Multi-Section Partially-Corrugated-Grating DFB Lasers for Achieving High Power, Low Noise, and Narrow Linewidth

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Abstract: A novel DFB laser structure with multi-section partially-corrugated-gratings (PCG) is demonstrated with enhanced output power, reduced noise, and reduced linewidth, resulting from the equalized photon density in the laser cavity by the partitioned partial gratings.

1. Introduction

High-power DFB lasers with high efficiency and reliability are highly demanded for applications like light detection and ranging (LiDAR) systems, optical communications networks and sensing, free space optical (FSO) communication, and co-packaged optics (CPO) [1]. Besides high output power, reduced relative intensity noise (RIN) and narrow linewidth are required for next-generation switching and other applications [2]. Many groups have recently reported high-power, narrow linewidth, single-mode operation, and low-RIN semiconductor lasers by applying dual-channel ridge waveguide, SOA-integrated DFB laser, an asymmetric cladding based on the dilute waveguide, buried heterostructure (BH) CW-DFBs lasers using InGaAsP-based materials, the slab-coupled optical waveguide (SCOW) structure, and a partial corrugation grating (PCG) DFB structure [1,3-5]. 8-channel external laser sources (ELS) for CPO were also developed to provide 100-mW power at 75°C under 400-mA bias with a wall-plug efficiency (WPE) of 22% [6].

Most of the aforementioned research on high-power lasers focuses on lateral waveguide structure optimization. The PCG-DFB laser is well-known for its good side-mode suppression ratio (SMSR), high single-mode yield, high reflection tolerance, and allows for engineering the grating coupling strength to achieve high output power [7,8]. Fig. 1 compares the side-view of high-power PCG-DFB lasers with single and multiple segments, where S is the number of grating segments along the cavity with S=1 being the conventional PCG-DFB laser. The nature of a conventional PCG-DFB laser, including a Fabry-Perot section (without grating) and a DFB section, tends to have lower photon density at the output facet, as shown in Fig. 1(c). We proposed to use asymmetric two-section cascaded PCG-DFB structure to raise the photon density at the output end and thus enhance the output power [9]. Here, we demonstrate experimentally the performance enhancement for high-power PCG-DFB laser with up to 10 grating segments (Fig. 1(b)) and manifest the potential mechanisms leading to the enhanced power and reduced linewidth.

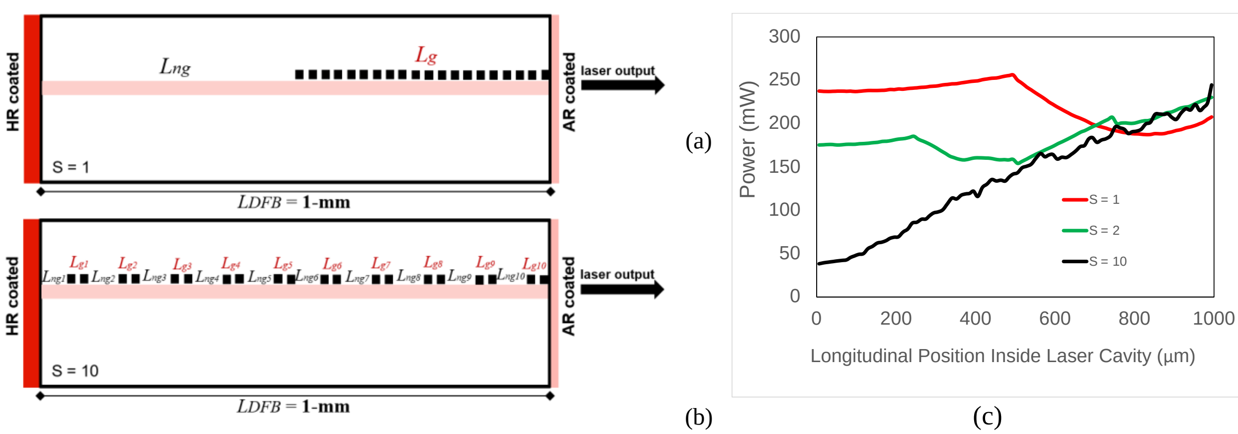

Fig. 1. Schematic of high-power PCG-DFB laser for (a) S=1 and (b) 10, and (c) Simulated power distribution along the laser cavity for S=1, 2, and 10 at the same injection current (500 mA). The simulation was conducted using VPIcomponentMaker Photonics Circuits Tool with laser parameters extracted from single-section PCG-DFB lasers.

2. Device structure

The idea of dividing the grating section into multiple sub-sections is to equalize the power density inside the cavity for it to rise toward the output facet in order to increase output power. The difference in the power distribution along the cavity can be clearly observed among different S-values, and S=10 can provide the largest output power. The power distribution is averaged over the rear phase fluctuation for each case. In general, the grating length of each segment and the spacing in between can be different and can be optimized for further enhancing the laser performance.

The laser is designed to operate at 1.31 μm wavelength with 1-mm cavity length (L_{DFB}). L_{ng} and L_g are the lengths of the non-corrugated and grating sections, accordingly. All lasers of different S-values are arranged on the same wafer, so they share the same gain material and waveguide structure. The total grating length is 500 μm, same for the lasers with different S-values. The devices were fabricated using standard semiconductor foundry service that includes the epitaxial growth of InGaAsP/InP layer structures with metal-organic chemical vapor deposition (MOCVD) on 3-inch InP substrate. Thus, the devices are ready for mass-production. The grating structures were patterned by e-beam writing and formed with wet chemical etching. The front- and back-facets are coated with AR and HR coatings, respectively.

In addition to enhance the output power by equalizing the photon density in the cavity, the partition of the grating into multiple sub-gratings can provide some merits over the conventional PCG-DFB laser. Firstly, a larger photon density at the output end suppresses the laser noise such that RIN can be reduced. Secondly, a larger number of grating segments reduces the series resistance, which may attribute to the suppression of the current crowding effect on the no-corrugation section. This is due to the use of p-side grating of which the quaternary grating layer induces potential barriers and increases the series resistance. Since the grating layer of the non-corrugation region remains intact and has higher series resistance, which eventually decreases the output power. By dividing the long grating into multiple sub-gratings, the injection current can flow through the gain section more uniformly. Thirdly, the multi-section PCG-DFB with more segmentations can suppress the linewidth re-broadening phenomena on PCG-DFB structure, which may appear due to saturated output power, inhomogeneous intrinsic effect, and longitudinal spatial hole burning in a long-DFB [10].

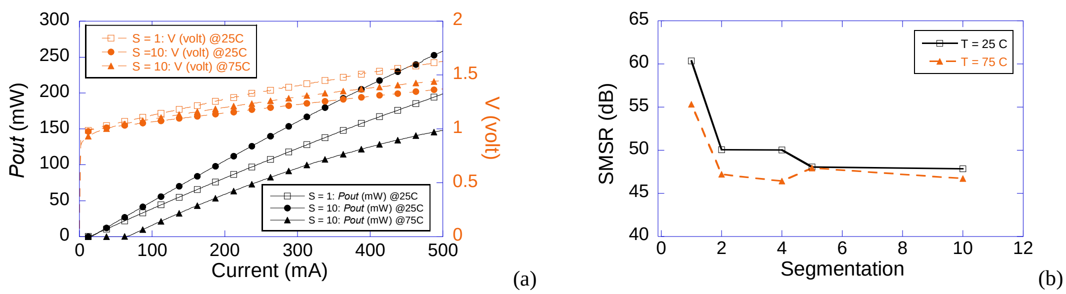

Fig. 2. (a) L-I-V characteristics of S=1 and 10, (b) Measured sidemode suppression ratio (SMSR) versus the number of grating segments at 25°C (solid line) and 75°C (dashed line) at 500-mA bias.

3. Experimental results

All the lasers are measured with a bar tester without bonding on a carrier or sub-mount. Fig. 2(a) reveals a reduced voltage (V = 1.473 volt) for S=10, by comparing to conventional PCG-DFB lasers (S=1). The series resistance *Rso*, which is determined from the slope of I-V curve for the output power between 5 and 10 mW, is 1.3847 and 1.01 Ω for S=1 and 10, respectively. The series resistance is reduced by 28% for the 10-section PCG-DFB lasers than S=1. Such reduction in series resistance is critical for achieving high output power. Fig. 2(b) shows that the SMSR is slightly decreased for a greater S, but all lasers can have >45 SMSR, even at 75°C.

Fig. 3 compares the measured *Ppeak* and slope efficiency at 500-mA bias for different segmentation. As expected, the *Ppeak* gradually increases towards the larger number of segments, and the largest S-value of 10 layout in the experiments could achieve the highest light output (248.146 mW at 25°C and 151.22 mW at 75°C), about 24% enhancement by comparing to the case of S=1. In terms of this improvement, S=10 provides a slope efficiency of 0.476 mW/mA and wall-plug efficiency of 35.7% and 20.7% at 25°C and 75°C, respectively. This enhancement in output power for greater S results from an enhanced photon density inside the laser cavity and also a reduction in the series resistance. Higher output power and efficiency are expected when the laser is bonded on a heatsink sub-mount.

The measured laser linewidth for both S=1 and 10 at 100-mA bias current is depicted in Fig. 4. The laser linewidths were measured with the self-heterodyne technique that includes an acousto-optic modulator (AOM) at one arm and a long fiber (7.2-km) at another arm. A polarization controller is used to match the polarization of the two paths, which are combined with an optical splitter and output to a photodiode and electronic spectrum analyzer. Noticing that an attenuator is added to control the power level and facilitate the measurement, especially at high injection current. Fig. 5 summarizes the measured laser linewidth for different S-values. At a lower bias of 50-mA, the lowest linewidth of 34-kHz can be obtained for S=5. It seems that the PCG-DFB lasers are more subject to the linewidth re-broadening, especially for the conventional one (S=1). The PCG-DFB with more grating segments can suppress the linewidth re-broadening effect. Thus, at 500-mA of driving current, the linewidth decreases with the S-value. A narrow linewidth of 42.31 kHz is obtained at 500 mA for S=10.

Fig. 6 depicts the RIN characteristics of PCG-DFB lasers for different numbers of grating segments. The RIN is roughly decreased with the increase in S-value and the increasing bias current. The measured RIN of S=10 at 500-mA bias is <-167 dB/Hz from 1 MHz to 20 GHz, which represents a relatively low noise from the high-power semiconductor lasers, comparing to the data reported by other groups.

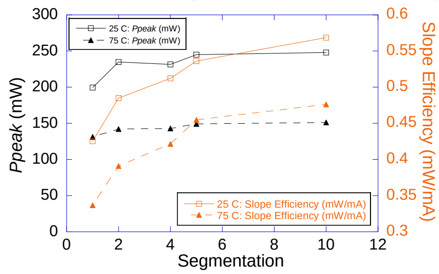

Fig. 3. Measured *Ppeak* and slope efficiency of different segmentation at 25°C (solid line) and 75°C (dashed line).

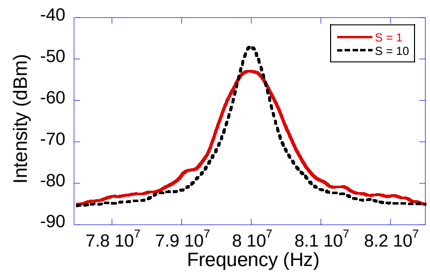

Fig. 4. Measured laser linewidth for S=1 and 10 at 100-mA bias.

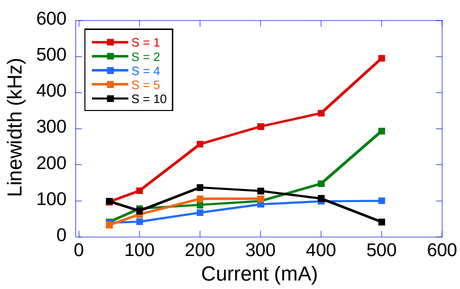

Fig. 5. Measured 3-dB linewidth of different currents and S-values.

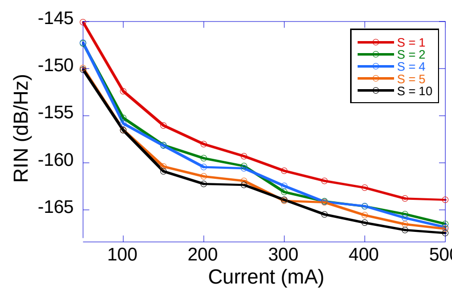

Fig. 6. RIN characteristics versus current for different S-values.

4. Conclusion

We propose a novel approach to enhance output power while reducing RIN and linewidth by using multi-section PCG-DFB lasers and verify the performance enhancement by measuring the PCG-DFB lasers operating at 1.31-μm wavelength with different number of grating segments. The laser with the largest number of grating segments (S=10) can achieve the maximal optical output power of 248-mW at 25°C and 151-mW at 75°C, 34-kHz laser linewidth, >49-dB SMSR, <-167 dB/Hz RIN with an injection current of 500 mA. With 500-mA current injection, the wall-plug efficiency can reach 35.7% and 20.7% at 25°C and 75°C, respectively, and the efficiency is expected to be higher by bonding the lasers to a heatsink sub-mount to improve thermal conduction. The multi-section PCG-DFB with S=10 can boost the output power by >24%, by comparing to conventional PCG-DFB lasers. The laser performance can be further improved by optimizing the lateral waveguide geometry and materials as well as the grating ratio of the PCG.

5. References

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