Multi-tone Injection Locking of Three-section AlGaInAS Mode-locked Lasers for Space Applications

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Abstract—**We fabricate and test the three-section mode-locked laser diode. The shortest pulse is 3.34ps with time-bandwidth product of 0.65. We conduct multi-tone injection locking which result in an RF linewidth reduction of 20× while maintaining the pulse width, with 7.62µW injection power at 1562nm.**

Keywords— Multi-quantum-well, laser mode locking, injection locking, space application *(key words)*

I. INTRODUCTION

High repetition rate monolithic mode locked laser diodes, (MLLDs) based on III-V semiconductor material have attracted significant attention in space applications due to their high speed, compactness, high stability, excellent efficiency, and wide wavelength coverage when they are operated under passive mode-locked (PML) conditions. However, semiconductor devices can deteriorate in space environments due to radiation and temperature fluctuations, leading to reduced device performance, increased device loss, broadened RF linewidth, etc. and consequently, reducing the device lifetime in space. Several techniques have been demonstrated to achieve linewidth reduction including nested cavity approach [1] and electro-optic feedback [2]. However, these approaches may also suffer from total ionized dose effects and radiation damage due to their long-term operation in the space environment. One potential approach to overcome these limitations is to use multi-tone optical injection locking technique. This technique will simultaneously reduce the axial mode linewidth and stabilize the repetition rate of the semiconductor mode-locked laser [3]. In this paper, we fabricate a three-section AlGaInAs/InP multi-quantum-well(MQW) MLLD and conduct multi-tone injection locking using a tunable continuous wave(CW) laser as a master laser. We achieve a reduction in the RF linewidth and increase in the optical spectrum bandwidth, demonstrating great potential for space applications.

II. DEVICE FABRICATION AND TEST SETUP

The three-section MLLD is fabricated from a commercially available AlGaInAs-InP multiple quantum well (MQW) wafer. The MLLD comprises a gain section of 1.89mm, a saturable absorber section (SA) of 40 µm and a modulation section of 40µm. Fig.1 illustrates a schematic of a characterization setup for multi-tone injection locking of the MLLD under PML conditions. The laser diode is mounted on a gold-coated copper stud with a TEC temperature controller attached to it. A narrow linewidth tunable laser is injected through the SA side port for injection locking the MLLD. The output light from the SA side is coupled to fiber using a tapered fiber lens and sent to the diagnostic setup. The optical signal is boosted using a semiconductor optical amplifier (SOA). The diagnostics consist of an optical spectrum analyzer (OSA), an InGaAs PIN photodiodes (22GHz bandwidth), an RF spectrum analyzer (RFSA) and a SHG autocorrelator. The optical pulses are compressed with a 4-f grating compressor.

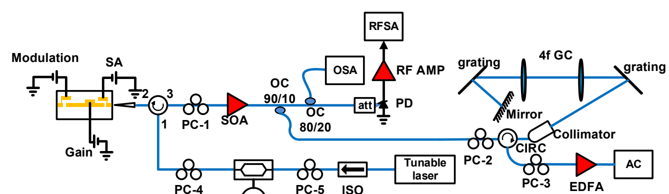

Fig. 1: Experimental setup. PC, polarization controller; PD, photodetector; OSA, optical spectrum analyzer; ISO, optical isolator; SOA, semiconductor optical amplifier; ATT, attenuator; RFSA, RF spectrum analyzer; CIRC, circulator; 4f GC, 4-f grating compressor, AC, intensity autocorrelator

III. EXPERIMENTAL RESULTS

The three-section MLLD is passively mode-locked by applying 129.92mA in the gain section and a reverse bias voltage of -2.81V in the SA section. We apply 4.2mA forward bias current in the modulation section and operate the MLLD at 21°C. The output pulse is compressed with the 4f grating compressor. The typical optical and RF characteristics, as well as the intensity autocorrelation trace of the output pulse from the MLLD are shown in Fig. 2. Specifically, Fig. 2(a) depicts an optical spectrum full width half maximum (FWHM) of 2.27nm, Fig. 2(b) shows the RF spectrum centered at 21.436GHz with a broad linewidth, which is typical of a PML semiconductor laser. Fig. 3(c) shows the intensity autocorrelation (AC) trace of the PML laser of a pulse with a 4.86ps pulse width. After compression using a 4-f grating compressor with dispersion coefficient of 0.464ps/nm. The compressed pulse shows a 3.34ps pulse width on the AC, which deconvolves to Δτ=2.36ps. The time-bandwidth product is 0.65, which is close to the transform limited.

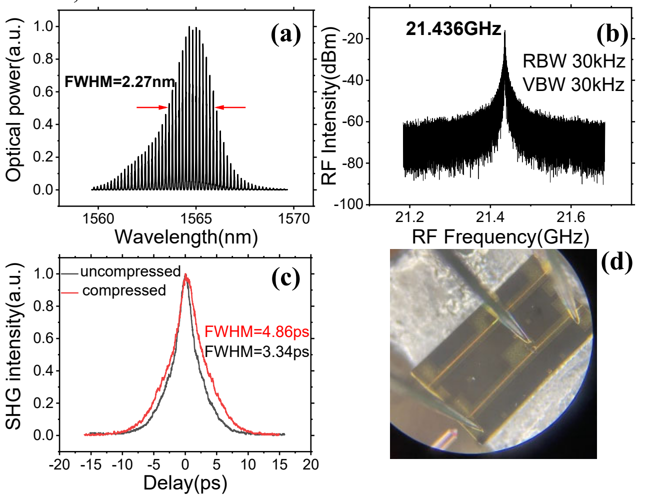

Fig. 2. Characterization of three-section MLLD under passive mode-locking. (a)OSA spectrum.(b)RF spectrum.(c)Pulse intensity autocorrelation trace, red: umcompressed and compressed with D=0.464ps/nm. (d)Microscope images of the device. RBW: Resolution bandwidth. VBW: video bandwidth. FWHM: full width half maximum.

The multi-tone injection locking of the three-section MLLD is conducted using the experimental setup shown in Fig. 1. First the MLLD is biased under passive mode-locking condition, as described earlier. Then, a narrow linewidth CW laser from a tunable laser is coupled into the MLLD through the taper fiber lens. The CW laser's wavelength is tuned to fall within the locking range of one of the axial modes of the MLLD. An RF frequency synthesizer is employed to generate microwave, driving the $LiNbO_3$ modulator and generating sidebands around CW laser carrier exactly at the repetition rate of the three-section MLLD. We tune the master CW laser wavelength to be around the center of the PML optical spectrum (approximately 1565.77nm) and at blue side of the optical spectrum (approximately 1562.79nm). Injection locking of the three-section MLLD leads to a reduction of its RF linewidth. We optimized the master laser power injection to achieve the shortest AC trace pulse width. The best master laser power is 10.40μW at 1565nm and 7.62μW at 1562nm. The RF frequency synthesizer modulate the $LiNbO_3$ modulator at 21.4128GHz.

Fig. 3(a) displays the optical spectrum after injection locking at different master laser wavelengths. Spectral broadening from 2.27nm to 4.34nm is observed when the master laser is near 1562nm. Additionally, it shows a wider optical bandwidth as compared to the injection locking result obtained at 1565nm. In Fig. 3(b), with the three-section laser injection locked on the blue side at 1562nm, the RF spectrum exhibits a reduction in the RF linewidth from 2MHz to 100kHz at -23dBc, which shows an improvement of 20×. Fig. 3(c) demonstrates the use of the 4-f grating compressor to get the shortest pulse. When the three-section MLLD is injection locking around 1562nm, the shortest pulse is achieved by apply dispersion D=0.325ps/nm, resulting in AC pulse width of 3.48ps, which deconvolving to Δτ=2.46ps, with a time-bandwidth product of 1.29. When the injection master laser wavelength is around 1565nm, the shortest pulse is achieved by apply dispersion at D=0.232ps/nm. The AC trace shows a much broader pulse width at 4.35ps. In Fig. 3(d), a comparison of the shortest AC trace pulse width between the free running case and injection locked operation around 1562nm reveals that the minimum pulse width is almost the same. These results show that this multi-tone injection locking technique can successfully transfer the narrow RF linewidth from the master laser to the slave laser while preserving the short pulse width.

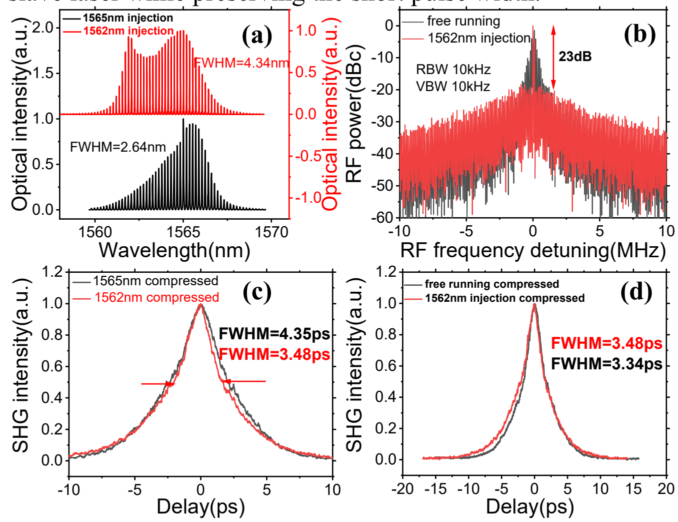

Fig. 3(a) OSA spectrum after multitone injection locking at 1562nm and 1565nm. (b) The RF spectrum before and after multitone injection locking at 1562nm. The injection power is 7.62 μW. (c)Intensity autocorrelation trace after multitone injection locking at 1562nm and 1565nm (d)Intensity autocorrelation trace of free running and multitone injection locking at 1562nm.

IV. Conclusion

In this work, we fabricate and test the three-section MLLD at 21.436GHz. The optical spectrum FWHM is 2.27nm and the shortest compressed pulse is 3.34ps, result in a time-bandwidth product of 0.65. We also present our approach for using the multi-tone injection locking technique to narrow RF linewidth. We observed a 20× RF linewidth reduction at -23dBc with an injection power of 7.62 μW. The optical pulse width remains constant after injection. With the small injection power requirement, it shows great potential in space application. In next step, we plan to conduct radiation tests on the three-section MLLD to verify its survivability the radiation environment.

V. Reference

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