CW-WDM MSA compatible 100-mW (up to 50°C), 400-GHz spacing highly-reliable CW-DFB 8-channel laser array

Ryosuke Hatai, Kouji Nakahara, Atsushi Nakamura, Takayuki Nakajima, Yoshihiko Kobayashi, Takeo Kageyama and Shigehisa Tanaka
Lumentum Japan, Inc., 4-1-55 Oyama, Chuo-ku, Sagamihara, Kanagawa, 252-5250, Japan
Ryosuke.Hatai@lumentum.com

Abstract: We demonstrate a CW-WDM MSA compatible 8-channel 400-GHz spacing 100-mW CW-DFB laser array, with uniform channel spacings (±100 GHz) from 20 to 75°C, small channel-to-channel power deviations (0.56 dB) and over 2000-hour-operation reliability at 80°C.

1. Introduction

Due to the rapid growth of bandwidth demands, energy consumption in datacenters has been exponentially increasing, and energy-efficient optical modules have been highly demanded. In order to realize high energy-efficient transceivers, co-packaged optics (CPO) with silicon photonics (SiPh) is assumed to be a candidate because of its potential ability of high-density wiring. There are several approaches for modulators of SiPh-based CPO modules. Although Mach-Zehnder modulators are widely deployed for SiPh-based transceiver modules, ring modulators can enable high modulation efficiency due to their small footprint [1]. In SiPh-based CPO modules with ring modulators, a highly-reliable continuous-wave distributed-feedback (CW-DFB) laser is assumed to be used as an external light source (ELS). Although ultra-high-power (UHP) CW-DFB lasers (e.g., with 1-W output) could be one solution of the laser sources [2], power-consumption efficiency could be an issue [3]. Thus, it is more likely to adopt 100-mW output CW-DFB laser arrays. Under the circumstances, CW-WDM MSA, a multi-source agreement (MSA) to promote multiple optical interconnects including CPO application, defines a set of laser wavelength grids in the O-band, including 8-channel grids with 400-GHz and 200-GHz spacing [4]. Although multiple lasers could be applicable for the light sources of ELS modules, the assembly cost could be reduced by adopting a single array laser.

In this paper, we demonstrate 100-mW operation (up to 50°C) of a CW-WDM MSA compatible 400-GHz and 200-GHz spacing 8-channel CW-DFB laser array. In order to obtain gain uniformity and the Bragg-wavelength emission with each DFB laser, we apply n-modulation doped profile to multi-quantum well (MQW) and anti-reflection (AR) coating to the front and rear facets. The fabricated array laser exhibits small channel-to-channel power deviation of 0.56 dB at 50°C and maintains small channel-spacing deviation (± 100 GHz) from 20 to 75°C. In addition, to the best of our knowledge, we confirm the first stable operation of 100-mW CW-WDM MSA compatible DFB lasers over 2000 hours at 80°C.

2. Device Structure

Figure 1 (a) shows the schematic view of the 8-channel CW-DFB laser array. Here, a semiconductor optical amplifier (SOA) is integrated with each DFB laser. The SOA also functions as a spot-size converter (SSC) by tapering the waveguide mesa width. Each laser in the array laser including DFB and SOA sections is fabricated monolithically, with epitaxial layers grown on an n-InP substrate using metal-organic chemical vapor deposition (MOCVD). The MQW is InGaAsP-based structure, and the mesa structures including the MQW are formed by dry etching and buried with semi-insulating InP (SI-InP). The reliability of the DFB laser is already proven as an electro-absorption (EA) DFB laser [5] and a CW-DFB laser [6].

AR/AR facet coating is applied to the front and rear facets instead of using AR films and high-reflection (HR) films to the front and rear facets, respectively (AR/HR facet coating). Using AR/AR facet coating, lasing wavelength can be controlled just at Bragg wavelength, while wavelength deviation is inevitable using AR/HR facet coating. Furthermore, we apply n-modulation doped profile on the MQW to achieve gain uniformity along the O-band. With n-modulation doped profile, uniform optical gain distribution can be obtained at threshold carrier density since electrons are distributed widely in conduction band [7]. Figure 1 (b) compares the calculated optical gain distributions with undoped and n-modulation doped MQW at 330 K at the same carrier density. From Fig. 1 (b), we can know that the gain uniformity can be obtained with n-modulation doped MQW. Thus, n-modulation doped profile is applied to MQW, whereas the characteristics of each epitaxial layer, including the doping profiles and thicknesses, are designed to have optimized coupling coefficient (κ). In the following evaluation, the n-side of the lasers are mounted.

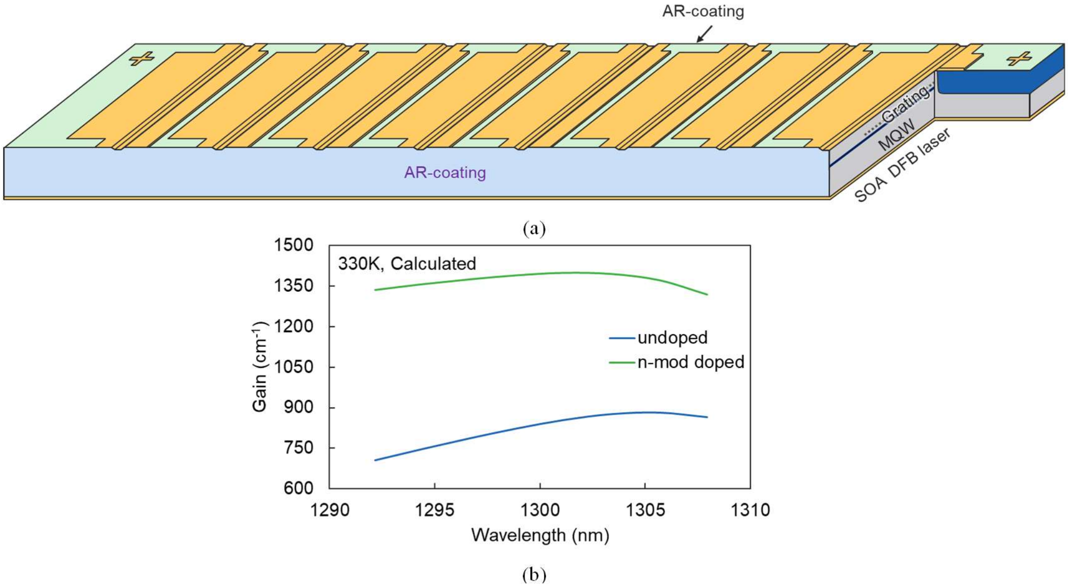

Fig. 1 (a) Schematic view of 8-channel CW-DFB laser array, (b) gain distribution comparison of undoped and n-modulation doped structure at the same carrier density.

3. Results and Discussion

Figure 2 (a) demonstrates the I-L characteristics of the CW-DFB laser array. The measurement is performed under CW operation at 50°C. The threshold current is approximately 25 mA, and the output power reaches 100 mW at 350 mA. The maximum-minimum deviation of output power at 350 mA is 0.56 dB. Also, the wavelength spectra at 350 mA (shown in Fig. 2(b)) exhibit that the frequency spacings of the peak wavelengths are 400 GHz, and more than 40 dB of side mode suppression ratio (SMSR) is confirmed with each laser. While SOA is integrated in order to obtain high output power, such small power deviation with the fine control of the lasing wavelength is obtained due to the gain uniformity and the Bragg-wavelength emission, which are attributed to n-modulation doped MQW and AR/AR facet coating. The lasing wavelengths and spacing frequencies at 20, 35, 50 and 75°C are shown in Fig. 2 (c) and (d), respectively. The measurement is performed at 350 mA under pulse-drive condition. Spacing frequencies are maintained within 400 ± 100 GHz from 20 to 75°C. Therefore, by applying the n-modulation doped MQW with AR/AR facet coating, stable longitudinal single-mode operation of 100-mW CW-DFB laser array is confirmed.

Also, aging test is conducted under the condition of auto-current condition (ACC), 80°C and 350-mA operating current. Figure 2 (e) exhibits that the power evolution of each laser remains stable over the 2000-hour aging test. The maximum shift of the lasing wavelengths between before/after the aging test is ± 0.2 nm, which corresponds to the frequency shift within ± 50 GHz. To the best of our knowledge, this is the first demonstration that 100-mW CW-WDM DFB lasers have passed the 2000-hour aging test.

Finally, the wavelength spectra of a 200-GHz spacing 8-channel CW-DFB laser array are demonstrated in Fig. 2 (f). The measurement is performed at 20°C, 350 mA under pulse-drive condition. As shown in the figure, 200 ± 30 GHz spacing is confirmed with the same structure of 400-GHz spacing array laser. This is also attributed to the AR/AR facet coating. From these results, the 400-GHz and 200-GHz spacing CW-DFB laser arrays satisfy CW-WDM MSA.

4. Conclusion

We demonstrate CW-WDM MSA compatible 8-channel 400-GHz spacing CW-DFB laser array, using the n-modulation doped MQW and AR/AR facet coating. Since uniform gain distribution and Bragg-wavelength emission are obtained using n-modulation doped MQW and AR/AR facet coating, each channel of the array laser exhibits 100-mW output (at 50°C, 350 mA), with a small channel-to-channel power deviation of 0.56 dB. We confirm the fine frequency spacing within 400 ± 100 GHz, which is maintained from 20 to 75°C. In addition, we confirm the stable operation of the array laser over 2000-hour aging test under the condition of 80°C. The first demonstration of the aging test with 100-mW CW-WDM lasers also exhibits that the maximum shift of the lasing wavelengths is ± 0.2 nm, which corresponds to the frequency shift within ± 50GHz. Furthermore, we demonstrate a CW-DFB laser array with the frequency spacings of 200 ± 30 GHz. Such fine control of wavelength spacing is also attributed to AR/AR facet coating. Therefore, the 400-GHz and 200-GHz spacing CW-DFB laser array satisfy CW-WDM MSA, and they are promising candidates for light sources of ELS modules in CPO application.

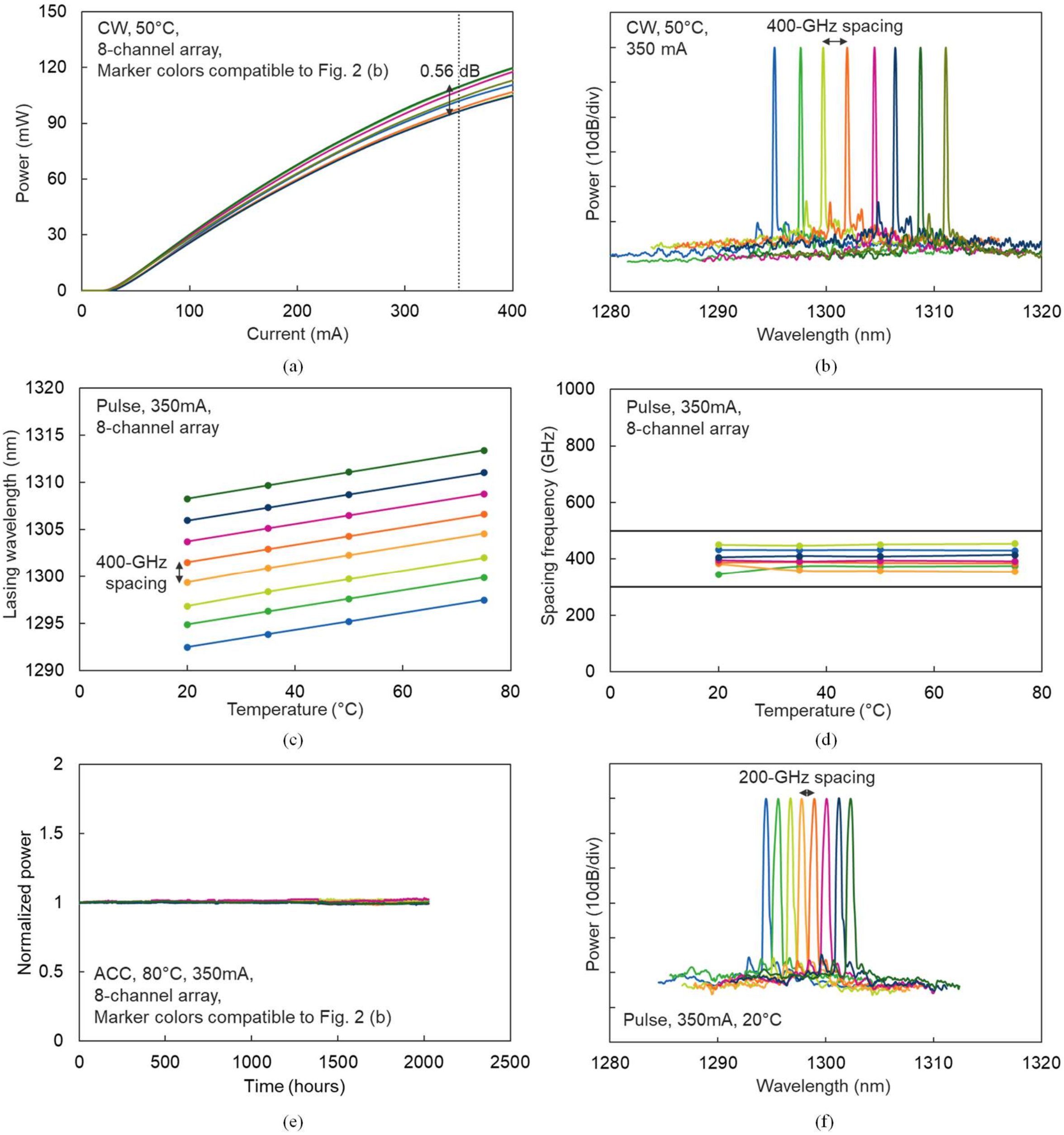

Figure 2 (a) I-L characteristic, (b) wavelength spectra, (c) temperature dependance of lasing wavelength, (d) spacing frequency, (e) power evolution at aging test of 400-GHz spacing laser array, and (f) wavelength spectra of 200-GHz spacing laser array.

5. References

[1] J. H. Han, et al., “Efficient low-loss InGaAsP/Si hybrid MOS optical modulator,” Nature Photonics, **11**, 486-490 (2017).
[2] Y. Mao, et al., “Record-High Power 1.55-µm Distributed Feedback Laser Diodes for Optical Communication,” in Proc. OFC W1B.7, (2021).
[3] J. E Johnson, “Advanced CW Lasers for Silicon Photonic Applications,” in Proc. OFC Tu5C, (2021).
[4] CW-WDM MSA Technical Specifications Rev 1.0, (2021).
[5] S. Yamauchi, et al., “224-Gb/s PAM4 Uncooled Operation of Lumped-electrode EA-DFB Lasers with 2-km Transmission for 800GbE Application,” in Proc. OFC Tu1D.1, (2021).
[6] S. Yokokawa, et al., “Over 100 mW Uncooled Operation of SOA-integrated 1.3-µm Highly Reliable CW-DFB Laser,” in Proc. OFC M4D.3, (2022).
[7] K. Uomi, et al., “Modulation-doped multi-quantum well (MD-MQW) lasers, I. Theory,” Jpn. J. Appl. Phys., **29**, 81-87, (1990).