Tbps Data Transmission with Quantum Dot Frequency comb laser

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***Abstract*—An QD-CPML has been demonstrated with twenty 100-GHz-spacing channels. 80 Gbps modulation rate for each comb line has been reached by PAM4 and one device has 1.6 Tbit per second transmission capability.**

Keywords—quantum dots, optical frequency comb, mode-locked, data transmission, heterogeneous integration

I. Introduction

Optical frequency combs (OFCs) have become a highly attractive source for a wide range of applications, including wavelength division multiplex (WDM) systems, data transmission, and precision metrology. On-chip OFC generation has been achieved using various methods, such as gain-switched combs, IM/Phase EO modulation, soliton microresonators, and passive mode-locked lasers (MLLs). Among these, semiconductor passive MLLs have emerged as a strong contender for WDM system integration in small-scale applications due to their high efficiency, low power consumption, and ease of control. However, recent advancements in semiconductor quantum dot (QD) MLLs have made them a promising alternative, with advantages such as a small linewidth enhancement factor (LEF), fast carrier dynamics, and defect insensitivity.

Here, we present the development of an O-Band QD colliding pulse mode-locked laser (CPML) that generates optical combs with a channel spacing of 100 GHz. By optimizing the injection current and reverse bias, a flat-top mode-locked condition was achieved with 20 channels within a 3 dB optical bandwidth. The linewidth of each channel averaged at 440 kHz, and the RIN ranged from -133 dB/Hz from 10 MHz to 20 GHz. The CPML was also capable of reaching 70 Gb/s NRZ modulation rates and 40 Gbaud/s PAM4 modulation rates, demonstrating a transmission capability of 1.6 Tb/s.

II. Device Dedign and Fabrrication

The QD-CPML was grown epitaxially on GaAs using molecular beam epitaxy (MBE) To enhance the high-temperature stability of the lasers, the active region of the dots in the well structure is p-doped. A symmetric cladding layer design is adopted using p-type and n-type Al0.4Ga0.6As layers, 1500 nm thick, for upper and lower cladding layers, respectively. Achieving a 100 GHz repetition rate typically requires an ultra-short laser cavity length of approximately 400 µm, which faces challenges with significant gain reduction issues that limit the maximum output power of individual comb lines. To address this issue, a high-order CPML design is introduced to maintain sufficient gain area while keeping a large mode spacing.

After the epitaxy, the martial is fabricated using a standard ridge laser fabrication process, as illustrated in Figure 1. The CPML consisted of four gain parts and three saturable absorbers (SAs), with electrical isolation exceeding 30 kΩ to ensure excellent isolation. The repetition rate can be varied by adjusting the cavity length, and the mode-locked region can be influenced by the length of SAs. After fabrication, the thickness of the laser die was reduced to 110 µm by lapping, and the laser was cleaved into devices and mounted on submounts with high-reflection coating for characterization experiments.

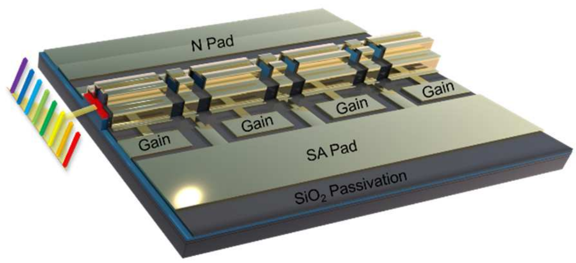


Fig. 1. The 4th order quantum dot colliding pulse mode-locked laser (QD CPML) features a structure diagram comprising of four gain parts and three saturable absorbers (SAs).

III. Device Characterrizations

The light-current (L-I) performance of this laser was characterized which is shown in Fig. 2(a). The lasers are driven with 0-300 mA gain current (I) and 0 V SA reverse biased (V) under temperature vary from 20 °C to 100 °C. It demonstrated that the QD comb laser could operate at 100 °C and still produce optical power over 10 mW at injection current of 200 mA. The high temperature characteristic of this CPML performs ensure that it can work in the harsh environment. At room temperature, maximum power of 54 mW can be achieved under 300 mA injected current.

By adjusting the working point, this device can generate an ultra-broad flat-top OFCs at different temperature, which is shown in Fig. 2(b). Obviously, in the range of 20 ºC to 100 ºC, this device can generate combs with stable frequency spacing. The average interval between adjacent modes is 103.43 GHz and each spacing goes up and down by no more than 2 GHz, which also shows the stability of the mode-locked state. On the other hand, the single noise ratio (SNR) of each individual mode is over 35 dB, which indicates it is suitable for transmission. With the broad 3 dB bandwidth of 18 channels, this device is a suitable OFCs generator for Continuous-Wave Wavelength Division Multiplexing Multi-Source Agreement (CW-WDM).

Another interesting thing is the whole optical spectrum is quite flat at 80 ºC, which the power of all combs in 3 dB fluctuates within 1 dB. This working point is an ideal light source for data transmission.

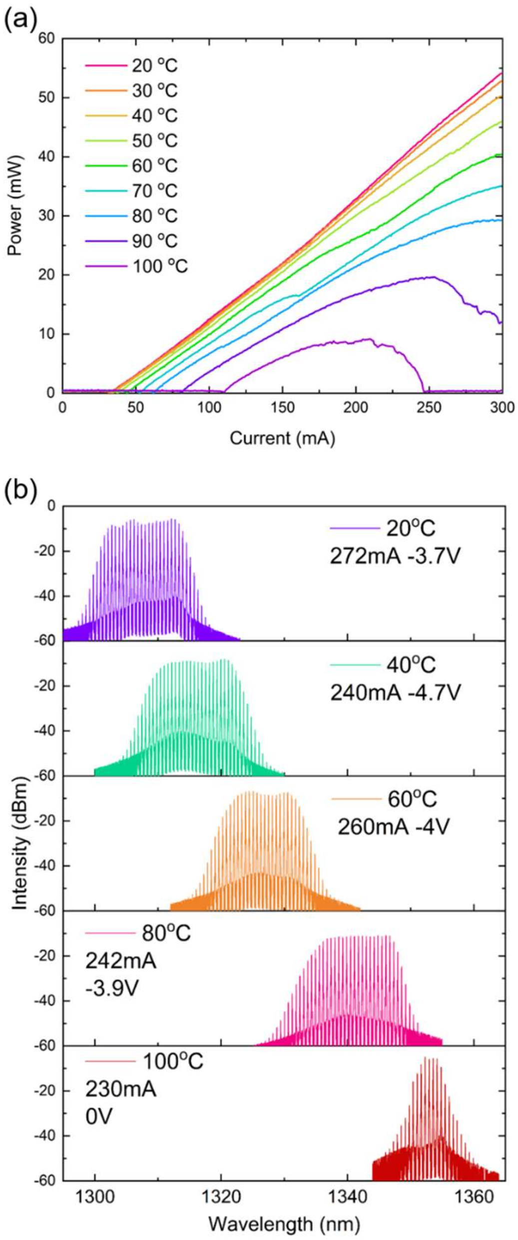
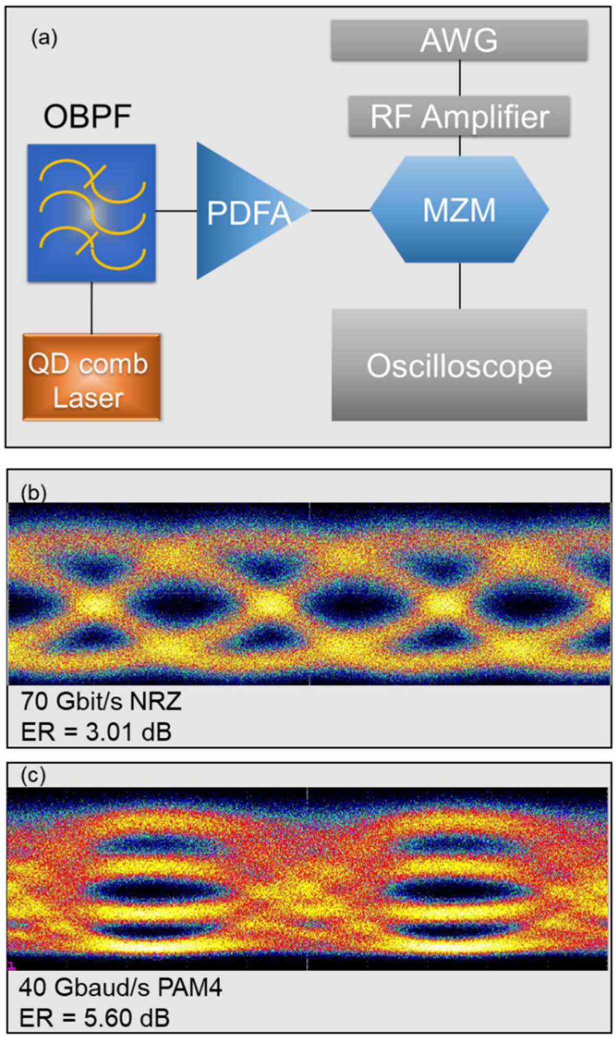


Fig. 2. (a) Continuous-wave light-current (L-I) characteristics of this CPML from 20 ºC to 100 ºC. (b) Optical spectrum with flat-top comb lines at different temperature.

Considering the life time of this device, a working condition of 224 mA, -4.8 V and 25 ºC producing 18 channels has been chosen for data transmission ability test. The relative intensity noise (RIN) values for both the 18 individual channels and the entire comb spectrum were measured in the frequency range from 0-10 GHz. The average RIN for the individual channels was -133 dB/Hz, while the average RIN for the whole comb spectrum was -160 dB/Hz. Although there was a decrease in RIN values of about 25 dB/Hz for individual comb lines, the average RIN values for each single sideband still met the necessary requirements for high-speed PAM-4 modulation and WDM standards.

A $LiNO_3$ modulator has been used here for high speed transmission, after an O-Band optical bandpass filter. Figure 3(a) shows the whole setup for single comb line transmission test. By adjusting the modulator bias, clear eye diagram of 70 Gb/s NRZ and 40 Gbaud/s PAM4 has been observed in Fig. 3(b) and Fig. 3(c), respectively. Extinction ratios of 3.01 dB and 5.60 dB for 40 Gb/s and 40 Gbaud/s PAM4 has also been measured separately. This result declares one individual channel has 80 Gb/s transmission capability and one device with 20 channels has data transmission capability of 1.6 Tb/s.



IV. Summary

To summarize, our study presents the successful development of an O-Band quantum dot colliding pulse mode-locked laser (CPML) on GaAs, capable of generating up to 20 optical frequency combs with a 100 GHz spacing. The average linewidth is 440 kHz and RIN is -133 dB/Hz. The device has a transmission capability of 1.6 Tb/s, with each channel utilizing 40 Gbaud/s PAM4 modulation rates. Our results demonstrate the potential of QD-CPML as an efficient and low power consuming source for WDM systems and high speed data transmission.

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