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Communication

25 Gb/s Data Transmission Using a Directly Modulated InGaAlAs DBR Laser over 14 nm Wavelength Tuning Range

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Abstract: With the deployment of the fifth generation of mobile networks (5G), 25 and 100 Gb/s directly modulated lasers and modules will become the mainstream optical transmitters. A directly modulated InGaAlAs/InP distributed Bragg reflector (DBR) laser is fabricated by butt-joint technology. A 25 Gb/s data transmission over a single-mode fiber of up to 10 km is demonstrated, and a wavelength tuning range of 14.28 nm is achieved through injection current tuning of a DBR section and temperature control of a thermoelectric cooler (TEC), which is the best candidate of colorless light sources for wavelength-division-multiplexed passive optical network (WDM-PON) systems.

Keywords: tunable laser; multiple quantum wells; data transmission

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1. Introduction

With the deployment of the fifth generation of mobile networks (5G), in the next few years, the demand for optical devices in 5G networks will mainly include three aspects: huge data throughput by optical devices, a wider operating temperature range, and low cost [1–6]. Directly modulated lasers and modules with 25 and 100 Gb/s data transmission characteristics will become the mainstream optical transmitters. Especially for the 5G fronthaul and data center, the demand for optical transmitter chips will increase rapidly. A wavelength-division-multiplexed passive optical network (WDM-PON) is the best solution for fronthaul due to the potential of low costs and high transmission capacity. InGaAlAs tunable distributed Bragg reflector (DBR) lasers have the advantages of compact size, easy wavelength tuning, superior temperature performance, and low fabrication cost, which are the best candidates of colorless light sources for WDM-PON systems [7–12]. Compared with an InGaAsP tunable laser, an InGaAlAs tunable laser has better high-temperature and high-speed characteristics, and all tunable wavelengths have better consistency. Under DBR current tuning, the tuning range of the tunable laser is about 10 nm, and at present, commercial tunable DBR lasers mostly work at a rate of 10 Gb/s. With the development of optical communications, tunable lasers with a rate greater than 10 Gb/s will be widely used.

In this paper, a packaged two-section InGaAlAs/InP DBR laser is reported to realize 25 Gb/s data transmission of up to 10 km in a single-mode fiber with a wavelength tuning range of 14.28 nm.

2. Device Fabrication

The two-section InGaAlAs DBR laser includes a gain section and a DBR section. There is an electrical isolation gap between the two sections, which is etched using ion-coupled plasma (ICP) followed by He^{+} implantation. The gain section contains six pairs of InGaAlAs multiple quantum wells (MQWs) with a photoluminescence (PL) spectral wavelength of 1.53 µm, and a thick InGaAsP layer with a PL wavelength of 1.4 µm is butt-jointed with the active layer of the gain section. A detailed fabrication process can be found elsewhere [13,14]. The width of the ridge waveguide is 3 µm, and the lengths of the gain and the DBR sections are 250 and 150 µm, respectively. The width of the isolation gap is 50 µm. Ti/Pt/Au electrodes are made as p-type ohmic contact electrodes through a stripping process. An Au/Ge/Ni alloy electrode is used as an n-type ohmic contact electrode, and then thickened with Cr/Au. The tunable DBR laser is mounted on an AlN heat sink for package and measurement after the chip fabrication is completed.

3. Experimental Setup and Results

A picture of a packaged DBR laser is shown in Figure 1a. The light–current characteristic of the device at 10 °C is shown in Figure 1b. The threshold current of the device is 24 mA, and the output power is 10.03 mW when the gain current is 100 mA and the DBR current is 0 mA.

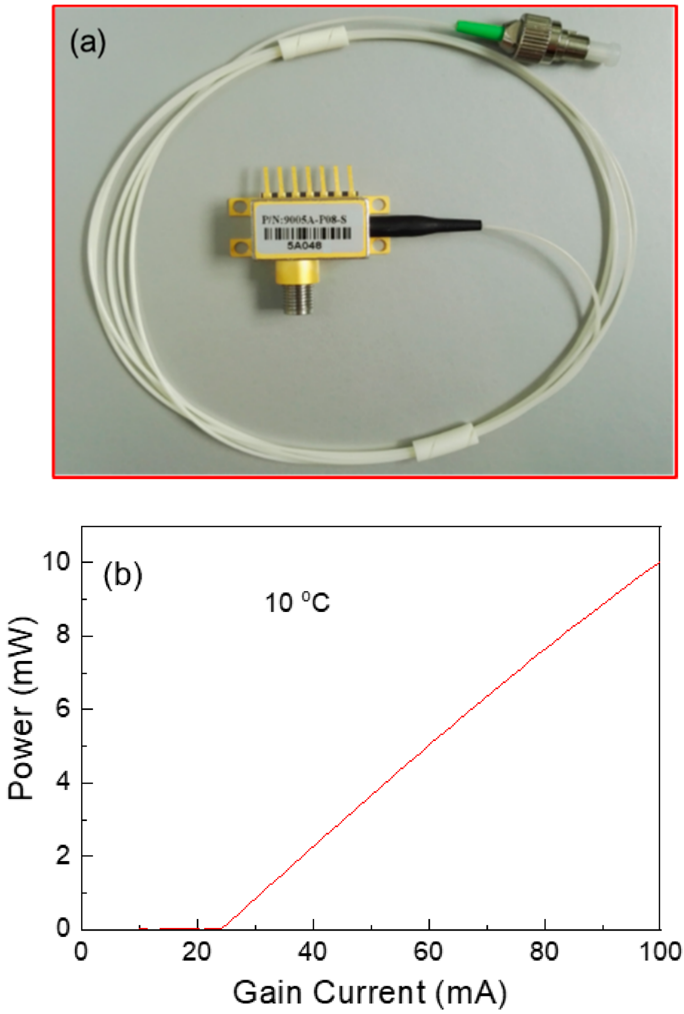

Figure 1. (**a**) Picture of a packaged distributed Bragg reflector (DBR) laser. (**b**) The light–current characteristic of the device at 10 °C.

The emission wavelength and the sidemode suppression ratio (SMSR) as functions of the DBR injection current at a gain current of 80 mA at 10 and 49 °C are shown in Figure 2a,b, respectively. The lasing wavelength can be tuned up by 9.24 nm from 1544.28 to 1553.52 nm at 10 °C and by 9.24 nm from 1549.32 to 1558.56 nm at 49 °C as the DBR current increases from 0 to 80 mA. Therefore, a total wavelength tuning range of up to

14.28 nm is realized with the combination of DBR current tuning and temperature tuning. The SMSR is greater than 35 dB during the entire tuning range except in the regions where a mode jump occurs. As the temperature changes from 10 to 49 °C, the wavelength tuning range remains the same, and the degradation of the SMSR is less than 5%, and that shows that the InGaAlAs multiple quantum wells, as the active layer of the tunable laser, have good temperature characteristics and can achieve the consistency of performance at different tuning wavelengths at different temperatures.

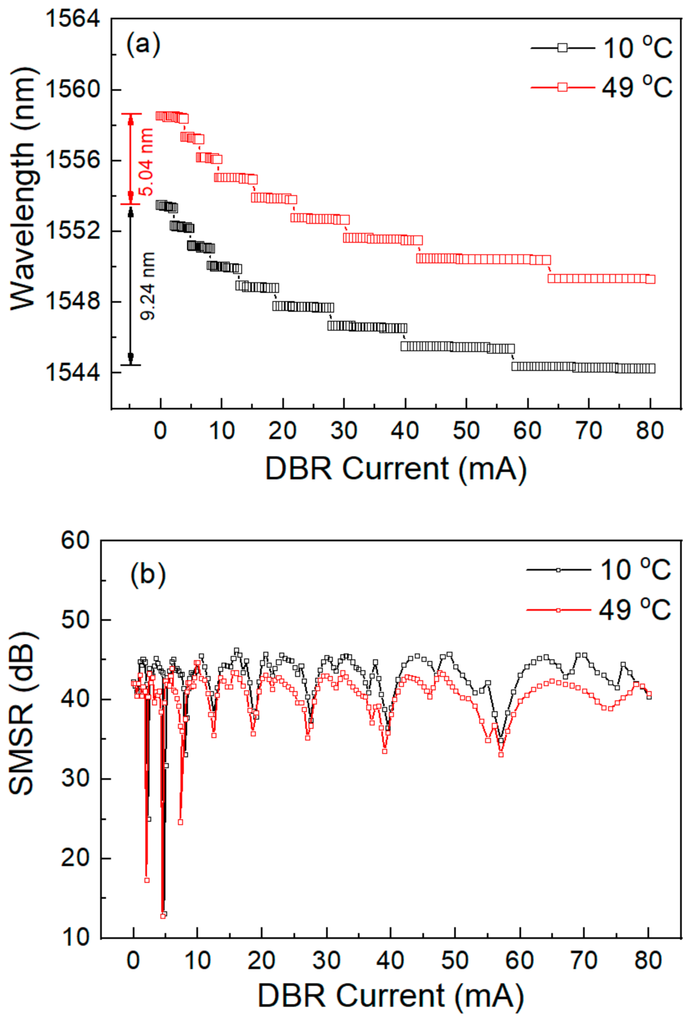

Figure 2. Laser emission wavelength (**a**) and sidemode suppression ratio (SMSR) (**b**) as functions of the injection current of the DBR section at a gain current of 80 mA at 10 and 49 °C, respectively.

In order to obtain a tuning range greater than 14 nm, the entire tuning wavelength at 10 °C and the partial tuning wavelength at 49 °C were selected to test the transmission performance of the tunable DBR laser. The typical optical spectra of the InGaAlAs DBR laser are shown in Figure 3, which are selected from the entire wavelength tuning range of 9.24 nm at 10 °C and 5.04 nm at 49 °C marked in Figure 2a, with SMSRs over 40 dB. The three wavelengths of 1544.34, 1551.18, and 1558.56 nm marked in Figure 3 are used to test the modulation and transmission performance.

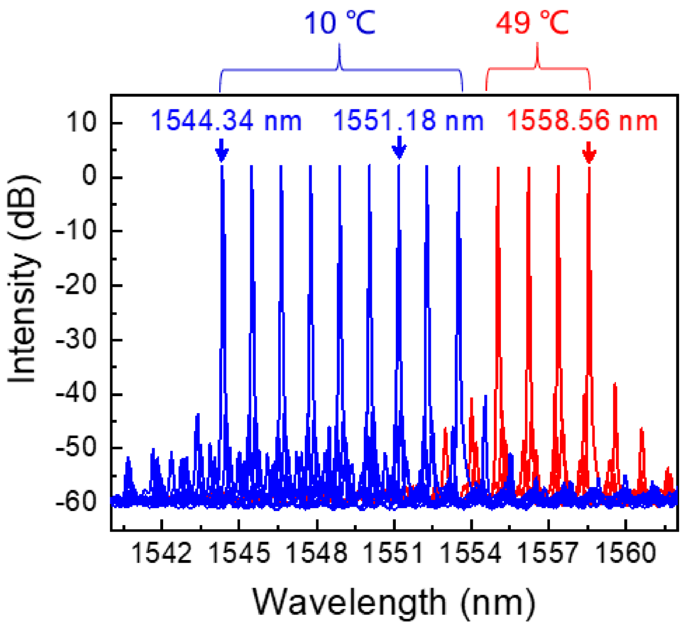

Figure 3. Typical optical spectra of the DBR laser at 10 and 49 °C.

A 50 GHz network analyzer is used to measure the small-signal modulation response of the packaged DBR laser. The 3 dB bandwidth of the device is 12.53 GHz at 10 °C. During the measurement, the gain current was biased at 80 mA, and the DBR current was 0 mA. The small-signal modulation property is shown in Figure 4.

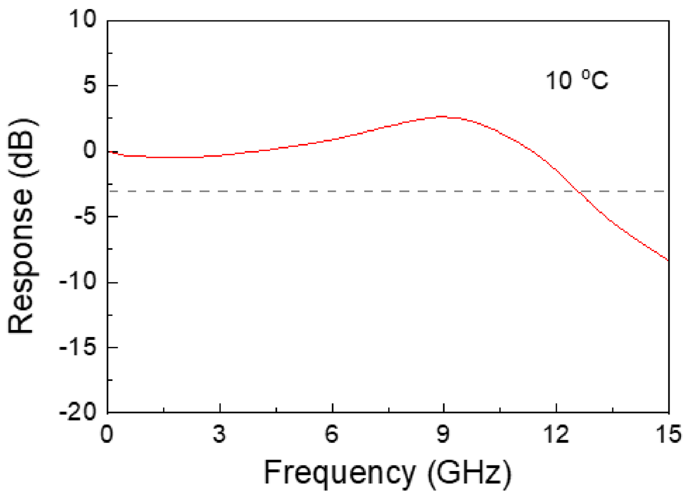

Figure 4. Small-signal modulation response at 10 °C when the gain section and DBR section were biased at 80 and 0 mA.

The experimental setup of the transmission system is shown in Figure 5. A 25 Gb/s non-return-to-zero (NRZ) pseudo random bit sequence (PRBS) signal with a word length of 2^{15}-1 generated from a pattern generator was combined with the DC gain current I_{gain} by a bias tee, which was applied on the gain section of the tunable DBR laser. The wavelength was tuned by the DBR current I_{DBR} and the temperature of the thermoelectric cooler (TEC). A commercial receiver ZTE SFP 28 was used to receive the signal, and the eye diagram was monitored in a digital sampling oscilloscope. For signal synchronization, the pattern generator also provides a clock signal to the oscilloscope.

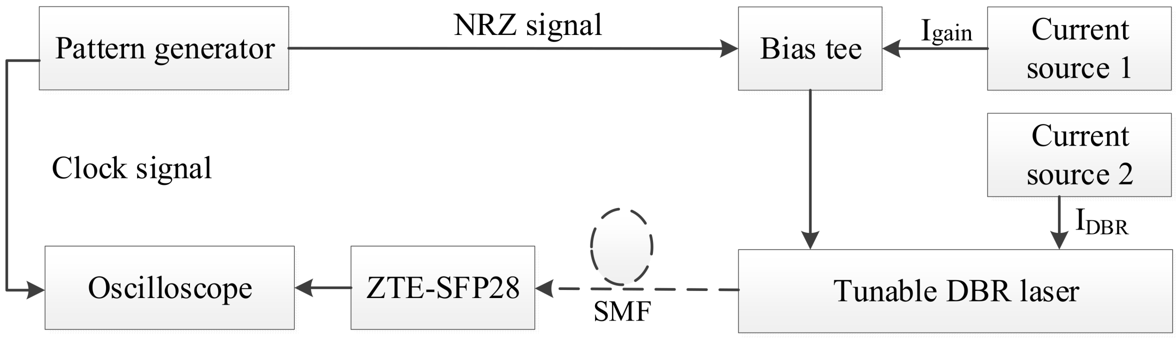

Figure 5. Experimental setup used to measure the 25 Gb/s transmission characteristics of the packaged DBR laser. NRZ: non-return-to-zero; SMF: single mode fiber; DBR: distributed Bragg reflector.

Figure 6 shows the 25 Gb/s eye diagram of the packaged DBR laser in the case of back-to-back (BtB), 10 km, and 20 km transmission when the wavelengths are tuned at 1544.34, 1551.18, and 1558.56 nm, respectively. The gain currents of the three wavelengths are kept the same at 80 mA; the corresponding DBR currents are 67, 5, and 0 mA; and the temperatures of TEC are 0, 0, and 49 °C, respectively. These three typical optical spectra obtained from the device are marked in Figure 3. The peak-to-peak modulation voltage is 1.5 V. As can be seen, at both BtB and 10 km conditions, clearly opened eyes can be obtained for all the different wavelengths. After 20 km transmission, however, the eye diagrams degraded notably. A typical 20 km blurred eye diagram at 1544 nm wavelength is shown in Figure 6. For the other wavelengths, the eye diagrams are similar.

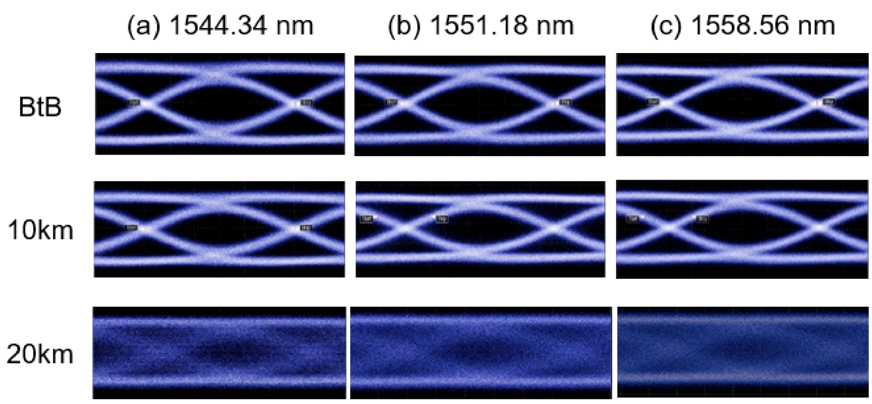

Figure 6. A 25 Gb/s eye diagram of a tunable DBR laser for BtB, 10 km, and 20 km transmission when the tuned wavelength is (**a**) 1544.34 nm, (**b**) 1551.18 nm, and (**c**) 1558.56 nm.

4. Discussion

A typical tunable directly modulated DBR laser has a wavelength tuning range of about 10 nm, which is obtained by a DBR injection current [13,14]. In order to increase the wavelength tuning range of the tunable DBR laser and thus expand the data transmission capacity of WDM communication systems, a variation of chip temperature can be used as an assistant, as in the case reported in this paper. This is a relatively easier way to enlarge the tuning range of a DBR laser. As shown in Figure 4, the small-signal modulation bandwidth of the device is around 12 GHz, which is similar to that of our previous devices [13]. The data shown in Figure 6 show, for the first time, that the DBR laser can be used for up to 25 Gb/s NRZ data modulation. For 25 Gb/s data transmission, the application of devices with relatively lower bandwidth, which are also lower in price, helps lower the fabrication cost of the optical communication networks.

5. Conclusions

A two-section tunable DBR laser is fabricated with InGaAlAs multiple quantum wells as the active layer. A wavelength tuning range greater than 14 nm is obtained through the change of the DBR injection current and the TEC temperature. The wavelength tuning range and the sidemode suppression ratio of the tuned wavelength spectrum show good stability at different temperatures. Three typical wavelengths are selected for 25 Gb/s data transmission, and the eye diagram is clearly opened after a 10 km single-mode fiber. This directly modulated wavelength-tunable DBR laser has a simple structure, has a simple wavelength tuning method, is low cost, is easy to achieve high product yield, and can be used in data centers and WDM-PON systems in large quantities.

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Conflicts of Interest: The authors declare no conflict of interest.

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