Fabricating And Testing AlGaInAs Multiple Quantum-Well Laser Diodes For Space Application

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***Abstract*—We report our work on the fabrication and testing of AlGaInAs MQW lasers for space applications. A radiation test of an FP diode laser with 1.8MeV protons shows a red shift to the lasing optical spectrum. We conducted the fixed-point frequency analysis for three parameters on a 15GHz repetition rate mode locked laser diode at 1.57 µm. The measurements show our capability to compensate the combine offset frequency f_0 and comb spacing f_{rep} shift during long-term operation. We are able to hybrid mode lock the laser by modulating the saturable absorber at the fundamental repetition rate. Pulses of 1.84ps were obtained with a time-bandwidth product of 0.68.**

Keywords—AlGaInAs, multiple quantum well (MQW), proton radiation damage, space application, mode locked laser diode (MLLD). Hybrid mode locking (HML).

I. Introduction

High repetition rate monolithic mode locked laser diodes, (MLLDs) based on III-V semiconductor 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) condition and hybrid mode locked(HML) conditions. However, space applications pose unique challenges, including extreme temperature variations and radiation. Therefore, examination of the behavior of laser diodes under radiation conditions is important to understand how the device would perform in space [1]. On the other hand, MLLD's optical combine frequency f_0 and cavity repetition rate f_{rep} are very susceptible to fluctuations of MLLD's temperature, DC bias on the gain section and saturable absorber voltage (SA). Thus, fixed point frequency analysis is crucial to understand changes in the refractive index and dispersion, and optimally control the device [2][3].

II. Device Fabrication and Test Setup

The one-section Fabry-Perot (FP) laser and two-section MLLD are fabricated from a commercially available AlGaInAs-InP multiple quantum well (MQW) wafer. The one-section FP laser has a length of 2.12mm. The two-section MLLD has a gain section of 2.78mm and a saturable absorber (SA) of 100 µm.

Fig.1 illustrate a schematic of a characterization setup for MLLD under both PML and HML conditions. The laser diode is mounted on a gold-coated copper stud with a TEC temperature controller attached to it. The 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 (20GHz bandwidth), an RF spectrum analyzer (RFSA) and a SHG autocorrelator. The optical pulses are compressed with a 4-f grating compressor under HML condition. An Erbium doped fiber amplifier boosts the optical power of the pulse before guiding it to the SHG autocorrelator.

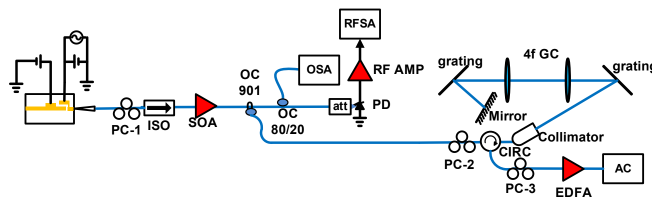

Fig. 1: Experimental setup. PC, polarization controller; PD, photodetector; OSA, optical spectrum analyzer; ISO, optical isolator; SOA, Semiconductor optical amplifier; ATT, attenuator; RFSA, RF spectrum analyzer; CIRC, circulator; 4f GC, 4-f grating compressor.

III. Experimental Results

The one section FP laser was exposed to 1.8MeV protons with fluences of 1×10^{10}, 1×10^{11}, 1×10^{12}, 3×10^{12} and 1×10^{13} H^+/cm^2 at Vanderbilt University. The device was then stored at room temperature for 2 weeks for passive annealing. The standard characterization methods of the FP lasers were conducted. First, the optical power was measured by butt-coupling a power meter to one facet of the laser. The optical power per facet versus gain current (I_{Gain}) between pre- and post-radiation shows a threshold shift from 73.3mA to 256.43mA. The slope efficiency decreased from 71.1µW/mA to 19.11µW/mA, as illustrated in Fig. 2(a). The amplified spontaneous emission (ASE) spectrum was taken at gain current below lasing threshold, as shown in Fig. 2(b). The gain spectrum shows some red shift after radiation. An OSA peak red shift was observed when I_{Gain} was above lasing threshold. The peak moves from 1559.18nm to 1564.95nm, as shown in Fig. 2(c). These indicates that some quantum well intermixing happens during the radiation process. The close-in OSA spectrum shown the pre- & post-radiation longitudinal modes overlaping each other, as shown in Fig. 2(d), indicating that the effective refractive index of the device didn't change during the radiation test.

For two-section MLLDs, varying the laser parameters including gain current, SA reversed bias, or device temperature will influence the MLLD's optical combline frequency f_0 and the comb repetition rate f_{rep}. It is important to monitor how these parameter changes affects the absolute combline frequency as

This work was supported by funding from the National Science Foundation EPICA program.

well as the cavity repetition rate. This monitoring also grants us the possibility to compensate the potential drift in long-term use. Moreover, a distinct fixed point frequency can be found that would not be modified by the changing of each parameter. The fixed point frequency can be computed by utilizing $\nu_{fix} = -\frac{\delta f_o/\delta X}{\delta frep/\delta X} \times f_{rep} + f_o$ [2][3].

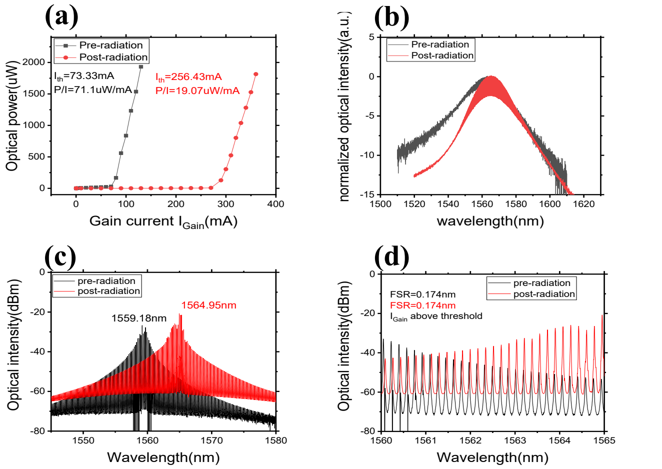

Fig. 2: (a) Output power-current characterization at 21^{O}C. (b) Amplified spontaneous emission spectrum below threshold at 60mA and 250mA for pre- and post-radiation. (c)OSA spectrum above threshold at 81mA and 290mA for pre- and post-radiation. (d)zoom in of the OSA spectrum above threshold.

We performed the fixed point frequency analysis for three MLLD's parameters under PML condition: 1) gain current, 2) SA reversed bias voltage, 3) device temperature. First, we measured the variation of gain section injection current (I_{gain}) while keeping the SA reverse bias voltage (V_{SA}) at -1.80V and the TEC temperature controller temperature T_{TEC} at 21^{o}C. As shown in Fig. 3(a), The I_{Gain} was varying from 138mA to 168mA. Increasing the I_{Gain} resulted in a red shift in the combline frequency f_0 with slope of -777.97MHz/mA, and repetition rate f_{rep} shows a positive slope of 1.585MHz/mA. The fixed point frequency ν_{fix} is calculated to be 198.40THz. Next, we conducted fixed point frequency analysis for changes in the saturable absorber reversed bias (V_{SA}) were performed with I_{Gain}= 150 mA and T_{TEC} = 21^{o}C. The V_{SA} was varied from -1.62 V to -1.86V. As shown in Fig. 3(b), an increasing in both f_0 and f_{rep} is observed for higher V_{SA}. The slope was determined to be 10246.5 MHz/V for f_0 and 9.396 MHz/V for f_{rep}. The calculated fixed point frequency, ν_{fix}, was 174.82 THz. Thirdly, we performed the fixed point frequency analysis for changes in the TEC temperature (T_{TEC}), and were performed with I_{Gain}= 150mA and V_{SA}=-1.80V. The T_{TEC} was varied from 16.5^{o}C to 23.5^{o}C. As shown in Fig. 3(c), a decrease in both f_0 and f_{rep} was observed for higher T_{TEC}. The slope was calculated to be 11121.01 MHz/^{o}C for f_0 and 1.349 MHz/^{o}C for f_{rep}. The calculated fixed point frequency, ν_{fix}, was 68.63 THz.

Finally, we attempted to improve the performance of the two section MLLD by operating it under a hybrid mode-locked (HML) condition. We successfully achieved stable hybrid mode locking by injecting a current of 83.14mA into the gain section, reversed biasing of -2.93V of the SA section and applied RF modulation at 15.072434GHz with 32dBm of power on the SA section using a bias tee. The output characteristics are shown in Fig. 2(d-f). In Fig. 2(d), the optical spectrum centered at 1569nm has a FWHM of 3.05nm. In Fig. 2(e), the RF spectrum shows a peak of 15.0721GHz, which is locked to the external modulation. Fig. 2(f) displays the intensity autocorrelation of the compressed optical pulses. The compressed was achieved by applying anomalous dispersion with dispersion coefficient of 0.636 ps/nm. The autocorrelation signal of the pulse is equal to 2.61ps, which deconvolves to Δτ=1.84ps. The time-bandwidth product is 0.68, which is close to the transform limited.

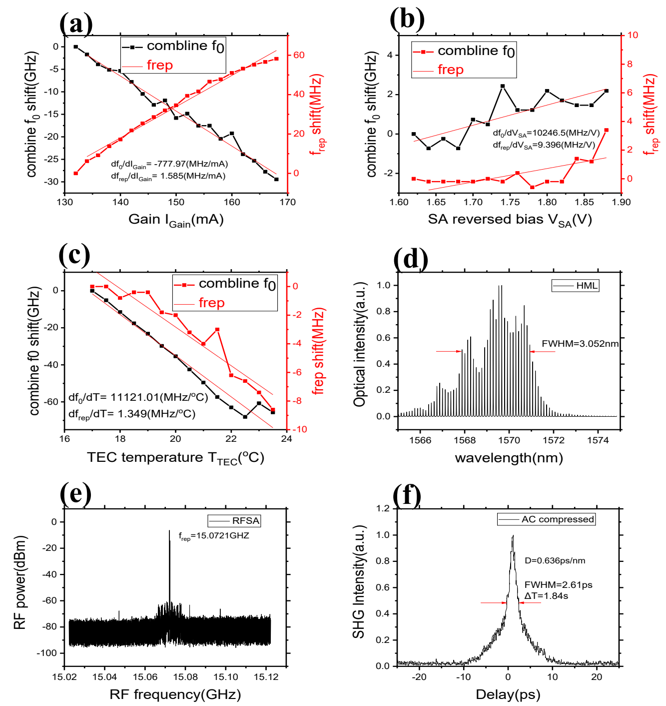

Fig. 2: (a) gain section current changes, (b) saturable absorber (SA) reverse bias voltage changes, (c) temperature changes, (d) Optical spectrum of hybrid mode locked laser, (e) RF spectrum of the hybrid mode locked laser. (f) SHG autocorrelation trace.

IV. Conclusion

We conducted a series of test on the AlGaInAs-InP MQW diode lasers for their future space applications. We have tested the one section FP diode laser before and after radiation exposure, revealing that radiation may cause some quantum well intermixing effects and inducing a red shift of the optical spectrum. We performed the fixed point frequencies for three different parameters in a two-section MLLD. The analysis will aid in improving the stability of the laser by modulating these parameters. We also operated the MLLD under HML condition. A pulses duration of 1.84ps were obtained with a time-bandwidth product of 0.68, which is close to transform limited.

V. References

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