100 GHz Multiple Colliding Pulse Generation from Cleaved Facet-free Multi-section Semiconductor Laser Diode

Student Paper

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ABSTRACT

A monolithically integrated semiconductor laser with a cavity laser of a 25 GHz fundamental repetition rate has been designed to generate an optical signal of four-times of the fundamental repetition rate working on the fourth harmonic colliding pulse mode locking configuration. This device was developed and fabricated within a multi-project wafer run in an InP-based active-passive generic foundry. The Fabry-Pérot laser cavity structure of the semiconductor laser is formed with two on-chip reflector building blocks rather than cleaved facets of the chip. The Fabry-Perot laser cavity length is around 1.66 mm the cavity three absorber sections symmetrically divide the cavity into four gain segments. An electrical linewidth of 350 KHz and 150 KHz with a frequency spacing of 25 GHz y 100 GHz is generated by the laser in passive regimen condition, respectively.

Keywords: semiconductor laser, electrical linewidth, multiple colliding pulse, mode locking laser.

1. INTRODUCTION

Passive mode locking (PML) based on III-V semiconductor lasers in photonic integrated circuits (PIC) generating optical frequency combs (OFC) have been increasingly attracting attention in recent years, due to its chip-scaled compactness and simplicity of DC operation. Especially, Passive mode locking laser diodes at repetition rates in millimetre-wave (mmW, 30-300 GHz) and terahertz (THz, 0.1-10 THz) ranges have been considered promising in communications, spectroscopy, and sensing [1] – [2]. However, in most cases an extremely high repetition rate (>100 GHz) of a mode-locked lasers (MLL) is corresponding to only a few hundreds of µm cavity length (<400 µm). For this reason, harmonic mode locking (HML) schemes have been investigated to produce multiple pulses per round trip in a sufficiently long cavity, thus pushing the RR beyond the low-GHz fundamental cavity round trip frequency [3]. HML is achieved by means of colliding pulse ML [4], coupled cavity ML [5], and methods based on the wavelength selectivity of distributed Bragg reflector (DBR) grating [6]. In colliding pulse ML, one saturable absorber is placed at the midpoint of cavity, where two counter propagating pulses circulate and collide, producing a train of pulses at a repetition rates that are twice the fundamental round trip frequency. Evolving from colliding pulse ML, multiple colliding pulse ML features multiple saturable absorbers concatenated with gain sections, for repetition rates multiplication >2 as has been extensively investigated [7] –[8]. Recently, a new class of on-chip broadband reflector based on the multimode interference (MMI) principle has been proposed [9], and demonstrated its wide applicability [10] – [11]. Such multimode interference reflectors (MIRs) are so simple to create in lithography with greater fabrication tolerance to replace DBRs and cleaved facets. Furthermore, they can be placed anywhere on a chip, and the transmitted light is manipulable on chip to fulfill more functionalities [12].

2. DEVICE DESCRIPTION

Fig. 1 shows a photograph of the layout of the semiconductor laser with a multi-section structure. The Perot-Perot laser cavity is formed with a pair of MIRs, in which there are four gain sections separated by three saturable absorber sections, placed at every quarter of the cavity length. The on-chip reflectors MIRs, define a cavity length (L) of around 1.66 mm, corresponding to a cavity round trip frequency of 25 GHz.

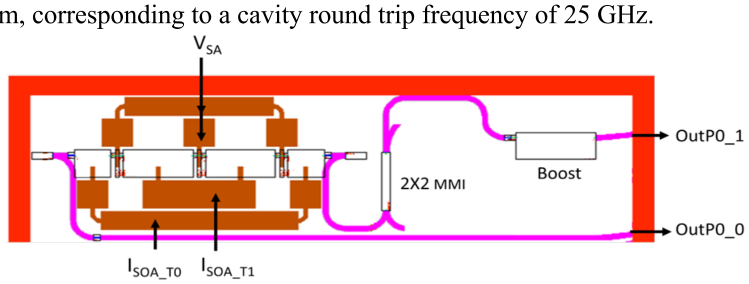


Figure 1. Photograph of the layout of the investigated semiconductor laser diode.

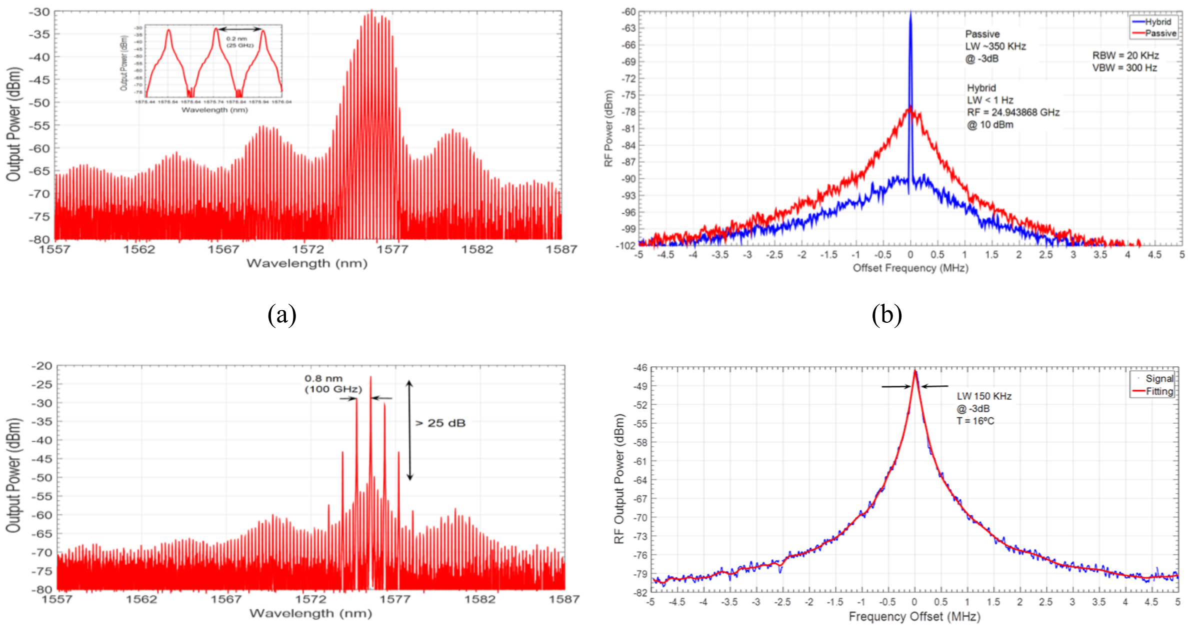
Every quarter (L/4) is around 0.42 mm long. In the design, all three SAs length is 20 µm. The two inner gain sections, which are much longer (~350 µm) than the two outer gain sections ~180 µm. Electrical isolation sections were inserted between every two adjacent SOAs to avoid undesirable back current flows . At each end of the cavity, one 2-port MIR terminates the straight waveguide at one port defining the overall Fabry-Pérot cavity length, but also carrying light out of the cavity through the other port. The two MIRs are ~55-µm long, having two ports with ~40% transmissivity and ~40% reflectivity, based on the multimode interference principle and internal etched reflection walls.

3. CHARACTERIZATION RESULTS

The device is glued with a thermos-conductive paste and mounted on an Alumimum Nitride (AlN) submount. This subcarrier has different DC and RF tracks for biasing of each optical component of the device. The DC pads extensions of the gain sections and the metal layer of the boost are wired bonding to the DC tracks on the submount, while the pads extensions of the saturable absorbers are wire bonding to the RF tracks. The subcarrier is placed on a cooper chuck of a probe station where is stabilized in temperature. The working temperature is set to 16ª for all the measurements. To control the integrated device, all gain sections and saturable absorbers are electrically connected to external current and voltage sources, respectively. Three DC probe needles are physically contacted on the DC tracks for the outer gain sections, inner gain sections, and boost, respectively. A RF probe head is contacted on the RF tracks for the saturable absorbers in order to inject a RF signal and to get the hybrid regimen condition. For evaluating the spectral performance on the wavelength domain and on the electrical domain, two of the optical spectrums are shown in Fig. 2, respectively. The bias conditions to get these optical spectrums are shown in Table 1. On both optical spectrums an optical frequency comb near 1577 nm is presented. For Fig 2 (a), twenty comb lines and the mode spacing between each optical mode is approximately 0.2 nm, equivalent to 25 GHz in frequency. An inset on the left side of the optical spectrum shows the modal spacing between three optical modes.

TABLE 1. Bias conditions to achieve optical frequency combs with a modal spacing of 25 and 100 GHz .

I_{SOA_T0} (mA)	I_{SOA_T1} (mA)	I_{boost} (mA)	V_{SA} (V)	Section
40	62	20	2.0	a
50	50	20	1.6	c



(a) (b) (c) (d)

Figure 2. Optical and electrical spectrum of the multi-section semiconductor laser diode. (a) Optical frequency comb with a modal spacing of 0.2 nm (25 GHz). (b) RF electrical tone both in passive (red) and in hybrid (blue) regimen condition, thus the achieved electrical linewidth are ~350 KHz and less than 1 Hz, respectively. (c) Optical spectrum with lasing modes separated each 0.8 nm (100 GHz). (d) RF electrical tone generated at the laser output in passive regimen condition.

Regarding Fig 2(c), the optical spectrum shows seven comb lines and the modal spacing in between is around 0.8 nm, which is equivalent to 100 GHz in frequency. The seven lasing modes constitute an optical frequency comb which exhibits a suppression ratio of ~25 dB, with respect to the level of the suppressed modes that are associated with the fundamental cavity round-trip frequency of 25 GHz. Only, three lasing modes in every four lasing modes are supressed, and thus, only one mode in every four lasing modes is excited. The electrical linewidth in passive regime condition is measured at the round-trip frequency as well as the four times the fundamental repetition rate as shown in Fig 2 (b) and (d), respectively. In Fig 2(b), the optical signal is collected at OutP0_0, getting an electrical linewidth of ~350 KHz centered around 25 GHz. In order to get hybrid regimen condition, a RF signal of 24.943868 GHz and with a power level of 10 dBm is injected into the saturable absorbers. The electrical linewidth of the generated RF signal is reduced and its value is less than 1 Hz. In Fig 2(d), the electrical linewidth of the generated electrical tone at 100 GHz ~150 KHz, and the optical signal is collected at OutP0_1, thus the electrical tone generated by the laser has an electrical level greater than the 25 GHz electrical tone.

4. CONCLUSIONS

We have successfully presented an InP mode-locked semiconductor laser for 100-GHz optical frequency comb generation. The laser cavity features multiple segments in a symmetric arrangement in which short SOAs separate the overall 1.66-mm-long resonator into four shorter divisions in equal length to achieve fourth harmonic generation. The on-chip multimode interference reflectors have shown the potential to replace the cleaved facets.

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