Up to 25 Gb/s direct modulation of high power SOA integrated with a 1.5 μm InGaAlAs/InP DFB laser

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Abstract *We report a 1.5 μm InGaAlAs/InP DFB laser integrated with high power SOA, which emits 411 mW light power at 20 °C. The SOA is used for NRZ data modulation at up to 25 Gb/s. Clearly opened eyes and BER below 10E-10 can be obtained.*

Introduction

High power semiconductor lasers have important applications in many fields including optical fiber communication, free space optical communication, light detection and ranging and medical treatment and silicon photonics. There have been different types of high power semiconductor lasers up to now such as distributed feedback (DFB) lasers having dilute waveguide structure [1] or large optical cavity [2], and lasers integrated with semiconductor optical amplifier (SOA) [3, 4]. For applications such as time division multiplexed passive optical network (PON) [5] and free space optical communications [6], high speed modulation is needed at the same time with high power. Integrated external modulators such as MZM and EAM can be used [6], which, however, induce apparent optical loss. Direct modulation of high power DFB laser can also be adopted. Though the lasers usually has a long cavity, a larger than 8 GHz direct modulation bandwidth has been reported [7]. For the SOA integrated DFB lasers, SOA can be used as a modulator [6]. When the SOA input power is high the reduced carrier lifetime in the SOA makes it possible for data modulation at larger than 10 Gb/s [8].

In this paper, we report a 1.5 μm SOA integrated InGaAlAs/InP multi-quantum well (MQW) DFB laser. At 20 and 80 °C, the measured optical power are 411 mW (26.1 dBm) and 148 mW (21.7 dBm), respectively. The device shows a good single mode emission performance, the side mode suppression ratio (SMSR) of the optical spectra is larger than 35 dB. The SOA of the device has a larger than 5 GHz 3dB direct modulation bandwidth. Data modulations are performed at 5, 10, 15 and 25 Gb/s NRZ data rate and room temperature. Clearly opened eye diagrams can be obtained at all the conditions for the back to back (BtB) transmission. Bit error rate (BER) performance has also been studied. After 10 Km fiber transmission, lower than 10E-10 BER can be obtained for 5 and 10 Gb/s data modulations. For 25 Gb/s data modulation, lower than 10E-10 BER can be obtained for back to back condition and lower than 10E-4 BER can be obtained after 2 Km fiber transmission. This laser device has potential applications in PON and free space optical communication systems, in which both high power and high speed modulation are desired.

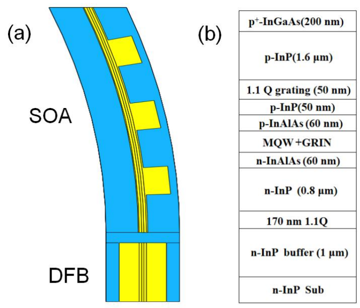

Fig. 1: Schematic waveguide (a) and material (b) structures of the device.

Device structure and fabrication

Fig. 1(a) shows the schematic structure of the SOA integrated DFB laser, which consists a 400 μm long DFB section and a 1500 μm long SOA section. The device has a 3 μm wide ridge waveguide structure for both the two sections. A 50 μm region, in which the InGaAs material on top of the ridge waveguide is removed, is inserted between the two sections to introduce electrical isolation. The waveguide at the output of the SOA is tilted for 7 degree with respect to the chip facet to reduce the interface reflectivity. Both the DFB and SOA sides of the chip are coated, with a 30% and 0.1% reflectivity, respectively. Three 100 μm ×100 μm pads are formed for the SOA for wire bonding. The width of the SOA electrode in other area is 10 μm.

As shown in Fig. 1(b), the material structure of the device consists of a 1μm thick n-InP buffer layer, a 170 nm thick InGaAsP layer having 1.1μm bandgap wavelength (1.1Q), a 0.8 μm thick n-InP layer, a 60 nm n-InAlAs cladding layer, and a 60 nm thick graded-index separate confinement heterostructure (GRINSCH) InGaAlAs layer. The MQW active layer has three 5 nm thick compressively strained (+1.0 %) InGaAlAs wells and four 11 nm thick tensilely strained (−0.2 %) AlGaInAs barriers. Above the MQWs, there is another 60nm thick GRINSCH InGaAlAs layer and a 60nm thick p-InAlAs cladding layer. A 50 thick 1.1Q is used as grating layer, which is separated from the MQWs by a 50 nm thick InP layer. After gratings are formed by E-beam technique and the grating layer in the SOA section is removed, a 100 nm InP space layer, a 30 nm 1.1Q etch stop layer, a 1.6 μm thick p-InP cladding layer and a finally 0.3 μm thick p-InGaAs contact layer are successively overgrown.

As shown above, different from a conventional semiconductor laser, a 170 nm thick 1.1Q layer is inserted into the lower InP cladding layer. The layer drags the optical near field in the vertical direction down toward the n cladding layer side. Thus the optical confinement factor in the highly doped p cladding layer is reduced, resulting in a lower related modal loss. In addition, the small number of QWs reduces the optical confinement factor in the active layer, also helping to increase the output optical power. The 1.1Q layer also expends the optical near field, leading to a reduction of the far field divergence angles.

Static optical characterizations

Before static and high speed testings, the device is soldered onto an AlN heat sink whose temperature is controlled by a TEC. The optical power from the device is measured with an integrating sphere. Fig. 2 (a) shows the optical power as a function of DFB section current measured from the DFB facet when the SOA section is left open. The threshold current and the optical power are 13.9 mA and 7.7 mW at 200 mA current at 20 °C and change to 32.5 mA and 3.3 mW, respectively at 75 °C. Fig. 2(b) shows the optical power as a function of SOA current. At 20 °C and when the DFB current is 190 mA, the measured optical power is 411 mW at a 750 mA SOA current. At 75 °C, a 149 mW optical power can be obtained when the DFB and SOA sections are biased at 167 and 450 mA, respectively. Though the optical power from the DFB section increases with the DFB current below 200 mA as shown in Fig. 1(a), further increase of the DFB current leads to a decrease of the optical power measured from the SOA facet.

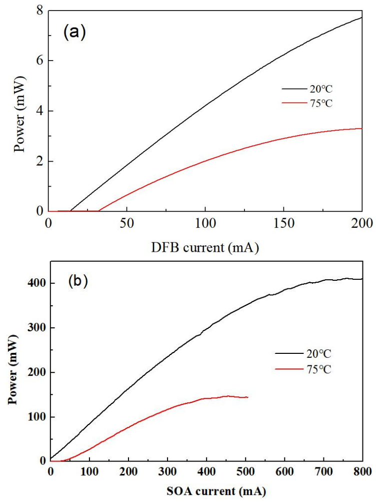

Fig. 2: Optical power vs. DFB (a) and SOA (b) current.

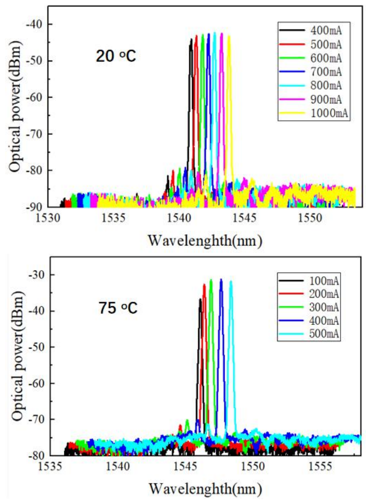

Fig. 3: Optical spectra at different SOA current.

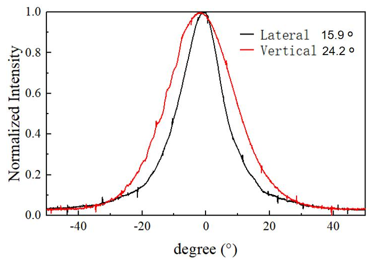

Fig. 4: Far field patters of the device.

Fig. 3 shows the optical spectra of the device measured at different SOA current. The emission wavelength of the device is at around 1542 and 1547 nm, for the temperature of 20 and 75 °C, respectively. A good single mode emission property can be seen from the larger than 35 dB SMSRs for all the spectra shown in the figure. Fig. 4 shows the far field patters measured from the SOA facet. The measured divergence angles are 24.2 and 15.9 degree for the vertical and horizontal directions, respectively. This small divergence angles can be attributed to the 1.1Q layer inserted below the MQWs and helps to increase the coupling coefficiency between the laser and a fiber.

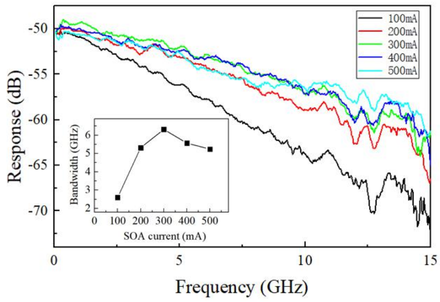

Fig. 5: Modulation response of the SOA. The inset shows the modulation bandwidth as a function of SOA current.

High speed modulation performance

The high speed modulation performance of the SOA is tested at 20 °C. To study the small signal direct modulation properties, a 50-GHz network analyzer is used. The modulation signal is fed to the SOA through a 50 GHz GSG probe. Fig. 5 shows the measured small signal direct modulation response of the SOA when the DFB section it is biased at 100 mA. As can be seen, the 3 dB modulation bandwidth increases from 2.6 GHz to 6.3 GHz when the SOA current is increased from 100 mA to 300 mA. Further increase of the SOA current decreases the modulation bandwidth. At 500 mA SOA current, the bandwidth is 5.2 GHz. The DFB current effects the SOA modulation only slightly. For example, for a 200 mA SOA current, the modulation bandwidth is 5.24 GHz when the DFB current is increased to 200 mA.

The SOA is then modulated at different data rate by nonreturn to zero (NRZ) pseudo random bit sequence (RPBS) data patterns, which are generated by a commercial pulse pattern generator (PPG, SHF-12125B). The SOA and DFB are biased at around 450 and 150 mA, respectively. Fig. 5(a) shows the measured BtB eye diagrams when the SOA is under 5, 10, 15 and 25 Gb/s NRZ data modulation. As can be seen, clearly opened eyes can be obtained for all the data rates. The BER performance is studied at 5, 10 and 25 Gb/s data modulation of the SOA. As shown in Fig. 5(b), for the 5 Gb/s modulation lower than 10E-10 BER can be obtained after 25 Km of standard single mode fiber transmission. For the 10 Gb/s modulation, lower than 10E-10 BER can be obtained after 10 Km of fiber transmission. For the 25 Km transmission, the lowest BER is 10E-5. When the data rate is increased to 25 Gb/s, 10E-10 BER can only be obtained for the BtB condition. After 2 Km of fiber transmission, lower than 10E-4 BER can be measured.

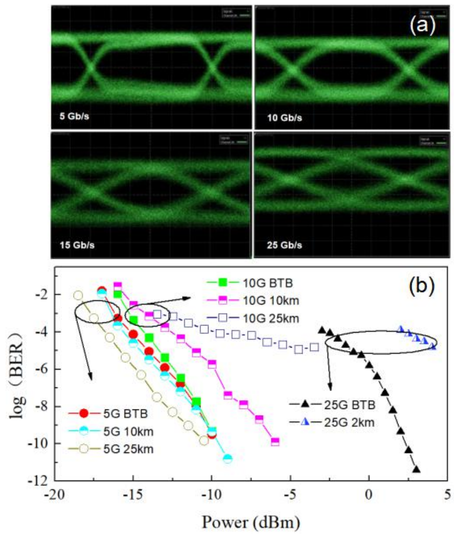

Fig. 6: Eye diagrams and BER performance of the device.

Modulation of a high power discrete SOA has been reported in an earlier reference [9], however, with lower than 10 Gb/s date rates. Over 25 Gb/s modulation of SOA has been shown feasible numerically [8]. To the best of the authors' knowledge, we report for the first time the experimental modulation of a high power SOA at up to 25 Gb/s. Clear eyes can be obtained without the application of equalizers. Compared with an external modulator, the SOA amplifies light at the same time of modulation, helping to enhance the light power. Due to the low carrier lifetime at high SOA power, modulation of a SOA seems better than the direct modulation of a high power DFB laser. In our experiments, we find that for a DFB laser having a 8 GHz bandwidth [7], eyes are closed for 10 Gb/s NRZ data modulations.

Conclusions

In this paper, we report a 1.5 μm InGaAlAs/InP DFB laser integrated with a high power SOA, which emits 411 mW light power. The SOA is used for NRZ data modulation at up to 25 Gb/s. Clearly opened eyes and BER lower than 10E-10 can be obtained. The device has small divergence angle, helping to ease its coupling with a single mode fiber. This laser device has potential applications in ares such as PONs, in which both high power and high speed modulation are desired.

Acknowledgements

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