Ultra-stable 25.5 GHz quantum dot mode-locked frequency comb operating up to 120 °C

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Abstract: We report a frequency comb source based on a quantum dot mode-locked laser that generates a frequency comb with a stable 25.5 GHz mode spacing over an ultra-broad temperature range of 20 °C - 120 °C.

1. Introduction

Semiconductor mode-locked lasers (MLLs) motivated by the ability to generate stable and cost-effective ultrafast, high-repetition-rate and low-noise optical pulses, have led to significant advances in a range of applications from optical-communications, clock distribution/recovery to sampling [1-3]. Large tone spacing and high optical signal-to-noise ratio (OSNR) frequency combs, suiting for dense wavelength-division-multiplex (DWDM) data communications, could be easily achieved with a short-cavity MLL. Typically, an MLL could provide 5-10 nm bandwidth, promising comb-based transmitters [4]. Quantum dot (QD) structures have, for many years, been regarded as one of the most promising materials systems for ultrafast science and technology [5], given their inherent properties, such as ultrabroad gain bandwidth as well as ultrafast carrier dynamics. Besides, QD MLLs operating at the ground state (GS) are especially favoured in optical communication systems owing to the desirable features like low power consumption and high wall-plug efficiency.

In this work, we report a 25.5 GHz QD MLL-based frequency comb source that operates over an ultra-broad temperature range of 100 ℃ (between 20℃ to 120℃), exclusively from the GS transition, with nearly unaltered tone spacing [6]. A relatively broad, coherent comb bandwidth with a low average RIN value of less than -146 dBc/Hz is realised even at 100 ℃, making it a promising candidate for multi Tbit/s transmission applications in optical communications.

2. Material and device design

The GaAs-based InAs QD laser structure was grown by molecular beam epitaxy (MBE). The 10-layers QD active region was engineered for a high optical modal gain, as well as a large quantized-energy difference between the GS and the first excited state (ES1). The cross-sectional transmission electron microscopy (TEM) image of the active region is shown in Fig. 1(a) with a high-resolution bright-field scanning TEM image of a single dot presented in the inset. By optimizing the growth conditions, a dot area density of 5.9×10^{10} cm^{-2} could be obtained. Then, a typical two-section ridge-waveguide laser structure is employed (Fig. 1(b)). The fabricated laser with 5 µm ridge width has a total cavity length of 1615 mm, leading to a 25.5 GHz repetition rate. The saturable absorber (SA) length and the gain section length are designed to be 200 µm and 1400 µm, respectively. As can be seen in Fig. 1(c), there is a 15 µm gap in the p-type contact metal which brings an 8 kΩ measured isolation resistance. Finally, the as-cleaved devices are mounted p-side up on a heat sink and gold-wire-bonded to enable testing.

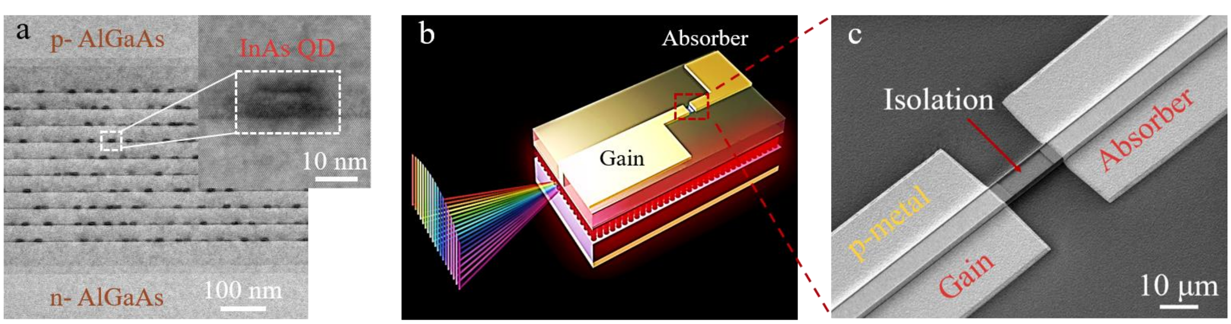

Fig. 1. (a) The crossed-sectional TEM image of the active region. (Inset: the high-resolution bright-field scanning TEM image of a single dot.). (b) Schematic of the designed passively two-section MLL. (c) The SEM image showing the gap between the gain and SA sections.

3. Results and discussion

Figure. 2(a) shows the temperature-dependent light-current (*L-I*) characteristics with a fixed reverse-bias voltage at 0 V. As can be seen, continuous-wave (CW) lasing without any thermal rollover behaviours is maintained until the upper-limit temperature of the test system is reached (120 ℃). RF spectra as a function of temperature at a fixed reverse-bias voltage of 2 V is presented in Fig. 2(b), where the chosen conditions generate the shortest pulse width at each given temperature. As observed, stable mode-locking at temperatures ranging from 20 °C to 120 °C exclusively from the GS transition with nearly unalter repetition rate (Δ~0.07 GHz) over this entire temperature range is achieved. To the best of our knowledge, this is the broadest mode-locking operation temperature range ever reported to date for any types of MLLs. It is worth to mention that, even at a temperature as high as 100 ℃, the device maintains an impressing performance with 31 potential channels within a relatively broad 6-dB comb bandwidth of 4.81 nm (Fig. 2(c)). Moreover, the corresponding relative intensity noise (RIN) spectrum, as shown in Fig. 2(d), obtains a low average value of -146 dBc/Hz from 0.5 GHz to 10 GHz.

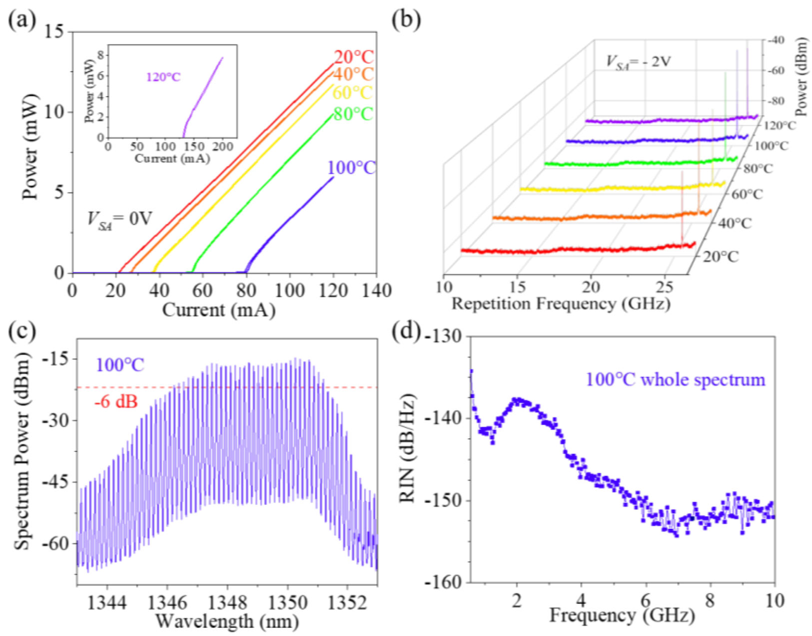

Fig. 2. (a) Temperature-dependent CW *L-I* characteristics of tested device with V_{SA} = 0 V. (b) RF spectra with a constant V_{SA} = -2 V and I_{gain} of 49, 60, 64.7, 85, 148.5, and 210 mA at 20, 40, 60, 80, 100, and 120℃, respectively. (c) Optical spectrum at 100 °C with bias conditions of I_{gain} = 148.5 mA and V_{SA} = - 2 V. (d) The average RIN from 0.5 to 10 GHz for the optical comb shown in (c).

4. Conclusion

In conclusion, we have demonstrated a frequency comb source based on a passively mode-locked InAs QD laser that has achieved ultra-stable repetition rate over the widest temperature range yet reported for any type of MLLs. The results show the suitability of the QD MLLs as ultra-stable, easy-operating, uncooled frequency comb sources for low-cost, high-bandwidth and low energy consumption optical data communications.

5. Reference

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