High Power Uncooled CW-DFB lasers with High Reliability

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Abstract: We demonstrate L-band and O-band CW-DFB lasers with kink-free and stable single mode lasing over 600 mW at 55ºC and 200 mW at 85℃, respectively. More than 2000 hours reliable operation at 90ºC is achieved. © 2023 The Authors

1. Introduction

High power semiconductor lasers are promising light sources for silicon photonics (SiPh) including on-board optics and co-packaged optics [1, 2], free space optical (FSO) communication [3], light detection and ranging (LIDAR) system [4] and manufacturing industries, due to their high performance of low cost, small size and low power consumption. Recently, we have demonstrated a 4-channel Combo-PON OLT transceiver using photonic integration technology with laser bank [5]. All ports of the transceiver comply with I-TUT G.984.2 Class C+ standard. It proved that silicon photonics is a cost-effective and power efficient way to implement the next generation PON transceiver for high density PON ports. In this module, the output power from the laser bank is only 16dBm per channel, which limits the power budget of the PON system. Therefore, high power CW-DFB lasers are needed for PON system with higher power budget. Moreover, DFB lasers with a high working temperature may help to reduce the power consumption of the transceiver.

In this paper, we optimize the structure of L-band DFB lasers based on our previous work [6], in order to increase the output power and wall-plug efficiency (WPE) of the lasers at higher working temperatures. The L-band CW-DFB lasers exhibit kink-free stable longitudinal single-mode operation over 600 mW with injection current less than 2 A at 55℃. More than 2000 hours accelerated aging test at 90ºC was implemented and no failures were observed. It proves that the lasers are highly reliable. Since O-band CW-DFB lasers are more commonly used in SiPh due to the low dispersion nature of single-mode fibers, we also demonstrate high power uncooled O-band CW-DFB lasers with the slab-coupled optical waveguide (SCOW) structure. The output power of the O-band CW-DFB laser is more than 200 mW with injection current less than 1 A at 85℃. Compared with the SOA-integrated DFB lasers reported in [7], our O-band CW-DFB lasers are with higher output power and higher WPE.

2. Design of the high power CW-DFB lasers

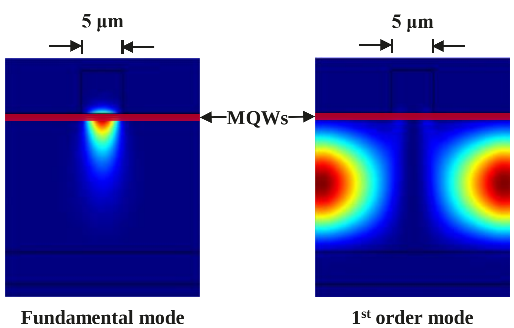

Fig. 1. Transverse modes profile of the high power SCOW-DFB laser.

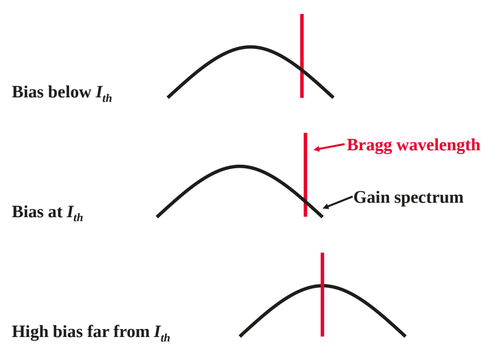

Fig. 2. Schematic of the wavelength detuning at different bias current.

The L-band high power CW-DFB laser is optimized based on SCOW structure described in [6]. To improve the laser performances at high temperature, AlGaInAs multiple quantum wells (MQWs) are included. For fundamental-mode operation, the width of ridge waveguide is chosen to 5 μm with properly designing the optical confinement factor. As shown in Fig. 1, the 1st order modes are leaked to the slab region with high radiation loss. In order to improve the slope efficiency (SE) of the lasers at high injection current and high temperature, wavelength detuning between the Bragg wavelength of the grating and the gain peak wavelength is selected appropriately. The relative relationship of the Bragg wavelength of the grating and the gain peak wavelength under different bias current is shown in Fig. 2. In order to align the Bragg wavelength of the grating with the gain peak wavelength at high bias current far from the threshold current (I_{th}), the Bragg wavelength of the grating at the injection current below I_{th} is located on the redshift side of the gain peak wavelength. As we know, the output power of a laser will be saturated at high temperatures. A cavity length of 2.5 mm instead of a cavity length of 2 mm in [6] is used to further increase the saturated output power. After finishing the fabrication of the ridge waveguide and electrode contacts, the lasers were cleaved into chips with AR (<0.1%) and HR (>95%) coatings at the front and the rear facets, respectively. The chips were mounted p-side down onto AlN submounts for high power measurements.

3. Performances of the high power CW-DFB lasers

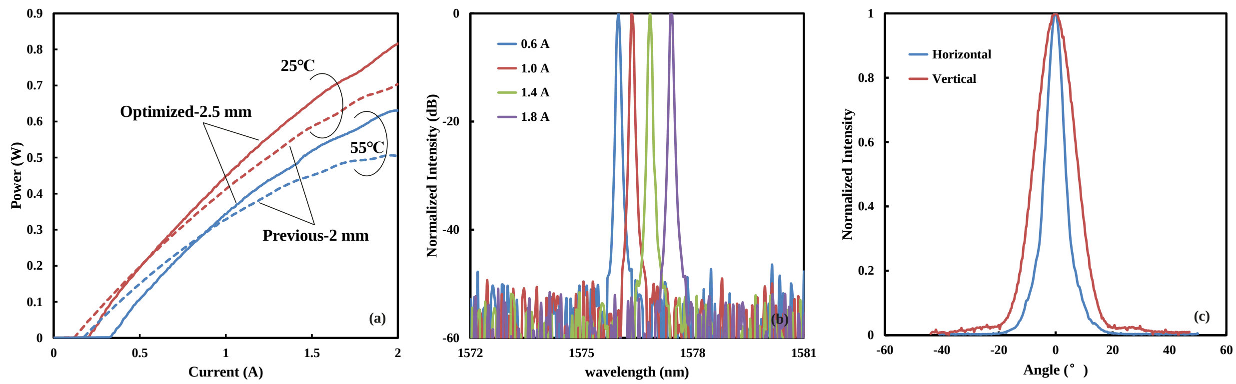

Fig. 3. Performances of the Optimized L-band CW DFB lasers: (a) L-I curves, (b) optical spectrum at 25℃, and (c) divergence angle at 25℃.

Fig. 3(a) shows the CW light-current (L-I) characteristics of an optimized L-band high power DFB laser at 25℃ and 55℃. The kink-free output power of the laser exceeds 800 mW at 25℃ and 600 mW at 55℃ with an injection current of 2 A. Compared with our previous work in [6], a higher SE is achieved here at high operating current accompanied by a bit higher threshold current, which is caused by larger wavelength detuning below I_{th}. The WPE of output power of 800 mW at 25℃ and 600 mW at 55℃ are 28% and 21%, respectively. As shown in Fig. 3(b), a stable single longitudinal mode with side mode suppression ratio (SMSR) of about 50 dB is obtained in the entire operating current range. The typical far-field divergence angle characteristics of the laser at 1.4 A injection current and 25℃ are shown in Fig. 3(c). A small single-mode far-field profile with a half-maximum (FWHM) divergence angle of 8.0°×16.5° is achieved by using wide ridge waveguide and introducing thick slab waveguide layer.

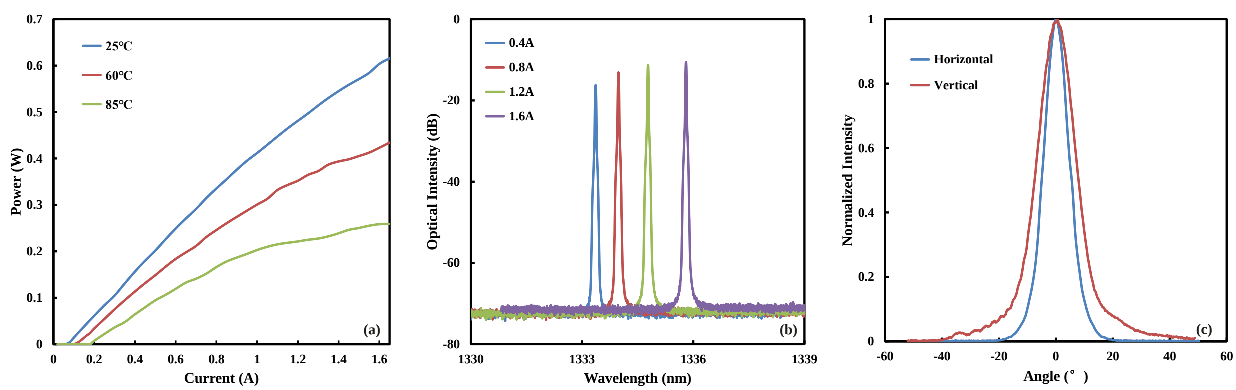

Fig. 4. Performances of the 2.5 mm-long O-band CW DFB lasers: (a) L-I curves, (b) optical spectrum at 25℃, and (c) divergence angle at 25℃.

Based on a similar design concept, we also demonstrate an O-band high power CW-DFB laser. Fig. 4(a) shows L-I curves at different temperatures for an O-band laser with cavity length of 2.5 mm. The laser can work in a kink-free operation with the injection current up to 1.65 A at 25℃ to 85℃, and output power reaches more than 600 mW at 25℃ and more than 200 mW at 85℃ with 1.6 A and 1.0 A injection current, respectively. This means that the laser can achieve uncooled operation with output power of more than 200 mW, which is twice of the uncooled output power reported in [7]. Fig. 4(b) shows the laser has stable single longitudinal mode operation at different injection current with SMSR over 50 dB. The farfield characteristics of the laser are shown in Fig. 4(c). The divergence angles at injection current of 0.4 A are 10.7° and 16.8° in the horizontal and vertical directions, respectively.

4. Reliability of the high power CW-DFB lasers

Long-term reliability of these high power CW-DFB lasers was investigated from the accelerated aging test under auto current control (ACC) mode at 1.5A and 90℃. The experimental results of 20 optimized L-band lasers are summarized in Fig. 5. The output power remains nearly constant for over 2000 hours except for several kinks caused by accident tripping of the aging test equipment during the measurement. The mean time to failure (MTTF) of random failure mode is estimated using the acceleration model [8]. The acceleration factor is given by (1):

$$AF = \left(\frac{I_{acc}}{I_{op}}\right)^n \left[exp\left(\frac{E_a}{k_B}\left(\frac{1}{T_{op}} - \frac{1}{T_{acc}}\right)\right)\right] \quad (1)$$

Where E_a is the activation energy, n is the current acceleration exponent factor, I_{acc} and T_{acc} are the current and temperature condition of accelerated aging test under ACC mode, I_{op} and T_{op} are the condition of actual work of the lasers, and k_B is the Boltzmann constant. Assuming 0.7 eV for E_a and 3 for n, the MTTF of L-band high power CW-DFB lasers is estimated to be more than 100000 hours at injection current of 1 A and operating temperature of 50℃.

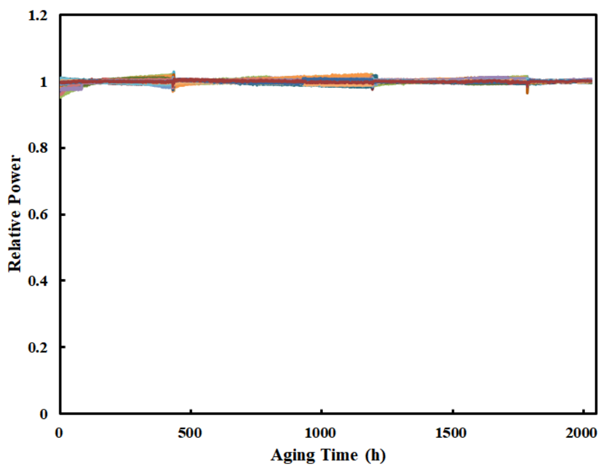

Fig. 5. Results of accelerated aging test on L-band CW-DFB lasers.

5. Conclusion

We demonstrate L-band high power CW-DFB lasers with the kink-free output power over 600 mW at 55ºC and O-band CW-DFB lasers with output power more than 200 mW at 85ºC. All lasers exhibit a stable single longitudinal mode operation in the entire injection current range at various temperatures with SMSR of 50 dB. Moreover, no failure was observed after an accelerated aging test of more than 2000 hours at 90℃. It verifies that the high power CW-DFB lasers are highly reliable.

6. References

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