High efficiency high-power uncooled CWDM4 wavelength CW-DFB lasers

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Abstract: We demonstrate high 75ºC power conversion efficiencies of 19% to 26% at 100 mW (1mm cavity) and 16% to 22% at 200 mW (2mm cavity) for CW-DFB lasers with single-mode operation across CWDM4 wavelengths.

1. Introduction

Silicon photonics links require high efficiency, uncooled, single mode lasers with 100-200 mW facet power to support 1:4 or 1:8 split ratios in DR4/DR8 links at 1310 nm or a 1:2 split ratio to reduce laser count in 2xFR4 links. Higher powers at higher efficiency allows reduction in laser count to improve reliability and reduce packaging cost for 800G DR and FR based transceivers. Co-packaged system-on-chip (SoC) and other generative AI driven optical networking links also demand high laser power at best-in-class power conversion efficiency (PCE). To address this need, new external laser source (ELS) modules that deliver greater than 100 mW per fiber per wavelength at 1270, 1290, 1310, and 1330 nm are proposed and require uncooled high efficiency lasers in the 150-175 mW facet power range across the entire CWDM4 wavelength band. In the last year, several groups have demonstrated higher optical power than conventional 75 mW uncooled, continuous wave distributed feedback (CW-DFB) lasers at 1310 nm [1, 2]. New architectures such as CW-DFB + SOA [2] and new quantum dot (QD) materials [3] have delivered high performance devices albeit with compromises in device length, drive complexity, optical mode shape and emission angle. Previously we had demonstrated record high efficiency and power levels over conventional designs [4] using a new low-loss, near circular far-field design with standard DFB structure and InGaAsP multi quantum wells (MQW) demonstrating record high performance with single spatial and longitudinal mode operation at over 390 mW with 30% PCE at 25ºC and over 230 mW with 20% PCE at 75ºC [5].

In this paper we extend our work on new, low-loss CW-DFBs to all four CWDM4 wavelengths with gains in power and efficiency over conventional designs across the 1270-1330 nm band. The poor high-temperature performance at 1270 nm due to the reduced energy band offsets in InGaAsP MQWs is mitigated to demonstrate record high power and efficiency for 2mm 1270 nm DFB lasers achieving 400 mW at 30% PCE at 25ºC and 150 mW at 19% PCE at 75ºC. Furthermore, for 1mm 1270 nm DFB lasers we demonstrate 270 mW at 30% PCE at 25ºC and 100 mW at 21% PCE at 75ºC. The PCE values for 1270 nm correspond to only a 5% drop in absolute efficiency when compared to 1310nm devices. We also demonstrate high performance at the other two wavelengths (1290 nm and 1330 nm) with each design achieving best-in-class performance.

2. Device structure and measurement setup

The buried heterostructure (BH) CW-DFBs were fabricated on n-InP substrates by metal-organic chemical vapor deposition (MOCVD) using InGaAsP-based materials, including the MQW active region. A constant-width active mesa is formed and buried with conventional p-n blocking InP layers. Two types of lasers with new, low-loss design that enables the reduction of optical losses in highly lossy p-doped cladding and MQW regions were fabricated: 1mm cavity targeting 100 mW uncooled operation; and 2mm cavity, targeting 150 mW uncooled operation. The doping profile and p-side grating for both types of lasers were optimized to maximize efficiency without adverse effect on laser noise. Conventional anti-reflection (AR) and high-reflection (HR) coatings were deposited on the front and rear facets of the laser, respectively. Lasers were mounted n-side down on AlN submount using Au-Sn solder and CW optical performance was measured at operating temperatures recorded at the base of the submount.

3. Experimental results

Figure 1 shows L-I curves and PCE at various temperatures for both 1mm cavity lasers. The measured PCE (PCE_{LD}) is defined as $PCE_{LD} = P_{LD} / (V_{LD} I_{LD})$ where P_{LD} is optical power, V_{LD} is voltage across laser (including wirebonds and submount traces) and I_{LD} is laser current. For 1310 nm, power and efficiency results match our previously reported data for such a laser [5]. Of note is the performance of the 1mm laser at 1270 nm where at 600mA laser current, optical powers of 270 mW at 25ºC, 210 mW at 50 ºC and 135 mW at 75ºC are obtained. This, to our knowledge, is the highest performance for a 1270 nm DFB structures with 1mm cavity length. The data also clearly demonstrates 100 mW uncooled operation with margin at all wavelengths, with PCE ranging from 19% to 26% at 75ºC, though performance for 1290 nm and 1330 nm can be improved to match the trend across wavelength.

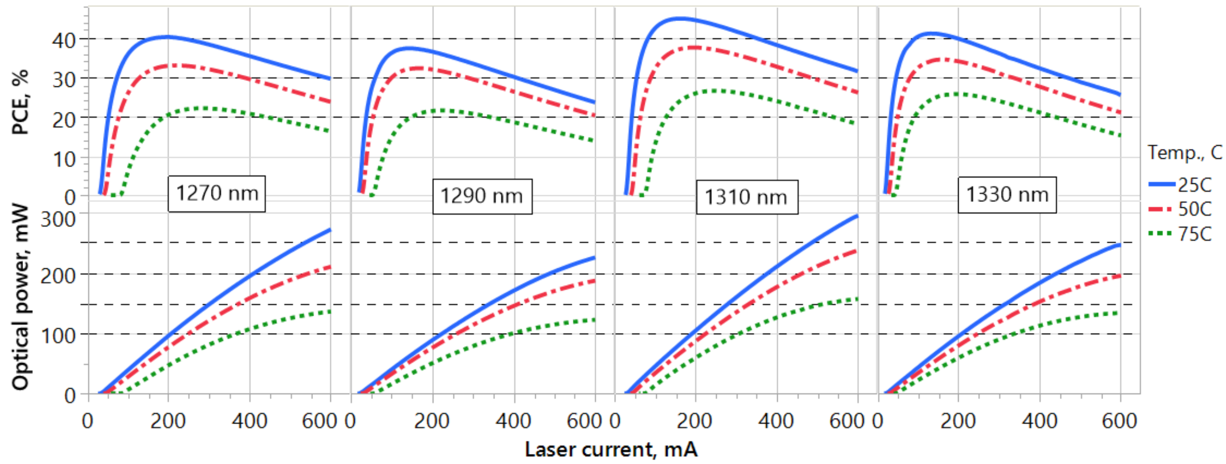

Fig. 1. L-I and PCE vs. laser current at various temperatures for 1 mm long CWDM4 wavelength DFBs

Figure 2 shows L-I curves and PCE versus laser current curves at various temperatures for 2mm cavity lasers. The 1310 nm performance exceeds our previously reported data for such a laser [5]. We have increased the output power by 10% across temperature compared to previous results and demonstrate here the best power and efficiency for a 1310 nm 2mm laser.

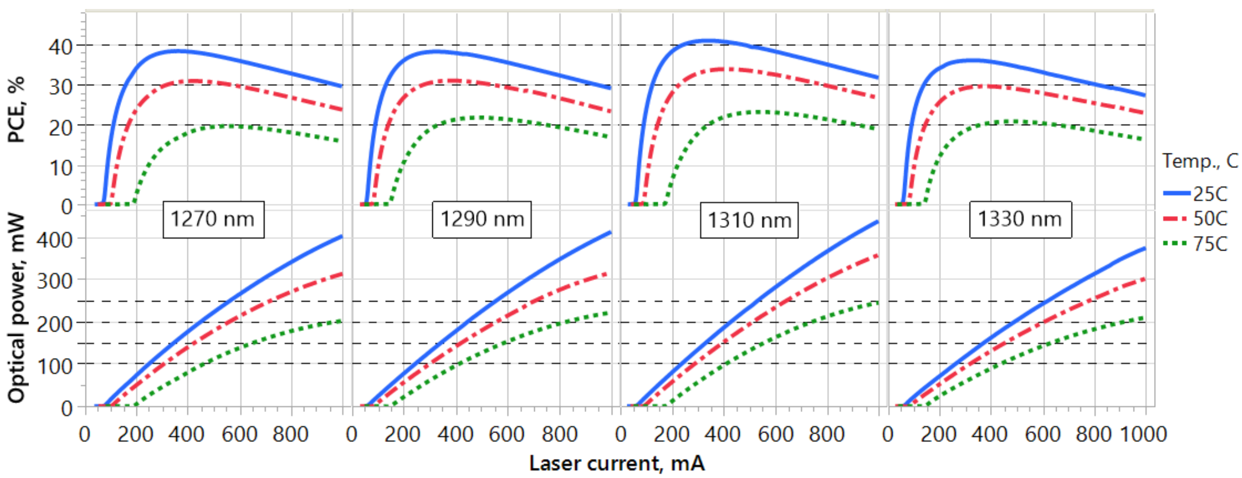

Fig. 2. L-I and PCE vs. laser current at various temperature for 2 mm long CWDM4 wavelength DFBs

Again, of note is the performance at 1270 nm. At 1A laser current, power of 400 mW at 25ºC, 310 mW at 50 ºC and 200 mW at 75ºC are the highest published data for conventional 1270 nm DFB structures with 2mm cavity length. The data also clearly demonstrates 150 to 175 mW uncooled operation with margin at all the CWDM4 wavelengths with PCE ranging from 18 to 22% at 75 ºC. Such power is sufficient to create efficient uncooled external light source modules with greater than 100 mW in the fiber. For semi-cooled operation around 50-55 ºC, these lasers can support greater than 200 mW per fiber in ELS modules to exceed the 100 mW per fiber power reported in [6]. Figure 3 shows typical far-fields for both 1mm and 2mm lasers across wavelengths. While the exact measurements are slightly different for each design, a near circular far-field with full width half maximum (FWHM) approximately of 17º(H) x 20º(V) is obtained for 1mm and a narrower FWHM of 12.5º(H) x 15º(V) is obtained for 2mm lasers, across all wavelengths. Also, the far-field pattern is shown to be stable across operating temperature range.

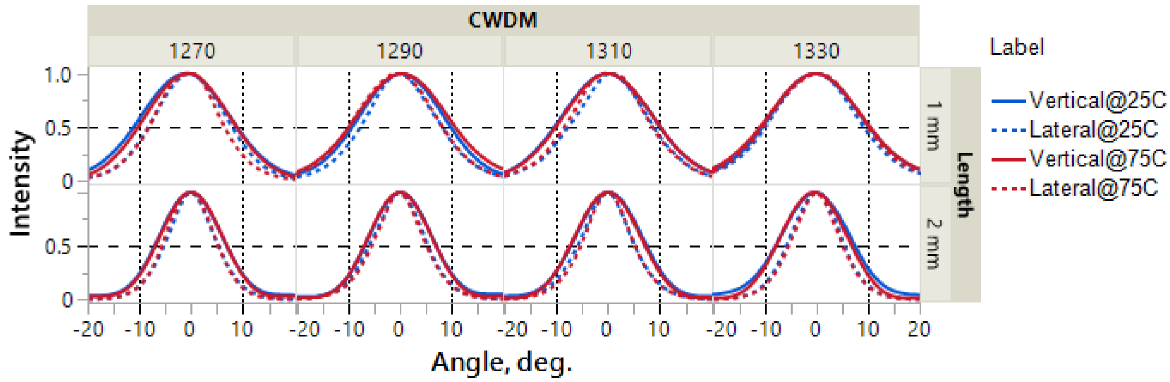

Fig. 3. Lateral and vertical far-field pattern for 1mm and 2mm long lasers showing stable single spatial mode across CWDM4 wavelength and operating temperature.

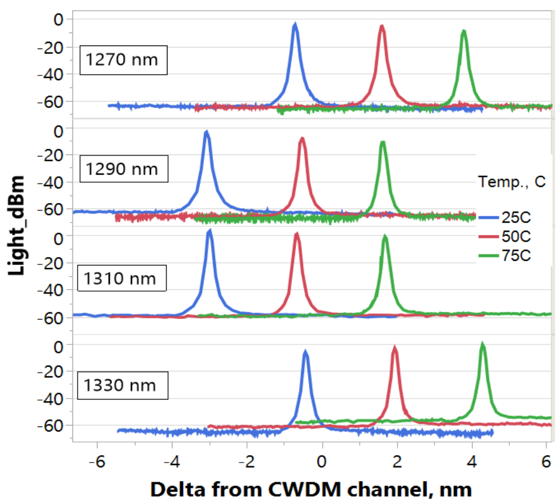

Fig. 4 Spectral data versus delta wavelength from CWDM4 channel (1271,1291,1311,1331 nm)

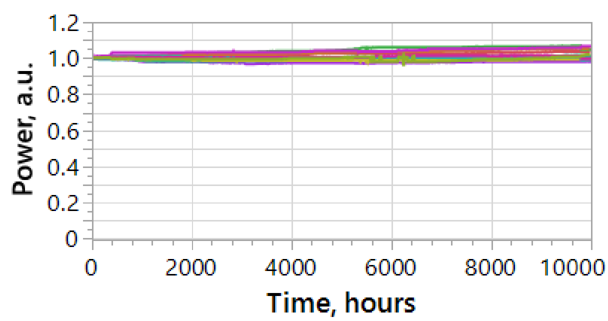

Fig 5. Accelerated aging data at 110°C junction temperature @ 0.9A for 2mm 1310 nm lasers (N=11)

Fig. 4 shows typical spectra, measured across wavelength and temperature at 1A current, from a 2mm laser with side mode suppression ratio (SMSR) greater than 55dB. We also measured RIN with no optical feedback from 1MHz to 26GHz with peak values of less than -150 dB/Hz achieved for all lasers at > 75 mW. Accelerated aging was conducted at 110C junction temperature and 900mA with results shown in Fig. 5 for 2mm, 1310 nm wavelength lasers. Output power remains stable for over 10,000 hours.

3. Conclusions

To the best of our knowledge, we demonstrate record high power and efficiency for CW-DFB lasers across the entire CWDM4 wavelength band from 1270 nm to 1330 nm under uncooled operation, achieving optical output power greater than 135 mW at 75ºC for 1mm and greater than 200 mW at 75ºC for 2mm lasers. We believe these lasers to be reliable and efficient sources for silicon photonics applications.

4. References

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