10Gb/s Low-Cost Directly Modulated Multi-Electrode Laser with Suppressed Thermal Wavelength Drift for Burst-Mode Upstream Transmission in TWDM-PONs

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Abstract: We report on a novel 10Gb/s low-cost multi-electrode DML employed as a very wavelength stable burst-mode source for upstream TWDM-PONs. 10X wavelength drift reduction is achieved compared to conventional DMLs enabling transmission on 100GHz grid.
OCIS codes: (060.2330) Fiber optics communications; (060.4510) Optical communications

1. Introduction

The deployment of passive optical networks (PONs) is currently driven by the incessant growth in capacity demand and in 2011 the Full-Service Access Network (FSAN) group initiated the next-generation PON stage-2 (NG-PON2) project with the objective of enabling a bandwidth increase beyond 10Gb/s. Time and wavelength division multiplexed PON (TWDM-PON) was selected as the primary approach, allowing stacking of multiple 10G PON channels using 4 or 8 WDM channels spaced 100GHz or 50GHz apart respectively. This dense WDM (DWDM) spacing put stringent requirements on the maximum allowed frequency drift for the burst-mode (BM) directly modulated lasers (DMLs) employed as sources in the upstream direction. Recently, techniques to mitigate the effect of wavelength drift due to self-heating of DMLs operated in BM have been proposed [1, 2] based on counter heating methods that compensate the self-heating effect. Their performance depends heavily on the thermal time constant of the device as well as on the actual duration of each burst (which can vary from ~0.5µs to 125µs [3]). In this paper, we discuss the performance of a directly modulated multi-electrode DFB laser (MEL) which is operated in BM in such a way that the aforementioned thermal wavelength drift is compensated quasi-instantaneously. Operation of a multi-electrode laser in BM was proposed for the first time in [4]. Here we demonstrate negligible bit error rate (BER) penalty in comparison to the continuous-mode (CM) case when modulated with 2.5Gb/s and 10Gb/s data.

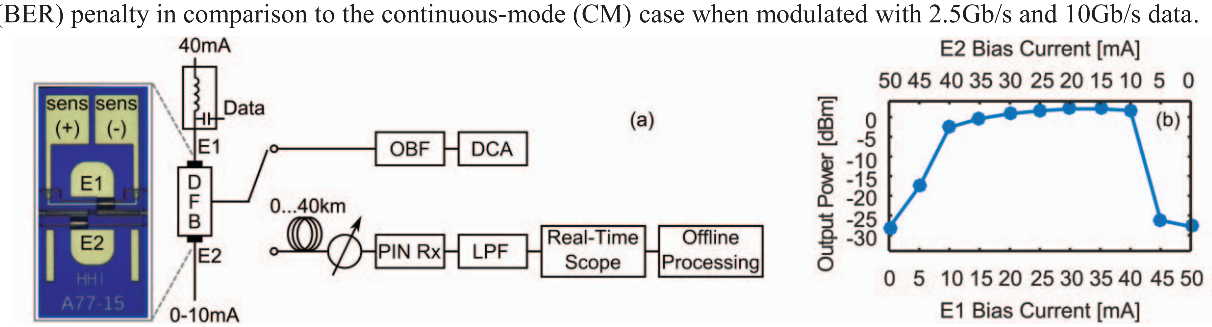

Fig. 1. (a) Experimental setup; (b) Output power as a function of different electrode current ratios for a constant total current of 50mA.

2. Principle of operation

Fig. 1(a) illustrates the top-view layout of the two-section directly modulated DFB tunable laser module as well as the experimental setup used for its characterization. The MEL consists of two electrodes (referred to as E1 and E2) that can be independently controlled. The output power and wavelength of the laser can be varied by changing the ratio of the currents applied to the two electrodes [5]. A conventional one-electrode DFB laser can be emulated with this device by connecting the two electrodes together. The device includes a sensor strip for temperature monitoring. Note that, in principle, this sensor can also be used to thermally fine-tune the laser wavelength.

Fig. 1(b) shows the MEL output integrated power for a continuous-wave (CW) signal in CM as a function of different current ratios applied to the two electrodes when the total driving current is maintained equal to 50mA. It can be seen that when E2 is driven at low currents (e.g. <10mA) the total output power drops significantly. This confirms that it is possible to switch-off the laser by applying 0mA on E2 while still maintaining the current on E1 at high values. The novel method that we propose here to suppress the wavelength drift associated with the BM

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operation of the laser consists of switching-on and -off only E2 with a current that varies from 0mA to a value that is high enough to ensure proper lasing but, at the same time, that is only a fraction of the current applied to E1. By driving E1 in CM with a constant current that is significantly higher than the current on E2 it is possible to maintain the chip at an approximately constant temperature and hence to minimize thermal wavelength drift. To demonstrate the feasibility of this method, the output power spectrum was captured using an optical spectrum analyzer (OSA) for different CM and BM operating conditions. In this work, each burst was generated by driving E2 with a square wave characterized by a period of 205µs. The duty-cycle was intentionally fixed to 50% as this represents the worst-case scenario in terms of thermal stress (i.e. relative wavelength drift) [2].

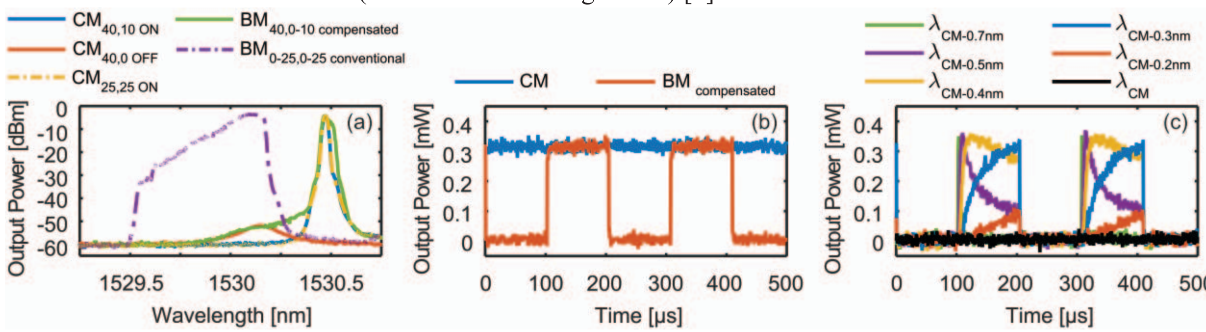

Fig. 2. (a) CM and BM spectra (CW, max/hold, 500 scans, resolution: 20pm, sensitivity: -55dBm); (b) Output power after 0.22nm OBF for the proposed approach and (c) for the conventional BM approach with various OBF tuning values with respect to λ_{CM}.

The spectra are shown in Fig. 2(a). Each trace was captured using the max/hold function over 500 scans in order to record the maximum values point-to-point for each wavelength. First, the spectrum of a CW signal was measured when the laser was switched-on (E1=40mA, E2=10mA) and -off (E1=40mA, E2=0mA) in CM. These two curves show that the MEL presents an on-off peak ratio of almost 50dB, with a difference of approximately 0.3nm between the two wavelength peaks corresponding to the CM 'on' and 'off' states. The latter can actually be beneficial in DWDM applications (on a 100 GHz grid or less [3]) as optical bandpass filtering potentially increases the on-off ratio to >60dB by further attenuating the off-state. Next, the spectrum was recorded using conventional operating conditions (i.e. both electrodes tied together, with E1=E2=25mA) both in CM and BM. Finally, the spectrum was recorded using our proposed laser driving method. From these curves, it is clear that when the DFB is operated with the conventional BM approach there is a substantial wavelength drift (~85GHz) due to self-heating which effectively makes the laser unusable in DWDM applications unless some other stabilization technique is adopted. In contrast, our method eliminates the wavelength drift between the CM and BM cases almost entirely (~9GHz). We note that measuring the wavelength drift of a BM laser from its optical spectrum provides only an approximative estimation, since the OSA is not fast enough to accurately measure the power at the beginning of the burst. Nevertheless, the max/hold function provides a practical and qualitative method for wavelength drift estimation [6].

The impact of wavelength drift due to BM operation of the MEL was also evaluated by recording the power at the output of a narrow optical bandpass filter (OBF) with a digital communication analyzer (DCA) oscilloscope, as illustrated in the setup of Fig. 1(a). The OBF had a -3dB bandwidth of 0.22nm (0.6nm at -20dB) and its central wavelength λ_{CM} was finely tuned in order to maximize the output optical power in the CM 'on' case (E1=40mA, E2=10mA). The results in Fig. 2(b) show that with our proposed approach, the burst envelope does not present any visible power loss nor transients associated with wavelength drift outside of the OBF bandwidth in comparison to the CM case. Conversely, if the laser is driven in the conventional BM on-off approach, substantial power loss as well as burst envelope transients are observed (Fig. 2(c)). In fact, when the OBF's center wavelength is kept equal to the CM case, the signal is almost entirely filtered/attenuated. Tuning the OBF to lower wavelengths as illustrated in Fig. 2(c) can partially compensate for the power loss but not for the burst envelope transients as the wavelength always drifts outside of the OBF bandwidth due to self-heating.

3. Direct modulation and transmission results

The performance of the MEL was finally evaluated in terms of bit-error-rate (BER) when the signal was modulated at 2.5Gb/s as well as 10Gb/s and transmitted over up to 40km of single-mode fiber (SMF). The received signal was captured using a real-time sampling oscilloscope (at 20GS/s) with an analogue bandwidth of 12GHz and the BER was measured by using offline-processing counting techniques. An electrical low-pass filter (LPF) characterized by a -3dB bandwidth of 1.87GHz and 8GHz for the 2.5Gb/s and 10Gb/s modulation case respectively was used as anti-aliasing filters. The MEL was modulated using a non-return-to-zero 2^7-1 pseudo-random binary sequence (PRBS). It should be noted that the modulation was applied only to the electrode operating in CM (i.e. E1). By changing the modulation voltage swing applied to E1 for the same CM bias current of 40mA it is possible to obtain different

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extinction-ratios (ERs) values and eye diagrams with slightly different features. It is well known [7, 8] that when a DFB laser is directly modulated there is a trade-off between frequency chirp reduction and loss in ER that leads to optimal transmission performance. In our case, the ER was set to approximately 9dB and 5dB for the 2.5Gb/s and 10Gb/s modulation case respectively. Figs. 3(a) and 3(b) show the corresponding optical eye diagrams.

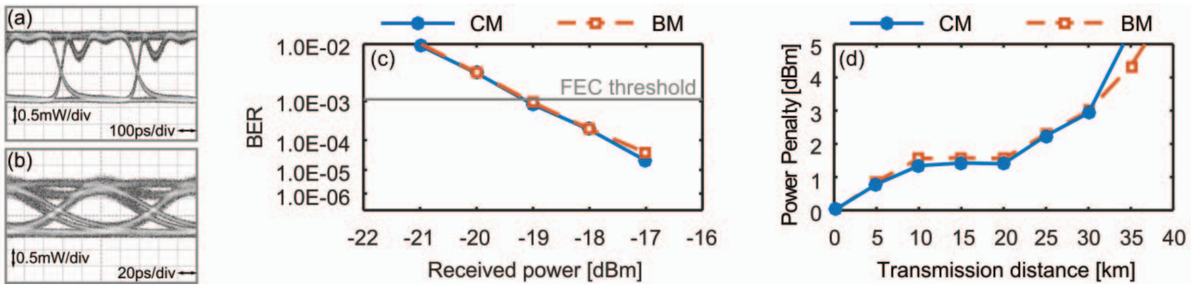

Fig. 3. Optical eye diagrams at (a) 2.5Gb/s and (b) 10Gb/s; (c) B2B BER as a function of the received power when the signal is sent through a 0.22nm OBF; (d) Power penalty at FEC threshold normalized to the CM B2B case.

At 2.5Gb/s the CM performance after 40km of SMF was comparable to the relative back-to-back (B2B) case with negligible penalty (<0.2dB at BER=1.1×10^{-3}, not shown here due to space limitations), hence the results discussed hereafter focus on the 10Gb/s modulation case only. The BER was first measured in B2B when the signal was sent thorough a 0.22nm narrow OBF both in CM and in BM, as shown in Fig. 3(c). The two curves lie on top of each other proving that the proposed method is very effective in suppressing the BM thermal wavelength drift. For this reason, and as the relatively high insertion loss (~6dB) of the OBF would have necessitated the use of optical amplification for the transmission experiment, the OBF was removed from the setup. Fig. 3(d) shows the power penalty for the CM and BM case as a function of the transmission distance. The penalty has been calculated with reference to the CM B2B case at a BER equal to 1.1×10^{-3} (i.e. assuming use of Reed-Solomon (255,223) forward error correction (FEC). The data points lie nearly on top of each other for all transmission distances except for the 35 and 40km cases, where there is a small discrepancy due to a minor difference in error floors. Fig. 3(d) confirms that the proposed multi-electrode DFB laser can be directly modulated up to 10Gb/s with no penalty between the CM and BM cases. We note that the realistic transmission distance is limited to around 20km, in line with typical DML performance when dispersion compensation is not employed [9].

4. Conclusions

We have presented a novel directly modulated multi-electrode DFB laser for burst-mode upstream transmission in TWDM-PONs. By minimizing the total current variation on the two electrodes it is possible to mitigate the thermal drift due to self-heating of DMLs operated in BM. We have shown that a 10X reduction in wavelength drift can be achieved in comparison to conventional DMLs operated in BM. The proposed BM driving method allows direct modulation of the MEL at up to 10Gb/s with no BER penalty in comparison to the CM case and with <1.6dB penalty at 20km in comparison to B2B. This opens the possibility of low-cost, highly wavelength stable sources for 100GHz-spaced channel transmission in next-generation TWDM-PONs.

5. Acknowledgements

The authors would like to thank Helene Debrégeas for discussion. This publication has emanated from research supported in part by Science Foundation Ireland (SFI) Grants 16/IFA/4341, 12/IA/1270, 12/RC/2276.

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