Enhanced performance of 450 nm GaN laser diodes with an optical feedback for high bit-rate visible light communication

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Abstract: First report on significant performance improvement of 450 nm blue edge-emitting laser in terms of optical linewidth (~6.5 times), modulation bandwidth (~16%) and SMSR (~7.4 times) by employing self-injection locking scheme.

1. Introduction

Visible light communication (VLC) has been identified as a potential solution for indoor high bit-rate communication owing to its unique feature of offering simultaneous illumination and communication, thanks to employment of semiconductor devices based light sources and detectors. Currently, extensive research has been undergoing to improve the performance of these optoelectronic devices, and laser diodes (LDs) in particular, to reinforce energy efficient high-speed green communication. In literature, injection-locking scheme has been identified as a potential candidate to significantly improve the laser characteristics thus abetting in achieving high data rate communication. Two variation of injection locking techniques has been reported in the literature; optical external injection locking (EIL) and self-injection locking (SIL). While the former requires an additional high-quality seeding source, the latter is based on optically feeding part of the LD's output power back into the device for the locking purpose. Non-linear semiconductor laser dynamics due to the optical injection, has been comprehensively studied in the NIR region. For instance, in [1], Peterman. mathematically showed that linewidth narrowing is possible when the round-trip phase is zero under strong optical feedback. He also suggested that higher injection ratio (ratio of optical feedback power to the optical source power) helps in decreasing the linewidth. Besides, improvement in the modulation bandwidth by applying a strong optical feedback has been demonstrated by Radziunas *et. al.* [2] on an external cavity injection locking scheme. In the visible region, very few recent reports on external injection locked blue [3] and red [4] semiconductor lasers are available, exhibiting improvement in the locked mode optical power and the modulation bandwidth, however, no report on the employment of SIL is available, to our knowledge, which is highly attractive because of its cost-effective and energy efficient deployment. In this work, we present the performance characteristics of self-injection locked InGaN/GaN blue edge emitting laser by demonstrating a significant enhancement of modulation bandwidth and side-mode-suppression-ratio (SMSR), and reduction in optical linewidth, under self optical feedback scheme, and at three external cavities. This would potentially enable straightforward deployment of SIL scheme on LDs to achieve high-bit rate VLC.

2. Experimental Setup

The experimental setup for self-injection locking is illustrated in Fig. 1 (a). We utilized off the shelf TO-can LD from Thorlabs (PL450B) at the transmitter, and Silicon ultra-fast Photodiode (UPD-50-UP, Alphalas) as the receiver. Two 92:8% pellicle beam splitters (BS, Thorlabs BP108) were placed in the system to ensure maximum optical feedback from the silver coated mirror, placed at an external cavity length, L_{ext}, and real-time characterization of the LD. Since the active region of the UPD and fiber coupler aperture is very small, a bi-convex (Lens 2, Thorlabs LA4148) and a plano-convex (Lens 3, Thorlabs LB1471) lens was installed before them to facilitate maximum transmission of optical power. A trans-impedance amplifier (TIA, Tektronix PSPL5865) of 26 dB gain is used to amplify the detected optical signal at the UPD which was then send to the Network Analyzer (Agilent E8361C) to obtain the frequency response. All the characterizations were performed at a fixed heat-sink temperature of 20°C with an injection current of 60 mA.

3. Results and Discussion

The small signal modulation response, for an external cavity of 26 cm, is shown in Fig. 1(b). We observe formation of peaks and valleys at a certain frequency interval which was also observed in the case of quantum dot laser [5]. The interval of the peaks is attributed to the reciprocal of the round-trip delay in the external cavity, which is τ_{ext} (L_{ext}) = ~1.27 (19), ~1.73 (26), and ~3.73 (56) ns (cm), and corresponds to ~790, ~580, and ~270 MHz interval in the frequency response. Our experimental data of the external cavity peaks interval ~730, ~570, and ~260 MHz are in excellent agreement with the calculated data. Fig. 1(c) represents the optical spectrum under free running and locked scenario, which clearly shows a significant improvement in the peak power from a dominant single longitudinal mode, thus considerably improving the SMSR. In Fig. 1(d) and (e), we plotted the modulation bandwidth and optical linewidth at the aforementioned external cavities, and compared with the free running case. A gradual deterioration in the modulation bandwidth and linewidth, as the external cavity is increased, is observed. This is ascribed to the reduction in the injection ratio as the external cavity increases (decrease in the feedback power due to scattering losses in the cavity). A maximum of 1.16 and 6.5 times improvement in the modulation bandwidth and optical linewidth was observed at 19 cm external cavity, respectively. In the case of SMSR, 7.43 times improvement was observed at 19 cm external cavity.

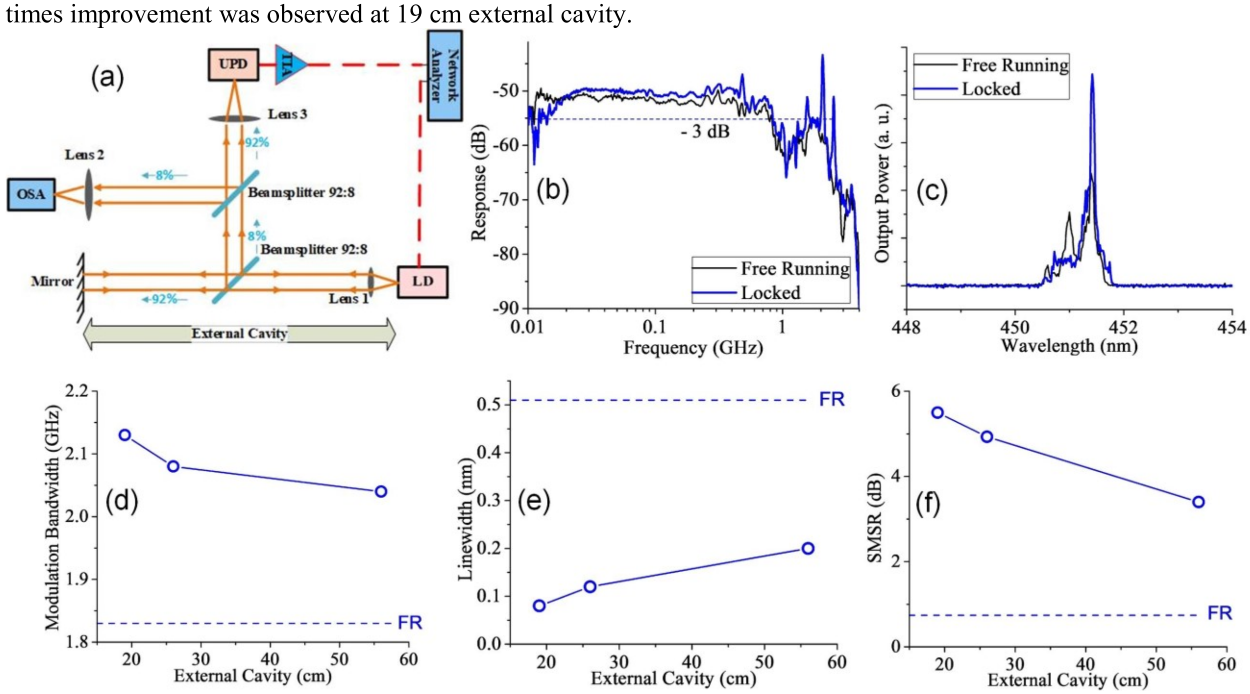

Fig. 1 (a). Experimental setup with optical feedback via an external cavity. The yellow lines and arrows illustrates the light beam and its propagation direction. (b) The small signal modulation response of 450 nm laser diode at 60 mA injection current, and 26 cm external cavity length, for the free running and the injection locked case. (c) Lasing spectrums. (d) Modulation bandwidth, (e) optical linewidth, and (f) SMSR as a function of external cavity length. The dashed lines in (d), (e), and (f) corresponds to the free running (FR) case.

3. Conclusion

Self injection locking on 450 nm GaN blue laser is demonstrated at three different external cavities, and their performance characteristics in terms of modulation bandwidth, linewidth, and SMSR was assessed. Improvement in the LD performance is observed from the smaller external cavities (i.e. at higher injection ratio). An overall of enhancement of 16% in the modulation bandwidth, 6.5 times in linewidth, and 7.4 times in SMSR improvement was observed.

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