailou, Edris, Abhijeet Ardey, and Peter J. Delfyett. "Low Noise Ultrashort Pulse Generation by Direct RF Modulation at 22 GHz From an AlGaInAs Multiple Quantum-Well Laser at 1.55μm"IEEE Photonics Technology Letters 24.17 (2012): 1561-1563.

[2] Sarailou, Edris, and Peter Delfyett. "Injection-locked semiconductor laser-based frequency comb for modulation applications in RF analog photonics." Optics Letters 41.13 (2016): 2990-2993.

[3] Zaman, Abdullah, and Peter J. Delfyett. "Fixed-point frequencies analysis of monolithic 10 GHz repetition rates AlGaInAs multiple quantum-well laser diodes." 2017 IEEE Photonics Conference (IPC). IEEE, 2017.