Optical Bistability in Monolithic Two-sectioned InAs/InP Quantum-dash Laser

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Abstract: Observation of optical bistability in a two-section InAs/InP quantum dash laser is reported. The hysteresis in the optical power-injection current (L-I) characteristics is found to vary with the absorber reverse bias condition. A reverse bias of −0.8 (0) V to the saturable absorber, a hysteresis of 32 (24) mW is measured when the injection current through the gain section is swept forward and backward. Moreover, the bistability is further affirmed through investigation of the lasing emission spectra at specific operating points.

1 INTRODUCTION

Optical bistability in lasers has gained attraction in several applications such as optical modulation, fast optical switching, next generation optical networks, and memory elements in optical circuits. Bistable lasers come in different shapes and forms such as external cavity lasers and fiber lasers (Kawaguchi, 2006; Huang, 2001; Tangdiongga, 2005; Qasaimeh, 1999; Feng, 2010). However, achieving bistability in monolithic semiconductor lasers would be a much more desirable alternative in terms of flexibility, cost, compactness, and integrability (Kawaguchi, 2006; Huang, 2001). A two-sectioned laser diode is one configuration where both power (optical) and wavelength bistability can be observed (Tangdiongga, 2005; Qasaimeh, 1999; Feng, 2010).

Power stability is referred to the exhibited hysteresis when the injection current is swept in upward and downward directions which has been investigated over a two-sectioned quantum dot laser in (Huang, 2001), emitting at 1300 nm in the O-band window.

In this report, we investigate the optical bistability of a two-sectioned InAs/InP quantum dash laser diode based on a highly inhomogeneous chirped barrier thickness structure and emitting around in the L-band. The power bistability is investigated by analyzing the hysteresis observed in the L-I curves under specific biasing conditions over the two separate sections. Thereafter, the wavelength bistability is examined through the emission spectra of the device under different significant operating points. To the authors' knowledge this is the first observation of bistability in InAs/InP quantum dash lasers.

2 EXPERIMENTAL SETUP

Figure 1(a) illustrates the four-stack 930-µm long InAs/InP quantum-dash laser diode (Qdash LD) that has been electrically isolated by etching a portion of the top metal contact resulting in an electrical resistance of ~0.4–0.6 kΩ. The resulting two sections are 600- and 330-µm long where the former is to be used as a gain medium while the latter as a saturable absorber.

The active medium of the Qdash LD in hand has been chirped by varying its barrier layer thickness atop each of its four quantum dash layers of. A more detailed description of the structure can be found elsewhere (Alkhazraji, 2018). Nevertheless, owning to this chirped structure, in addition to the inherent inhomogeneous nature of the self-assembled growth process of quantum dashes, the structure demonstrates ultra-broadband emission spectra

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qualifying it as a potent tunable laser source in its emission window in the L-band (~1600 nm) wavelength region.

In order to investigate the power bistability of the two-sectioned Qdash LD, the gain section (GS) was current-injected with a pulsed forward biasing current signal of a duty cycle of 0.2% and pulse width of 500 ns to minimize the temperate effects. Meanwhile, the absorber section (AS) was revers-biased with a continuous wave voltage signal. The bare Qdash LD was probed as such while mounted over a brass base whose temperature was controlled by a thermoelectric cooler.

3 RESULTS AND DISCUSSION

The L-I characteristics curves of the Qdash LD were obtained by sweeping the injected current through the GS (I_g) under different reverse biasing voltages (V_{RB}) across the AS at a constant temperature of 18ºC. Figures 1 (b) and (c) show the L-I curves at V_{RB} of 0 V and -0.8 V, respectively, where the output power was measured from the AS facet. Figures 1 (b) and (c) clearly show the optical bistability witnessed by this structure as evident by the counter-clockwise hysteresis loops when I_g is swept in forward then backward directions. The insets of the Figures 1 (b) and (c) show close-up images of the hysteresis loops and their four corners depicted by the points A, B, C and D.

Furthermore, not only did higher V_{RB} values result in shifting the hysteresis loop's position to a higher current injection value, possibly due to the associated higher absorption coefficient, but also, they resulted in a more optical bistable behaviour. This is shown by the 24-mW hysteresis value exhibited under $V_{RB} = 0\,V$ whereas the case of $V_{RB} = -0.8\,V$ resulted in a wider 32-mW hysteresis. This optical power bistability could be potentially exploited in switching operations by optimally biasing the Qdash LD at the middle of the hysteresis loops while direct modulation or on-off switching would be achieved by positively and negatively pulsed-current injecting the GS.

Moreover, in the contrary to other devices, the power bistability is observed here by merely reverse biasing the AS without the need of any additional components such as resistive loads as has been done in the case of the specimen reported in (Qasaimeh, 1999).

From a wavelength bistability point of view, Figure 2 shows the emission spectra of the Qdash LD

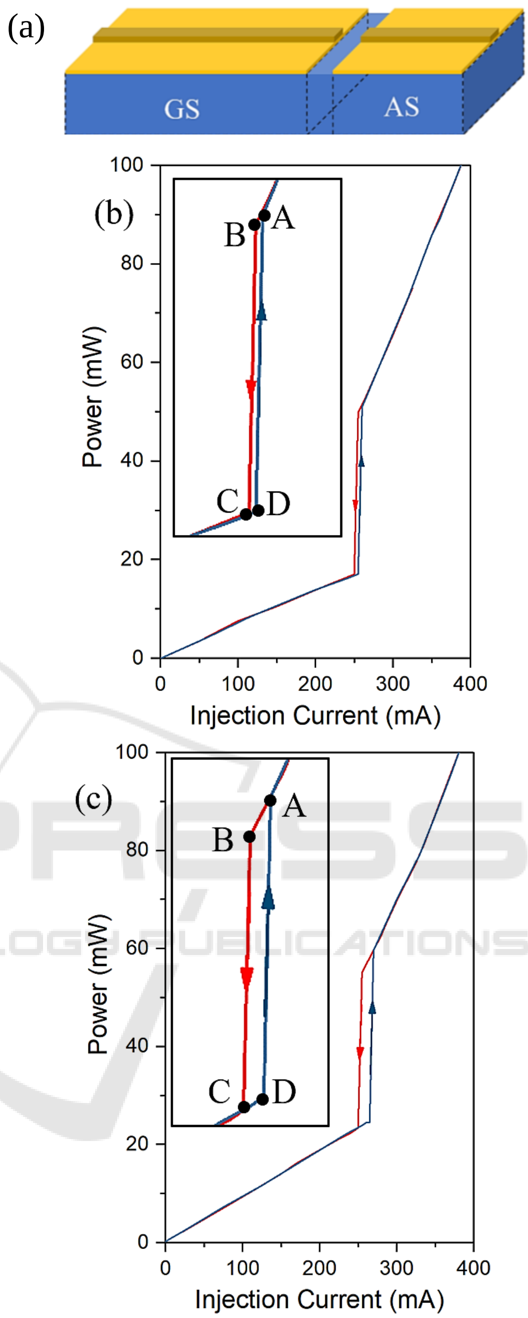

Figure 1: (a) Illustration of the two-sectioned chirped quantum dash laser diode. The LI characteristics curves showing the power bistability under a reverse bias voltage of (b) 0 V and (c) -0.8V. The insets show a close-up image of the corners of the hysteresis loops.

at the corners of the hysteresis loop under a fixed reverse bias voltage of $V_{RB} = -0.8\,V$ at points A, B, C, and D that have been discussed earlier. The y-axis optical power is in offset arbitrary units. As expected from the L-I curves shown in Figures 2 (b) and (c) in particular, each pair of (A, B) and (D, C) points shows a higher emission bandwidth, longer central wavelength, and more integrated power when the forward path points, A and D, are compared to the backward path ones, B and C. This behaviour suggests that achieving stimulated emission with broad emission near threshold is potentially more easily attainable in such two-sectioned inhomogeneous and dissimilarly biased structures compared to single section devices which can attributed to their different gain profiles (Swertfeger, 2017).

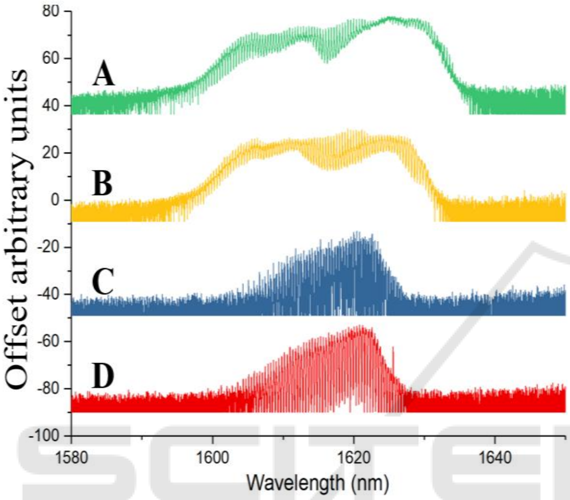

Figure 2: Emission spectra at the corners of the hysteresis loop of the Qdash LD at a fixed reverse bias voltage of -0.8V across the AS at points A, B, C, and D. The y-axis optical power is in offset arbitrary units.

4 CONCLUSION

The observation of optical and wavelength bistability of a two-sectioned multi-stacked chirped InAs/InP quantum-dash laser diode has been further investigated. The two-sectioned device showed power bistability when one of the sections is revers biased and was shown in the form of counter-clockwise hysteresis loops that get wider and elevated with higher current injections in the gain section and when the reverse biasing voltage across the absorber section increases.

As such, a hysteresis of 32 mW was observed under a reverse bias of −0.8 V. This behavior could be potentially utilized in on-off switching and direct modulation and could be further improved by further optimization of the growth process and the geometrical dimensions of the laser device.

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