A facet-free 1.3- μ m surface-emitting DFB laser for a low-cost optical module

Koichiro Adachi^{a)}, Takanori Suzuki, Kouji Nakahara,
Shigehisa Tanaka, Akira Nakanishi, and Kazuhiko Naoe

Oclaro Japan, Inc.,

4–1–55 Oyama, Chuo-ku, Sagamihara, Kanagawa 252–5250, Japan

a) koichiro.adachi@oclaro.com

Abstract: A facet-free surface-emitting distributed feed-back (DFB) laser is proposed for a low-cost optical module. A 45° mirror is integrated on front of a DFB laser for surface emission. Instead of a facet with a high-reflection (HR) coating, a distributed Bragg reflector mirror, a photodiode, and a window structure are integrated on its rear. It is experimentally confirmed this rear structure work same as the facet with the HR coating. The proposed facet-free laser demonstrated on-wafer measurement and attained high-reliability under high humidity. These results indicate the proposed laser can be manufactured cost-effectively without chip-level screenings and used in non-hermetic packages.

Keywords: DFB, facet free, non-hermetic

Classification: Integrated optoelectronics

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1 Introduction

The amounts of data traffic in data centers (DCs) are increasing at an explosive rate because of the rapid progress in cloud computing and mobile networks. The DCs have enormous of interconnections between switches and servers to handle these large amounts of data traffic. The main link distance in the interconnections is up to 2 km, and single-mode fibers (SMFs) are utilized to cover such long-range data transmissions [1]. Accordingly, a low-cost optical module using SMF for the interconnection is a key to support cost-effective operation in DCs.

Reducing number and manufacturing cost of components are essential to realize a low-cost optical module. Using non-hermetic packages are also effective way, since expensive hermetical subassemblies are generally used in current optical modules [2].

A distributed feedback (DFB) laser is attractive light source in terms of high-power, high-speed, and stable single-mode operation, and it is commonly used for an optical module using SMFs. However, a DFB laser requires extra optical components to realize enough optical coupling to a SMF due to its large-divergent beam. A DFB laser needs cleaved facets and facet coatings, and facet coatings sometimes cause degradation of lasing performance, particularly in high-humidity conditions, which prevent an optical module from using non-hermetic packages [3]. Moreover, due to using cleaved facets, an extra chip-level screening is indispensable to guarantee its basic specifications, such as single-mode operation [4].

A facet-free DFB laser can be expected to realize stable lasing performance even in high-humidity condition, which leads to utilize the non-hermetic packages. If a surface emission is realized in addition to the facet-free structure, an on-wafer measurement is possible. Thus, a manufacturing cost of the DFB laser can be reduced [5].

A lens-integrated surface-emitting DFB laser (LISEL) was previously developed by the authors for a low-cost optical module [6]. In the LISEL, a 45° mirror and a lens are monolithically integrated to a DFB cavity. The LISEL achieved highly efficient direct-optical coupling to a SMF [7], which can contribute to reduce the number of components in an optical module. An emission side of the LISEL is the surface-emitting structure which doesn't need any facet and facet coatings. However, the LISEL still uses a cleaved facet and a high-reflection (HR) facet coating on its rear in the same way as a conventional DFB laser. Accordingly, several cost issues concerning facets and facet coatings still remain.

In this study, we proposed a perfectly facet-free DFB laser based on a LISEL. A distributed Bragg reflector (DBR) mirror and a photodetector (PD) are monolithically integrated at the rear of the LISEL, and its rear end is buried with bulk InP (i.e., a window structure [8]) as shown in Fig. 1. A laser with the proposed “rear facet-free structure” was designed and fabricated, and its successful operation was confirmed. On-wafer measurement using a facet-free DFB laser (integrated with a 45°-mirror and the proposed rear facet-free structure) was successfully carried out. The fabricated facet-free DFB laser showed no degradation, even after 200 hours of a saturated pressure-cooker test (PCT) at 138°C and 85% RH, indicating that it can achieve highly reliable operation in a low-cost non-hermetic packaging.

Fig. 1. Schematic image of facet-free surface-emitting 1.3- μm DFB laser.

2 Laser design and experiments

A DFB laser integrated with a DBR mirror is known as a “distributed-reflector” (DR) laser, and it generally needs an anti-reflection (AR) coating on the facet of a DBR mirror [9]. In the case of the proposed rear facet-free structure, the PD and the window structure can provide the same function as the AR coating; thus, neither the facet nor the AR coating is needed. To confirm this AR function using the PD and the window structure, a DFB laser with a DBR mirror, a PD, and a window structure was fabricated as shown in Fig. 2(a). All these parts were monolithically integrated into a chip. A conventional DR laser, shown in Fig. 2(b), which uses AR coatings on both facets, was also fabricated in the same wafer for a reference. Except for their rear structures, both lasers were designed in the same way. A uniform grating was adopted in the DFB region. Lengths of DFB and DBR region were set to be 150 μm and 250 μm , respectively.

Although the lasing wavelength of the DFB region drifts due to the plasma effect and Joule heating, stable single-mode operation, even under high bias, can be achieved by designing the DR laser appropriately [10]. Calculated DBR reflectivity and wavelengths of DFB lasing modes are shown in Fig. 3. In this design, the difference between Bragg wavelengths of the DFB region and the DBR mirror was set to 2 nm. Thus, only one of the two DFB modes is located in the stopband of the DBR mirror.

To evaluate on-wafer measurement and reliability under high-humidity conditions, facet-free DFB lasers were also fabricated as shown in Fig. 4. For each laser, a 45° mirror was integrated on the front (emission) side, and an AR coating was deposited on the emission surface. For simplicity, a lens was not integrated in the laser. A DBR mirror was integrated at the rear. The lasers can emit in on-wafer

Fig. 2. Schematic images of (a) DFB laser with DBR, PD, and window structure on the rear and (b) conventional DR laser using cleaved facets on both sides.

Fig. 3. Theoretical calculation of DBR reflectivity and two lasing wavelengths of DFB laser with uniform grating.

Fig. 4. Schematic image of facet-free DFB lasers.

state, since the laser outputs are totally reflected at the 45° mirrors toward the wafer surface.

3 Measured characteristics

Measured light-current-voltage characteristics under continuous-wave (CW) operation of the fabricated DFB laser, with a DBR mirror, a PD, and a window structure as shown in Fig. 2(a), are plotted in Fig. 5(a). The measurement results for the conventional DR laser [Fig. 2(b)] are also plotted for comparison. The two curves overlap one another, and the threshold current and slope efficiency of each device are almost the same values of around 10 mA and 0.33 W/A. Measured reflectivity of the DBR was about 98% while the reflectivity of the AR coating was designed to under 2.0%. These results indicate that the integrated PD with a window structure successfully operates in the same way as the AR coating (i.e., providing reflectivity under 2.0%).

Fig. 5. (a) Light-current-voltage characteristics of fabricated lasers and (b) lasing spectra of the fabricated DFB laser with DBR, PD, and window structure at various injection currents.

Fig. 6. Measured photo current of integrated monitor PD with respect to LD output power.

As shown in Fig. 5(b), the fabricated DFB laser demonstrated stable single-mode operations with side-mode suppression ratio over 40 dB under applied bias currents from 33 to 70 mA. Note that the lasing wavelength is the longer of the two DFB modes as designed.

Measured current of the PD with respect to light output of the laser are shown in Fig. 6. Bias current applied to the PD was 0 V. As shown in this figure, PD current increases in proportion to light output with good linearity. This result indicates that the PD can work efficiently as a power monitor.

A wafer photograph of the fabricated facet-free DFB lasers is shown in Fig. 7(a). On-wafer measurement of the fabricated facet-free DFB lasers was carried out using the experimental set up shown in Fig. 7(b). The wafer was set on a glass substrate, and the laser output from each device through the glass can be detected by the PD.

Typical examples of light-current characteristics measured with a pulse current with a duty of 0.4% are shown in Fig. 7(c). As shown in the figure, lasing characteristics were measured successfully. Thus, the proposed facet-free DFB laser allows the device performance to be efficiently measured on wafer and the screening process to be simplified and facilitated.

Experimental setup

Fig. 7. (a) Photograph of fabricated facet-free DFB laser, (b) experimental setup for on-wafer measurement of light-current characteristics of the facet-free DFB laser, and (c) measured light-current characteristics of the facet-free DFB laser.

Fig. 8. Measured light-current characteristics of surface-emitting DR laser before and after PCT.

The facet-free DFB laser was subjected to a 200-hour saturated pressure-cooker test (PCT) at 138°C and 85% RH. Measured light-current characteristics before and after the PCT are shown in Fig. 8. The facet-free DFB laser showed almost the same lasing characteristics with no significant degradation after the 200-hour PCT. These results experimentally confirm for the first time that a laser with a facet-free structure can supply high reliability under high-humidity conditions.

4 Conclusion

We proposed a perfectly facet-free DFB laser for a low-cost optical module. A 45° mirror was integrated on a front side of the DFB laser to generate surface emission. Instead of a cleaved facet with HR coating, a DBR mirror, a PD, and a window structure are monolithically integrated at the rear of the DFB laser. The PD and the window structure can provide an anti-reflection (AR) function to prevent residual reflection from the DBR end. This AR function was experimentally confirmed. Thus, the proposed “rear facet-free structure” serves the same function as the cleaved facet with HR coating.

To confirm the capability of on-wafer measurement and the reliability of the proposed facet-free structure under high-humidity conditions, a facet-free DFB laser integrating a 45° mirror on the front and a DBR mirror at the rear was fabricated. The lasing characteristics of the facet-free DFB laser in on-wafer state were successfully measured. The proposed facet-free surface-emitting DFB laser was subjected to an unsaturated PCT at 138°C and 85% relative humidity (RH). Before and after the 200-hour PCT, the proposed laser showed almost the same lasing characteristics without any significant degradation. These results indicate that the proposed facet-free surface-emitting DFB laser can be manufactured in cost-effective way without extra chip-level screening, and used in inexpensive non-hermetic packages.