Record high efficiency high-power uncooled 1.31 μm CW-DFB lasers

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Abstract: We demonstrate record high 75ºC power conversion efficiencies of 25% at 100mW (1mm cavity) and 20% at 200mW (2mm cavity) for CW-DFB lasers with reliable, kink-free, single-mode operation at 1.31 μm.

1. Introduction

Silicon photonics based optical interconnects in transceivers and co-packaged system-on-chip (SoC) require highly efficient, high-power, low-noise lasers at various wavelengths, a need addressed by both external and hybrid integrated continuous wave distributed feedback (CW-DFB) lasers [1-4]. With increased baud rate, lane count (4X or 8X) and optical loss in silicon photonics data encoders, the optical power requirements have increased. One approach is to use a single cooled ultra-high-power laser [5], and another is to use multiple lower-power lasers [3]. Recent publications have clearly documented the reduction in power efficiency as optical power is increased from 100mW to 200mW [3]. But the use of thermoelectric coolers results in unfavorable power consumption, while increasing laser count adversely affects packaging complexity and cost. Therefore, there is a need for new uncooled O-band lasers with higher optical power without sacrificing efficiency. Such lasers can be used with SiNx waveguides on silicon that allow higher power handling capability inside the photonics chips.

Conventional lasers rated at 75-100mW uncooled are available from various laser manufacturers. We demonstrate to the best of our knowledge, a 1.4X to 2X increase in uncooled laser power without sacrificing power efficiency for 1mm and 2mm long cavity CW-DFBs, respectively. These new lasers, designed for both transceiver and SoC applications, represent a significant improvement in power and power conversion efficiency (PCE) for DFB lasers operating at 1.31 μm under uncooled conditions. Laser with 2mm cavities exhibit single spatial and longitudinal mode operation at over 390 mW with 30% PCE at 25ºC and over 230 mW with 20% PCE at 75ºC. For good coupling efficiency to fiber or Si waveguide a large mode with near circular profile is demonstrated. Reliable operation is proven over 1900 hours test under accelerated aging conditions.

2. Device structure and measurement setup

The buried heterostructure (BH) lasers CW-DFBs were fabricated using InGaAsP-based materials, including for the multiple quantum well (MQW) active region, and epitaxially grown on a n-InP substrate by metal-organic chemical vapor deposition (MOCVD). A constant-width active mesa is formed by dry etching and buried with conventional p-n blocking InP layers. Two types of lasers were fabricated: Type A, based on a conventional design like [1-3]; and Type B, based on a new design that enables the reduction of optical losses in highly lossy p-doped cladding and MQW regions. The doping profile and p-side grating for both types of lasers were optimized to maximize efficiency without adverse effect on laser noise. The two laser types allow for direct comparison of improvements in performance for the new laser design when compared to a conventional design, both built on a common fabrication and test platform. Conventional anti-reflection (AR with <0.1%) 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 various temperatures, recorded at the base of the submount.

3. Experimental results

Figure 1 shows L-I curves for different temperatures for both conventional (Type A) design and new (Type B) designs. The curve for the 1mm long Type A laser is very similar to data reported for the conventional design in [1-3]. For a 1mm cavity, the new design increases the power at 600mA from 215mW to 295mW at 25ºC, from 175mW to 235mW at 50ºC and from 120mw to 155mW at 75ºC. With a 2mm cavity, the Type B laser achieves 395mW at 1A laser current at 25ºC and 235mW at 1A at 75 ºC. Figure 2 shows the measured PCE (PCE_{LD}) versus optical power across temperature: $PCE_{LD} = P_{LD} / (V_{LD}\ I_{LD})$ where P_{LD} is optical power, V_{LD} is voltage across laser (including wirebonds and submount traces) and I_{LD} is laser current. Previously [1,3] it has been stated that a 2X increase in power comes at a severe reduction in PCE. Here we demonstrate a new 2mm long Type B laser that more than doubles the available power compared to 1mm devices at any temperature without a concomitant decrease in PCE. For example, at 25ºC the 2 mm laser delivers 3.4X the power from 100 to 340mW at the same PCE of 30%. This trend is seen across all temperatures: 2.9X improvement from 100 to 290mW at PCE of 26% for 50ºC and 2.5X improvement from 80 to 200mW at PCE of 20% for 75ºC.

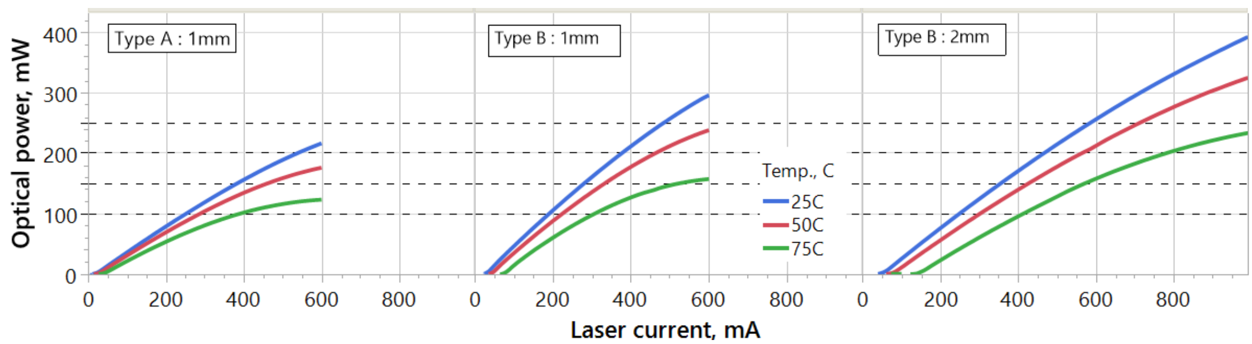

Fig. 1. L-I curve versus temperature for CW-DFB with conventional (Type A) vs. new design (Type B)

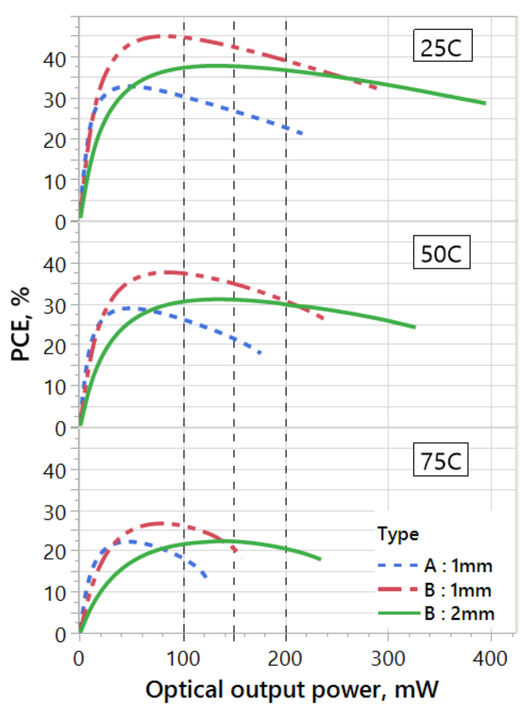

Fig. 2 PCE versus optical power for CW-DFB for conventional (Type A) vs. new design (Type B)

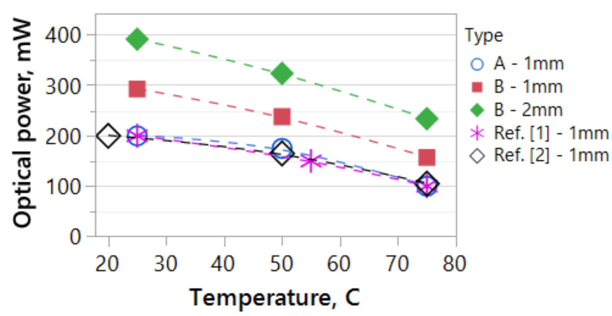

Fig. 3 Maximum power versus temperature for different laser types

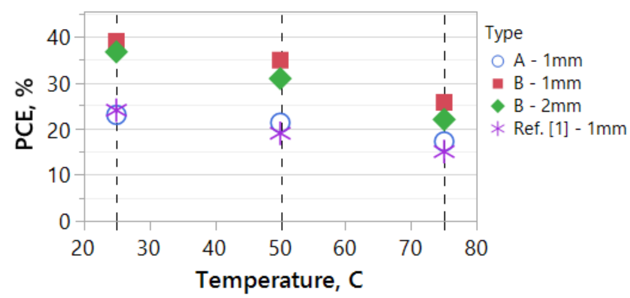

Fig. 4 PCE comparison at same power at each temperature

Figure 3 compares the maximum power from this work vis-à-vis previously reported results for BH CW-DFBs [1,2]. We note that the powers across temperature for our conventional type A laser are like in Ref. [1-2] while the new design demonstrates, to the best of our knowledge, record power levels across temperatures. At 75ºC, optical powers over 150 mW for 1mm lasers and over 240mW for 2mm lasers are reported. Figure 4 shows the comparison in PCE between this work and previously reported data [1] for 1mm devices measured at the same optical power value (set at 200mW @25ºC, 150mW at ~50ºC and 100mW @75ºC). Closed symbols represents improvement in power and efficiency for the new design.

Figure 5 shows typical far-fields for both Type A and B lasers. The conventional 1mm design has a standard far-field full width half maximum (FWHM) of 21º(H) x 26º(V) compared to 17º(H) x 20º (V) for the new design.

Figure 6 shows a narrower FWHM of 12.5º(H) x 15º(V) for the 2mm laser. All lasers maintain single spatial mode operation across operating range and have good overlap with gaussian profiles which couple well into single mode fiber using standard optics.

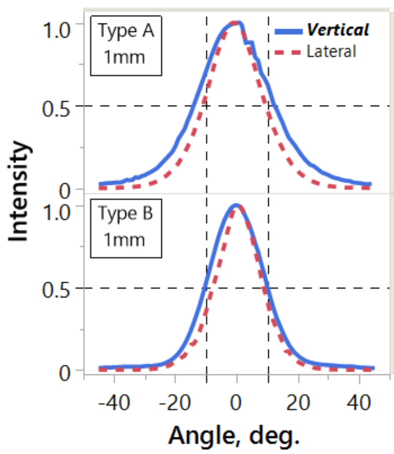

Fig. 5 Lateral and vertical far-field pattern for Type A (top) and Type B (bottom) showing single spatial mode

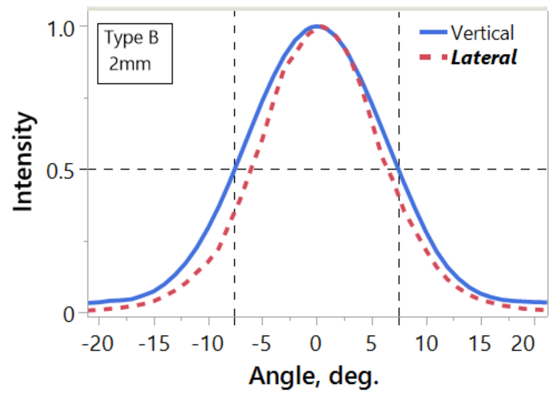

Fig. 6 Lateral and vertical far-field pattern for 2mm long Type B laser showing single spatial mode

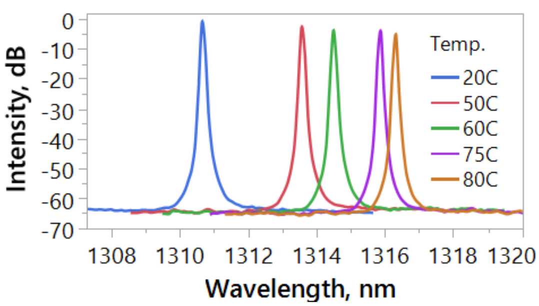

Fig. 7 Spectral data versus temperature at 1A for 2mm Type B DFB laser showing >55dB SMSR

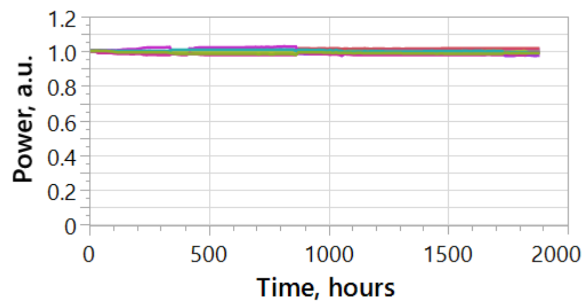

Fig 8. Accelerated aging data at 110ºC junction temperature @ 0.9A for 2mm Type B lasers (N=11)

Fig. 7 shows typical spectra, measured at 1A current, from a L=2mm long laser with single mode suppression ratio 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 > 75mW. Accelerated aging was conducted at 110C junction temperature and 900mA with results shown in Figure 8 for L=2mm lasers. Output power remains constant (other than few deviations due to reliability system interruptions) for over 1900 hours.

3. Conclusions

To the best of our knowledge, we demonstrate record high power and efficiency for CW-DFB lasers at 1.31 μm under uncooled operation, achieving optical output power of 150 mW at 75ºC for 1mm and 230 mW at 75ºC for 2mm lasers. We believe these lasers to be reliable and efficient sources for silicon photonics applications.

4. References

[1] J. Johnson et. al., "Performance and reliability of advanced laser for silicon photonics applications," OFC Tu2D1 (2022)

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