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High Power, Circular Beam CW DFB Laser using BEX Layer

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Abstract High output power CW DFB laser with 18°x18° FFP is experimentally demonstrated. BEX layer that contributes to circular beam was introduced. The optimal combination of BEX layer with the mesa width was investigated by simulation, resulting in coupling efficiency to increase 3 dB.

Introduction

With a steady growth of the communication data worldwide, the baud rate of modulators used in data center optical communication networks are increasing. Silicon photonics (SiPh) is an attractive technology as a potential cost-effective high-speed optical transmission solution. Although Mach-Zehnder (MZ) modulator is a widely used SiPh modulator, one of the problems of SiPh MZ modulator is that the optical insertion loss becomes large as the baud rate increases, due to its low modulation efficiency [1]. Therefore, a high power CW light source is required.

Co-Packaged Optics are emerging applications that are attracting attentions, and the demand of external laser source form factor pluggable (ELSFP), which in some cases requires eight high power CW DFB laser chips, is also increasing [2]. In both cases, to meet the expectations, power consumption has to be taken into consideration in addition to high output power. For CW DFB laser, a high optical output power of 75 mW at 75°C has been reported [3]. Previously, we also reported over 100 mW SOA (Semiconductor Optical Amplifier) – integrated CW DFB laser under uncooled operation [4].

One of the technologies that contributes to lower power consumption is the improvement of optical coupling efficiency. High-power CW-DFB laser with good coupling efficiency is a promising solution. Several studies about improving the coupling efficiency between DFB laser and SMF (Single Mode Fiber) using external cylindrical lens have been reported [5-6]. However, this method requires external lens, which leads to alignment complexity, high cost, and additional loss of the lens.

In this paper, we demonstrate a CW DFB laser that have both high output power and circular beam characteristics by introducing beam expander (BEX) layer. With this circular beam, the laser chip itself is expected to improve the coupling efficiency by 3 dB without using any external components, compared to the conventional structure (without BEX layer).

Device Structure

Figure 1 shows a schematic of the fabricated DFB laser. The laser structure concept is based on the LD section of uncooled EA-DFB [7], whose high reliability has already been proven. The epitaxial layers of the laser were grown on a n–InP substrate by metal–organic chemical vapor deposition (MOCVD). The MQWs are InGaAsP–based and the mesa structure including the MQWs are formed by dry etching and buried with semi-insulating InP (SI-InP).

BEX layer is formed below the mesa and is spread uniformly from the rear to the front of the laser. BEX layer consists of semiconductor layers whose refractive indices are higher than that of InP and lower than that of MQWs.

For high output power, SOA is integrated at the front part of the chip [4]. Facets of the chip are coated with anti-reflection and high-reflection film. The total length of the chip is 1 mm, and the chip is mounted n-side down.

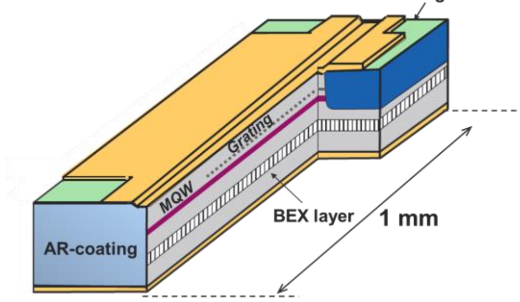

Figure 1. Bird view of BEX layer introduced CW DFB laser

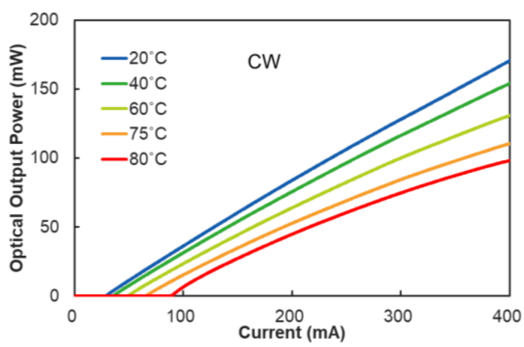

Figure 2. I-L Characteristics of the CW DFB laser with BEX layer

Figure 2 shows the typical I-L characteristics of the fabricated CW DFB laser with BEX layer at 20 - 80°C. The optical output power reaches 100 mW at 80°C, 400 mA.

Effects of BEX Layer

Introducing BEX layer contributes to the following advantages. First, the transverse-mode cut-off width gets wider than that of w/o BEX. In general, the saturation optical output power of the semiconductor laser gets higher as the mesa gets wider. However, the mesa width is usually limited because as the mesa width increases, the transverse higher-order mode appears, resulting in poor mode stability.

Figure 3 shows calculation results of the relation between the normalized mesa width and the confinement coefficient (Γ) of 2nd order mode. The green line represents w/o BEX, and the blue line represents a BEX layer structure. The insets show the simplified schematics of the cross-section of two structures. Γ of 2nd order mode starts to rise when the second transverse-mode appears. For w/o BEX, the second transverse-mode starts to appear when the normalized width is about 0.6, while it does not appear until the normalized width is over 1 for the BEX structure. This result indicates that BEX layer structure can be designed with wider mesa width than w/o BEX, which enables higher optical output power.

Second, since BEX layer is spread below all over the mesa, the light is pulled downward, expanding and shaping the Near Field Pattern (NFP) close to a circular shape. Figure 4 shows experimental results of normalized mesa width and the far field pattern (FFP). The black and grey square represents w/o BEX, and the blue and light blue circle represents BEX layer structure. The FFP of BEX layer structure is 18°x18° when the normalized width is 1. This indicates that the output beam is a complete circle, aspect ratio of 1. On the other hand, for w/o BEX, there are almost constant differences between the vertical and horizontal FFP. The aspect ratio of w/o BEX is about 1.5. In addition, both vertical and horizontal FFP of BEX layer structure is narrower than that of w/o BEX. The FFP of w/o BEX is about 20°x30°, while the FFP with BEX layer is about 10°x13° to 18°x22°.

The size and the shape of the FFP affect the coupling efficiency between the chip and other optical components. The coupling efficiency of the chip and SMF are calculated by Gaussian beam approximation and paraxial approximation. Figure 5 shows the relation between the normalized width and the coupling efficiency of BEX layer structure and the w/o BEX. When the normalized width is 1, the coupling efficiency is approximately 40% for BEX layer structure, whereby it is 20% for w/o BEX. From this calculation result, it can be said that the coupling efficiency increased 3 dB by introducing BEX layer.

Third, by pulling the light downward by BEX layer, the electric field to reach p-clad will decrease, which results in smaller loss.

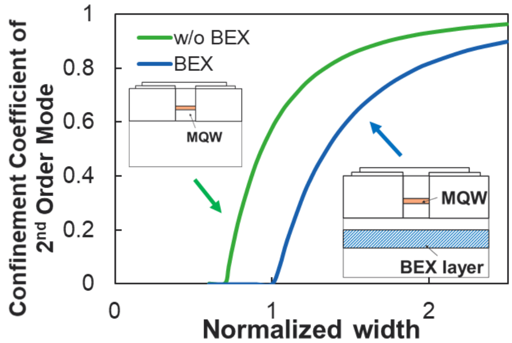

Figure 3. Calculation results of relation between normalized width and confinement coefficient of 2nd order mode. The insets show the simplified schematics of the cross-section of the structures. (Green: w/o BEX, Blue: BEX layer)

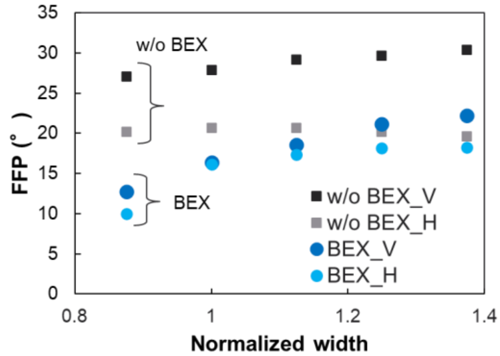

Figure 4. Experimental results of normalized mesa width and FFP

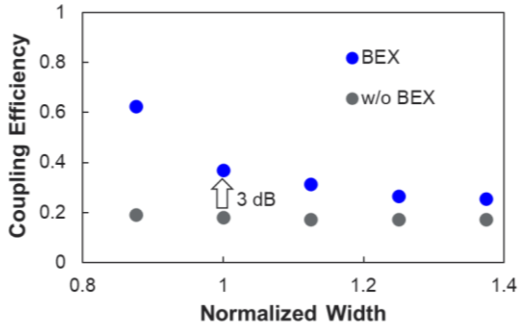

Figure 5. Calculated coupling efficiency of the chip and a fiber. (Blue: BEX, Gray: w/o BEX)

When designing a DFB laser, one of the important parameters needs to be considered is Γ (MQW) as it affects the threshold of the laser. The Γ (MQW) of BEX layer structure is designed to be same as that of w/o BEX. As a result, the transverse-mode cut-off width, beam shape, coupling efficiency and total loss are improved without changing Γ (MQW) of the laser.

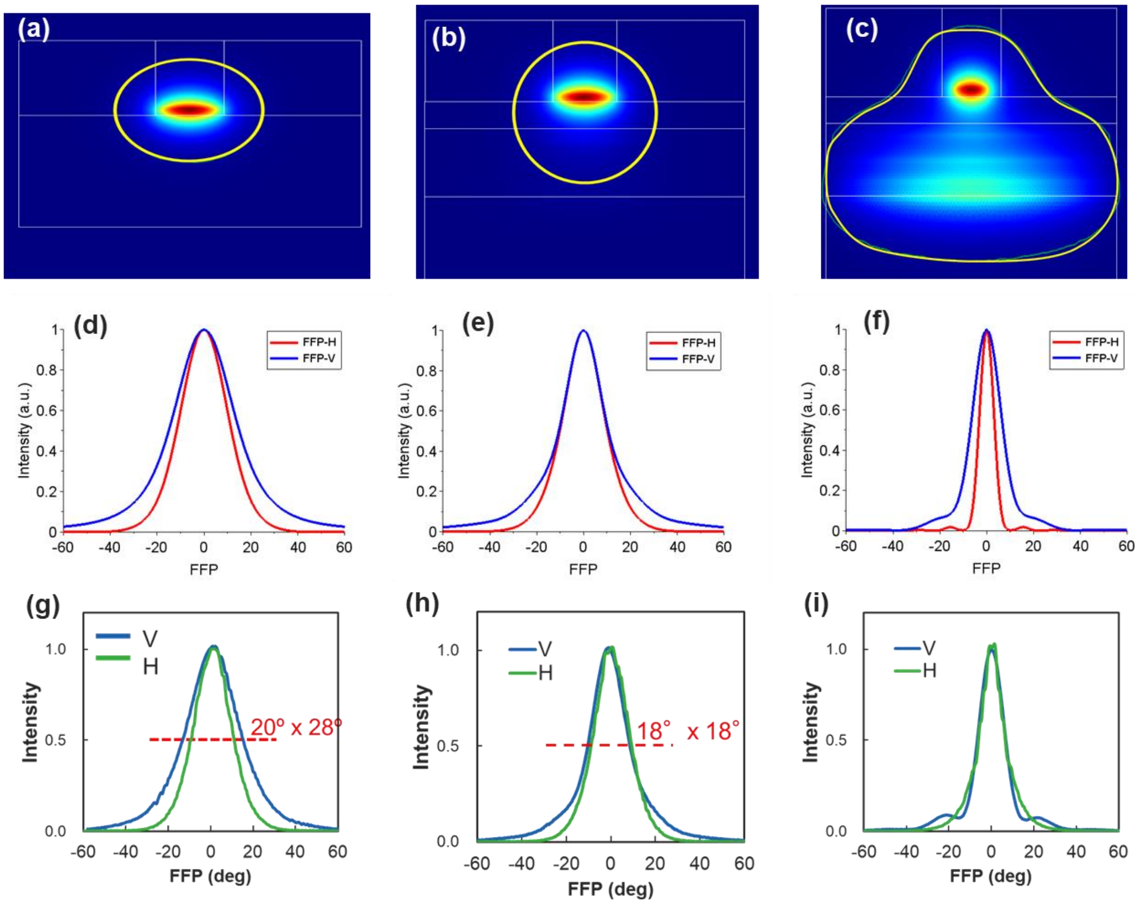

Figure 6. Simulation and Experimental results of w/o BEX and BEX layer structure.

(a-c) Simulated NFP. (d-f) Calculated FFP. (g-i) Experimental results of FFP.
(a,d,g) w/o BEX, (b,e,h) BEX layer structure with wide mesa, (c,f,i) BEX layer structure with narrow mesa.

Simulation and Experimental results

The balance of BEX layer and the mesa width is important when introducing BEX layer. Figure 6 shows the simulation and experimental results of w/o BEX and BEX layer structure. The electric field is simulated using finite element method, and FFP is calculated using two-dimensional Fourier transform. For w/o BEX, the NFP is elliptic and is extended transversely (Fig.6 (a)). With this NFP, the vertical and horizontal FFP will be different, and the aspect ratio will be as large as 1.5 (Fig6. (d)). In the experiment, the FFP is 20°x28° (Fig.6 (g)). This tendency for the w/o BEX does not change regardless of the mesa width. On the other hand, for BEX layer structure with appropriate mesa width, the NFP has circular shape (Fig.6 (b)). With this NFP, the vertical and horizontal FFP will be almost the same, and the aspect ratio will be as close as 1 (Fig.6 (e)). In the experiment, the FFP is 18°x18 (Fig.6 (h)). However, when the mesa width is narrow, part of the light is distributed to BEX layer and the NFP shape is distorted (Fig.6 (c)). This is due to the refractive index of BEX layer, which is higher than that of InP. Calculated and experimental FFP is shown in Fig.6 (f), (i), both of which have pedestals. It is likely that the coupling efficiency of this structure is lower than that of the former two structures. It is necessary to design the mesa wide enough to have a circular beam for BEX structure.

Conclusion

By introducing BEX layer, high output power CW DFB laser with circular beam of 18°x18° FFP is experimentally demonstrated. Coupling efficiency of BEX layer structure chip and SMF are calculated, and it is estimated to increase 3 dB compared to w/o BEX.

Relations between the mesa width and Γ of the 2nd order mode, FFP and the coupling efficiency are shown, indicating that the higher order transverse cut-off width to be wider and FFP to be smaller, leading to high output power and higher coupling efficiency. We believe this BEX layer structure, which emits circular beam, increases the coupling efficiency, and contributes to providing enough power to SiPh components at low power consumption.

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