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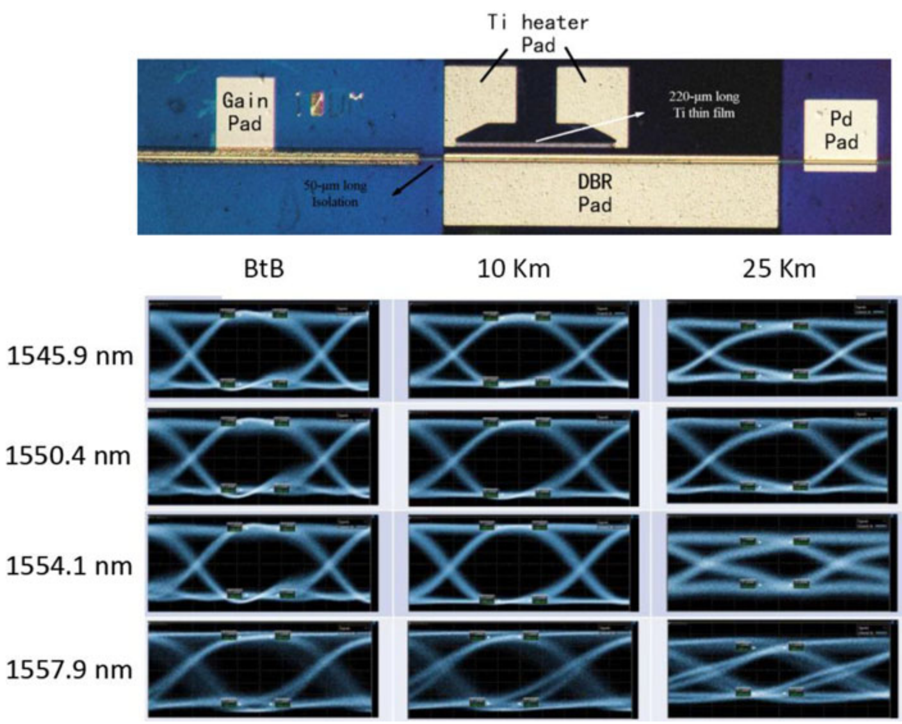

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Data Transmission Using a Directly Modulated Widely Tunable DBR Laser With an Integrated Ti Thin Film Heater

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Abstract: We present data transmission using a directly modulated distributed Bragg reflector (DBR) laser having an integrated Ti thin film heater in the DBR section and butt-jointed InGaAsP as DBR material. By combining DBR current tuning and thermal tuning effects, an over 16 nm wavelength tuning range is obtained. 5 Gb/s data transmissions are conducted at up to 25 km distance and different wavelengths. In the fabricated device, the butt-jointed InGaAsP material is also used for the formation of an integrated photodiode for monitoring the light power of the device.

Index Terms: DBR lasers, thin film heaters, direct modulation, data transmission.

1. Introduction

Wavelength division multiplexing (WDM) passive optical network (PON) has been arousing many interests for years [1], [2], because it increases the capacity of PONs greatly by transmitting a number of different wavelengths at the same time. In a WDM-PON, a large number of light sources with different emission wavelengths are needed in optical network units (ONUs) for upstream data transmission. Compared to multiple discrete lasers each having different wavelength emissions, the application of wavelength tunable lasers in a WDM-PON has several advantages, including simple logistics, low sparing cost and automated provisioning [3]. At present, different types of tunable lasers are available such as external cavity tunable laser (ECL) [4], sampled grating distributed Bragg reflector (SGDBR) laser [5] and modulated grating Y-structure laser [6]. Compared to these tunable lasers, two or three section semiconductor DBR lasers [7]–[10] have many advantages such as having no moving parts, simple structure and easy calibration, all helping to achieve a low cost of the device, which is a key factor for the wide application of WDM-PONs.

In this paper, we report data transmission experiments using a DBR laser with an integrated Ti thin film heater in the DBR section. In the DBR laser, InGaAsP bulk material is butt-jointed as DBR

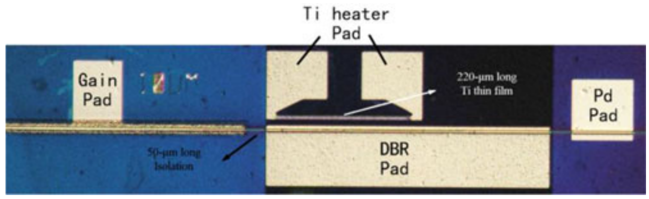

Fig. 1. Optical graph of a fabricated device.

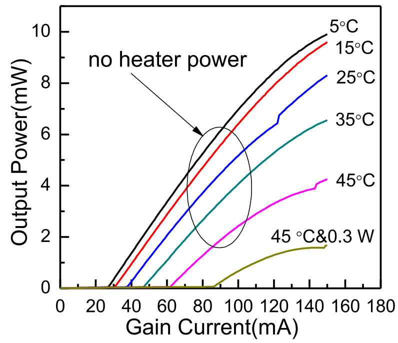

Fig. 2. Light output power characters of the device.

material. By combining DBR current tuning and thermal tuning effects, an over 16 nm wavelength tuning range is obtained. The butt-jointed InGaAsP material is also used for the formation of an integrated photodiode (PD) for monitoring the light power of the device. Data transmission experiments are demonstrated for 5 Gb/s direct modulation at up to 25 Km distance. The results indicate that the kind of DBR laser is promising as light source for future WDM-PON applications.

2. Device Fabrication

Fig. 1 shows an optical graph of the DBR laser, which consists a 300 μm long gain section and a 450 μm DBR section. A 50 μm long electrical isolation region, which is He$+$ implanted, is placed in between the two sections. As shown in the figure, a 220 μm long Ti thin film heater, which is 10 μm away from the ridge waveguide, is formed at the gain end of the DBR section. The device is formed through a three step MOCVD process, details of which can be found elsewhere [11]. A 300 nm thick InGaAsP layer which has 1.40 μm photoluminescence (PL) wavelength (1.4 Q) and is lattice matched to InP is butt-jointed as DBR material. The long PL wavelength helps to enlarge the wavelength tuning range induced by current injection into the DBR section [10]. Different from previously reported DBR laser devices [9]–[11], the butt-jointed 1.4 Q material is also used for the fabrication of an integrated PD which is 100 μm long. The device has a 3 μm ridge waveguide structure. Both facets are left uncoated. The device is soldered onto a Cu heatsink for testing.

3. Experimental Results and Discussions

Fig. 2 shows the light output power characters of the device measured by an integrating sphere when no current is injected into the DBR section. At room temperature (25 °C), the threshold current is about 38 mA and over 8 mW light power can be collected at 150 mA gain current. The wavelength tuning properties of the device are shown in Fig. 3. The emission wavelength of the device is around 1.55 μm and an 8.4 nm tuning range can be obtained for a 150 mA Bragg current. When the heatsink temperature is varied form 5 °C to 45 °C, the tuning range can be increased to 14.2 nm. As shown in Fig. 1, an integrated Ti thin film heater is used to further enlarge the wavelength tuning range. As can be seen from Fig. 3, with a 0.3 W heater power, an extra 2.25 nm

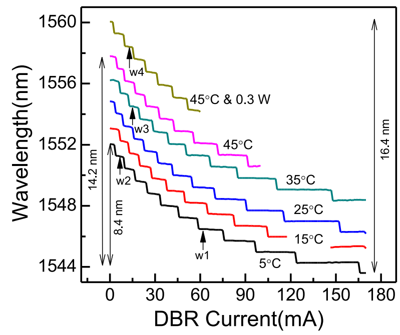

Fig. 3. Wavelength tuning properties of the device.

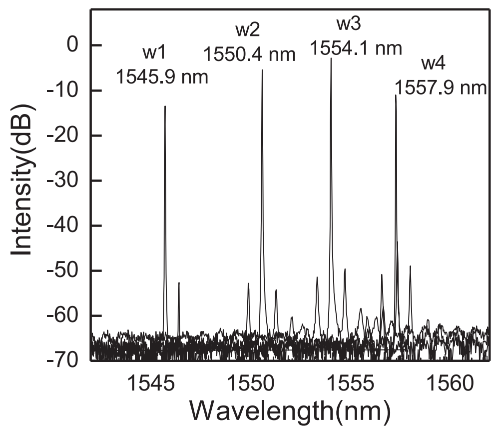

Fig. 4. Typical emission spectra of the device.

wavelength tuning is obtained, resulting in a total range of wavelength tuning of 16.45 nm. As light source in WDM-PONs, a larger tuning range of DBR lasers is highly favored, because more data channels can be used to get a higher transmission capacity. Because the heater locates in only the DBR region, its heating effect on the gain section is smaller than when the heatsink temperature is increased, which is an advantage of the heater. For the device, the 2.25 nm tuning range cannot be achieved by further increasing the heatsink temperature, because laser operation will stop at higher gain section temperatures. The wavelength of the DBR laser increases with the heater power in a step manner [11], similar to the variation of wavelength with the decrease of the DBR current shown in Fig. 3. The step of the wavelength change is 0.8 nm. As shown in Fig. 2, at 40 °C the 0.3 W heater power leads to a 2.6 mW light power decrease.

The 16.45 nm tuning range is smaller than the 20 nm of the device reported in reference 11, which has similar gain and DBR sections as the present device. This can be first attributed to the lower heater power used in this study. Then, the 8.4 nm DBR current induced tuning range, which is proportional to the PL wavelength of the DBR material [10], is smaller than that of the device in the reference. The DBR material of the present device has a 1.40 μm PL wavelength, which is smaller than the 1.45 μm used in the device in reference 11. To enlarge the wavelength tuning range of the DBR laser, InGaAsP with longer PL wavelength can be used as DBR material [10]. Further, DBR gratings with lower reflections can be adopted [12]. From the device, laser emissions having larger than 30 dB side mode suppression ratios (SMSR) can be obtained except at the DBR currents where there are wavelength jumps as shown in Fig. 3. Four typical optical spectra of the laser are shown in Fig. 4, all having larger than 35 dB SMSR. The heatsink temperature and DBR current used for obtaining the wavelengths are marked by the arrows shown in Fig. 3. Except the 1557.9 nm emission, which is obtained with 0.3 W heater power, the heater is not used for the other three wavelengths.

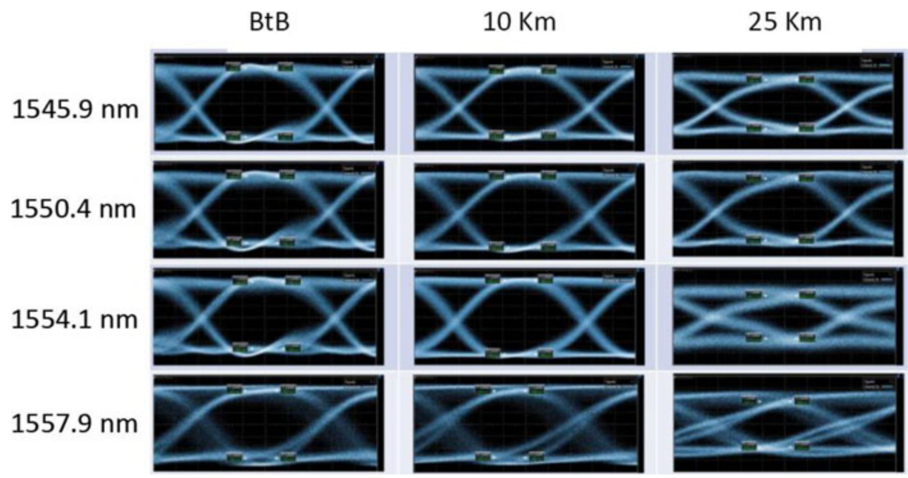

Fig. 5. 5 Gb/s eye diagrams at different wavelengths and transmission distances.

A 50-GHz network analyzer is used for measuring the small signal direct modulation properties of the device. At room temperature the modulation bandwidth when no current is injected into the DBR section is over 10 GHz. The bandwidth decreases with the DBR current, because the light power is lowered by the free carrier absorption in the DBR section. At 15 °C, for example, the light power is decreased for 1.6 dB as the DBR current is increased from 0 to 150 mA. Besides, the increase of both the heatsink temperature and the heat power of the thin film heater leads to a decrease of the bandwidth. As a result the modulation bandwidth of the device at 45 °C and 0.3 W heater power when there is no DBR current is about 4 GHz. 5 Gb/s data transmissions are performed with the device in standard single mode fiber. The device is modulated with non-return to zero (NRZ) pseudo random bit sequence (RPBS) data patterns having a $2^{31} - 1$ length, which are generated by a commercial bit pattern generator (BPG).

Fig. 5 shows the measured eye diagrams for the four wavelengths shown in Fig. 4 at back to back (BtB) conditions and after 10 and 25 Km of single mode fiber transmissions. As can be seen, clearly opened eyes can be obtained for all the conditions, with the eye opening decreasing gradually after fiber transmissions. Because the modulation bandwidth of the device at 1557.9 nm is smaller than the bandwidths at other wavelengths, the eye diagrams at the wavelength are worse than the diagrams at other conditions. The measured bit error rates (BER) as a function of received optical power at BtB configuration and after 10 and 25 Km fiber transmissions are shown in Fig. 6. To achieve 10^{-10} BER, the power penalty when comparing 25 Km transmission with BtB condition is less than 1.5 dB for all the wavelength channels. As shown in Fig. 6, at the wavelength of 1557.9 nm, the BERs for 10 km operation are better than the BtB condition, while at other wavelengths the BERs for the BtB condition are better. Results similar to the 1557.9 nm case have also been observed in other studies [13] and can be attributed to the specific chirp parameters of the device at the bias conditions which favor longer distance of data transmission.

The detection properties of the integrated PD is shown in Fig. 7, which plots the photocurrent as a function of the inject current of the gain section measured at 25 °C. As can be seen, the photocurrent increases linearly with the gain current, thus the optical power, as the gain current is smaller than 100 mA. An obvious nonlinear response appears at larger gain current, which might be resulted from the larger responsivity at higher photocurrent of the PD [14]. At higher currents, the photo-generated electrons can be swept more efficiently out of the absorption layer before being recombined. While the photocurrent of the PD can be used for monitoring the light power, the light absorption is relatively smaller than that of an integrated PD with MQWs as absorber material [15], [16] because the PL wavelength of the InGaAsP material is far away from the 1.5 μm working wavelength, helping to maintain a large output power for the integrated device.

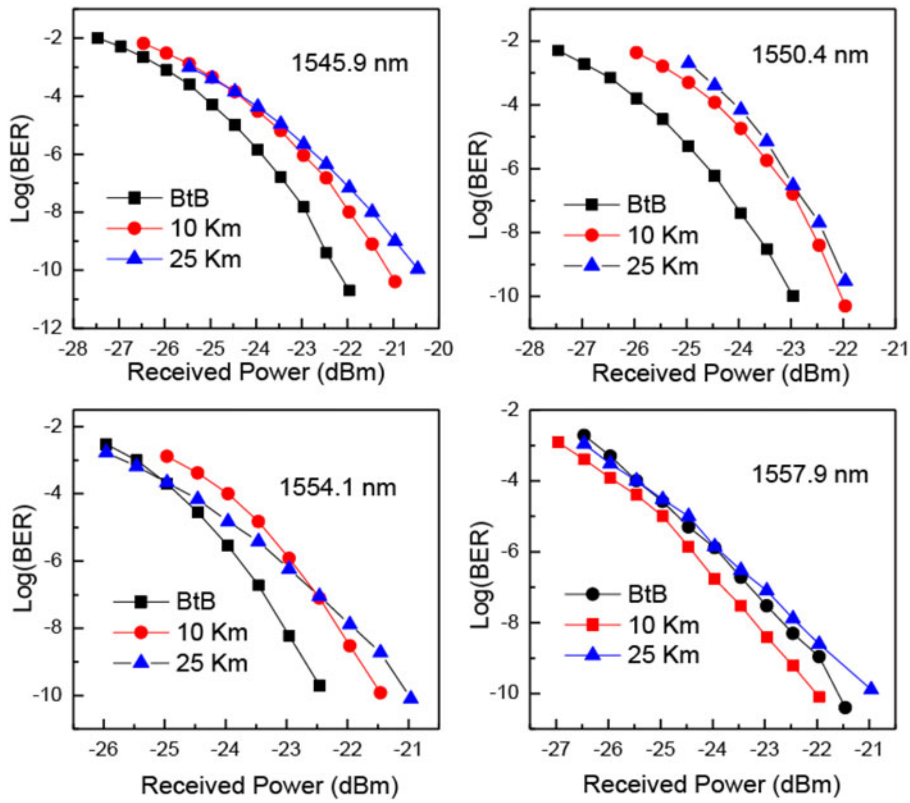

Fig. 6. Measured BER as a function of received optical power.

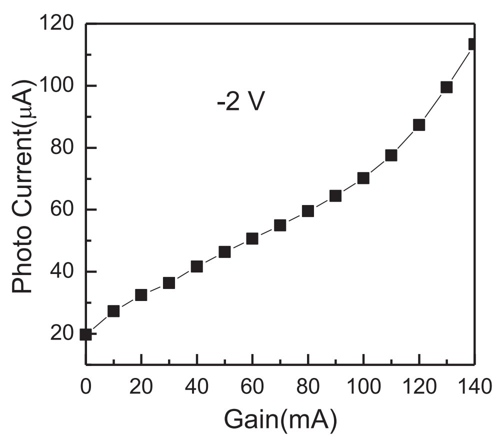

Fig. 7. Photo current as a function of gain current of the device.

4. Conclusion

In summary, data transmissions using a directly modulated widely tunable DBR laser with an integrated Ti thin film heater in the DBR section are presented. By combining DBR current tuning and thermal tuning effects, an over 16 nm wavelength tuning range is obtained. Transmission experiments are demonstrated for 5 Gb/s direct modulation at up to 25 Km distance and different wavelengths. To achieve 10^{-10} BER, the power penalty when comparing 25 Km transmission with BtB condition is less than 1.5 dB. In the fabricated device, besides being used as DBR material, the butt-jointed InGaAsP material is also used for the formation of an integrated PD for monitoring the light power of the device, which helps to maintain a large output power for the integrated device.

References

[1] J. Zhang, and N. Ansari, "Design of WDM-PON with tunable lasers: The upstream scenario," *J. Lightw. Technol.*, vol. 28, no. 2, pp. 228–237, Jan. 2010.
[2] S. Y. Kim, S. B. Jun, Y. Takushima, E. S. Son, and Y. C. Chung, "Enhanced performance of RSOA-based WDM PON by using Manchester coding," *J. Opt. Netw.*, vol. 6, no. 6, pp. 624–630, Jun. 2007.
[3] J. Buus, and E. Murphy, "Tunable lasers in optical networks," *J. Lightw. Technol.*, vol. 24, no. 1, pp. 5–11, Jan. 2006.
[4] J. De Merlier *et al.*, "Full C-band external cavity wavelength tunable laser using a liquid crystal based tunable mirror," *IEEE Photon. Technol. Lett.*, vol. 17, no. 3, pp. 681–683, Mar. 2005.
[5] A. J. Ward *et al.*, "Widely tunable DS-DBR laser with monolithically integrated SOA: Design and performance," *IEEE J. Sel. Topics Quantum Electron.*, vol. 11, no. 1, pp. 149–156, Jan./Feb. 2005.
[6] J. Wesström, G. Sarlet, S. Hammerfeldt, L. Lundqvist, P. Szabo, and P. Rigole, "State-of-the-art performance of widely tunable modulated grating Y-branch lasers," in *Proc. Opt. Fiber Commun. Conf.*, Los Angeles, CA, USA, Feb. 2004, Paper TuE2, pp. 389–391.
[7] L. Han *et al.*, "Fabrication of widely tunable ridge waveguide DBR lasers for WDM-PON," *Chin. Opt. Lett.*, vol. 12, no. 9, 2014, Art. no. 091402.
[8] L. Han *et al.*, "Electroabsorption modulated widely tunable DBR laser transmitter for WDM-PONs," *Opt. Exp.*, vol. 22, no. 24, pp. 30368–30376, 2014.
[9] D. Zhou, S. Liang, L. Zhao, H. Zhu, and W. Wang, "High-speed directly modulated widely tunable two-section InGaAlAs DBR lasers," *Opt. Express*, vol. 25, no. 3, pp. 2341–2346, Feb. 2017.
[10] J. E. Johnson *et al.*, "Fully stabilized electroabsorption-modulated tunable DBR laser transmitter for long-haul optical communications," *IEEE J. Sel. Topics Quantum Electron.*, vol. 7, no. 2, pp. 168–177, Mar./Apr. 2001.
[11] L. Han *et al.*, "DBR laser with over 20-nm wavelength tuning range," *IEEE Photon. Technol. Lett.*, vol. 28, no. 9, pp. 943–946, May 2016.
[12] G. Kyritsis and N. Zakhleniuk, "Self-consistent simulation model and enhancement of wavelength tuning of InGaAsP/InP multisection DBR laser diodes," *IEEE J. Sel. Topics Quantum Electron.*, vol. 19, no. 5, Sep./Oct. 2013, Art. no. 150331.
[13] K. Zhang *et al.*, "Chirp-aided power fading mitigation for upstream 100 km full-range long reach PON with DBR DML," *Opt. Commun.*, vol. 407, pp. 63–68, 2018.
[14] A. Hastings, D. Tulchinsky, and K. Williams, "Photodetector nonlinearities due to voltage dependent responsivity," *IEEE Photon. Technol. Lett.*, vol. 21, no. 21, pp. 1642–1644, Nov. 2009.
[15] U. Koren *et al.*, "Strained-layer multiple quantum well distributed Bragg reflector lasers with a fast monitoring photodiode," *Appl. Phys. Lett.*, vol. 58, no. 12, pp. 1239–1241, 1991.
[16] R. M. Lammert *et al.*, "Strained-layer InGaAs-GaAs-AlGaAs lasers with monolithically integrated photodiodes by selective-area MOCVD," *IEEE Photon. Technol. Lett.*, vol. 7, no. 3, pp. 247–250, Mar. 1995.