Experimental Investigation of Rapid Wavelength-Switching (<80 ns) in Fast Tuneable Lasers for Applications in Optical Packet and Burst-Switched Networks

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Abstract: We report novel results on the improvement in wavelength stability to less than 1-GHz and sub-80ns wavelength tuning times using intelligent wavelength selection in a compact three-section DBR laser module without an active locking mechanism. The performance of the module in terms of switching time and temperature induced wavelength drift is compared to other semiconductor tuneable lasers. The impact of a finite wavelength switching time on the length of datagrams in future optical packet and burst switched networks was investigated by bit error rate (BER) measurements in a WDM experiment. The results are directly applicable to the design of future dynamic optical networks.

1. Introduction

Fast tuneable lasers are key for the implementation of future dynamic wavelength routed optical network architectures as a means of establishing dynamic lightpaths [1-3]. Originally developed to reduce the requirement for distributed feedback (DFB) lasers in WDM systems they have also shown application to multi-terabit/s optical routers [5]. Previously a number of studies have demonstrated tuneable laser switching on a nanosecond time scale [3-5] but these studies did not consider burst lengths of the order of those expected in wavelength-routed optical burst switched (WR-OBS, ms) [1] and optical burst switching just-enough-time (OBS-JET, µs) [2] networks where it is expected that thermal drift effects, bypassed on the nanosecond time scale, will be dominant.

In this work, therefore, we focused on the investigation of tuneable laser switching time and wavelength drift over millisecond timescales by comparing two 4 section tuneable laser devices to a compact three section distributed feedback (DBR) tuneable laser module integrated with electronics for channel setting and fast switching without an active locking mechanism. The detrimental effects of the finite wavelength switching time in transmission were also investigated experimentally for the first time.

2. Laser Descriptions

The discrete and fully packaged and pigtailed GCSR (grating-assisted co-directional coupler with rear sampled-grating reflector) and SG-DBR (sampled-grating DBR) lasers both consist of front grating, rear grating, phase and gain sections controlled by 4 independent current sources. The DBR laser module (Intune INT1100) is based on a three section monolithic tuneable DBR laser integrated with all the necessary electronics and control firmware for temperature control, current control and a high-speed handshaking electrical interface for precise timing of the wavelength transition event. The laser has been fully characterised in terms of its power, frequency, mode stability, mode irregularities and hysteresis. Transient wavelength excursions are constrained by optimisation of the high-speed drive electronics and minimisation of total net current excursions required to obtain the required ITU frequencies. The calibration and set up method for each of these parameters are described in more detail in [6] and [7] demonstrated with a SG-DBR device.

3. Experimental set-up

Figure 1 shows the experimental set up used for both switching time (a) and BER measurements (b). Overall computer control was carried out with GPIB/RS232 and all triggering/gating signals were either provided from software or with an additional delay generator. To investigate the wavelength drift and switching time in the SG-DBR device constant phase and gain current values of 5mA and 150mA respectively were used. The front and rear gratings were varied between 10mA and 80mA. The GCSR laser was operated with 5mA phase current, 100mA gain current, and front and rear grating values varied between 0mA and 40mA. The DBR module was operated on 10 channels based on 100GHz ITU frequency grid with wavelengths between 1559.9 and 1568.1nm. BER analysis was carried out by observing a probe channel modulated with a 10 Gb/s PRBS signal with a 2^{31}-1 word length. This signal was then transmitted on a wavelength centred between 2 wavelengths of the DBR module.

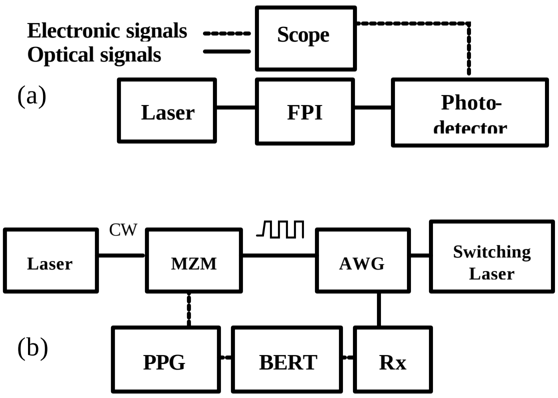

Figure 1. Experimental set-up for investigation of (a) fast switching times and (b) BER measurements.

4. Results and discussion

In the ranges studied wavelength drift between 0.06nm and 0.43nm was observed with 90% to 10% fall times between 900µs and 20ms. Figure 2 shows the distribution of these results for 15 wavelength pairs against the value of the tuning current applied. It can be seen that there is a clear correlation between the magnitude of tuning currents and laser performance due to its thermal response. For the GCSR laser a maximum wavelength drift of 0.035nm and 90% to 10 % fall times of under 0.06ms were observed for all switching currents. Although dependent on the actual design, wavelength deviation of more than 0.1 nm as observed with the SG-DBR laser would be expected to lead to crosstalk in future dense wavelength-division multiplexing (DWDM) systems, and hence to reduced signal to noise ratio (SNR).

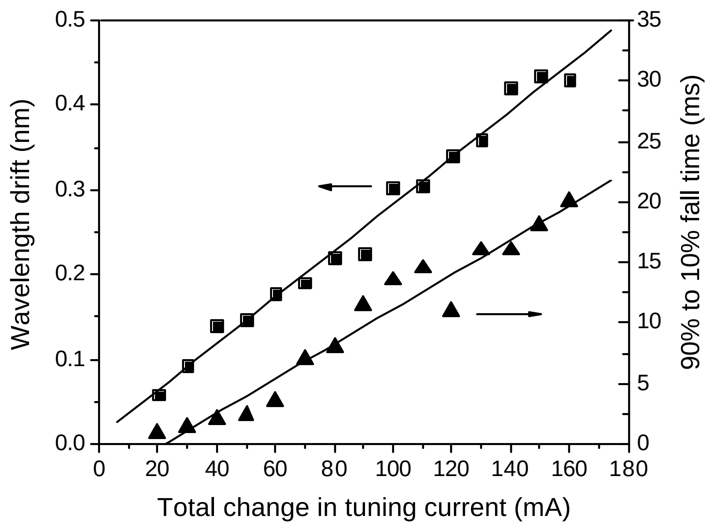

Figure 2. Measured wavelength stabilisation times with linear fit for several wavelength pairs with SG-DBR laser

The use of additional hardware, such as active wavelength locking, for compensation of such drift could be avoided by using a software based approach as in the tuneable laser module. Wavelength drift was effectively reduced by carefully selecting the drive currents to minimize distortions. The DBR module used in the experiments showed consistently lower wavelength drift of less than 0.01nm, limited by measurement resolution, and wavelength tuning times, excluding the electronic response time, of less than 80ns for 15 wavelength pairs. An example of the typical wavelength drift of all three lasers is shown in figure 3. It is observed that selecting suitable operating points to reduce thermal effects can reduce the transients observed with both 4 section devices.

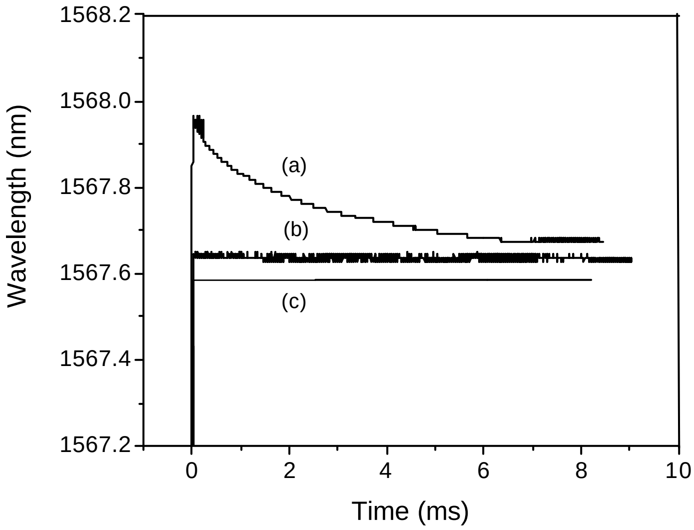

Figure 3. Typical wavelength drift observed in SG-DBR laser (a), GCSR (b), and DBR laser module(c)

The BER measurements of a probe channel (figure 4) show that despite rapid wavelength tuning times of less than 80ns, crosstalk on the probe channel wavelength was significant enough to produce an error floor for all burst lengths from 1ms to 1s. The BER at which this error floor occurs is proportional to the burst size or switching interval and corresponds to approximately 10 bits per burst for 1ms bursts.

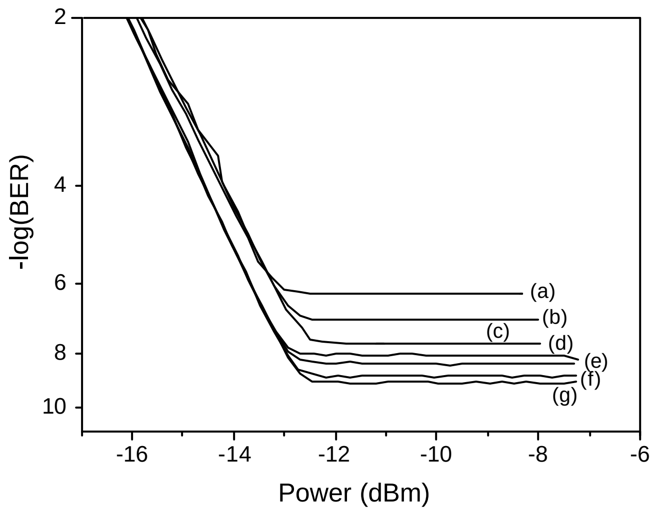

Figure 4. BER on probe channel vs receiver input power for DBR module switching intervals of 1ms(a), 10ms(b), 50ms(c), 100ms(d), 200ms(e), 600ms(f) and 1000ms(g)

5. Summary and Conclusions

A wavelength selection algorithm was shown to minimise thermal transients and improve wavelength stability to less than 1GHz and improve wavelength tuning time by 2 orders of magnitude from other multi-section semiconductor lasers, with a minimum of additional hardware required. These results are observed over the timescales envisaged for applications in optical burst switching architectures with no active wavelength locking mechanism present. It is expected that the electronic limited response time could be reduced to match the tuning times observed to produce tuneable modules suitable for future optical network transmitters with sub-microsecond switching times. The finite wavelength tuning time has a direct impact on the operation of optical packet networks (OPS) since it constitutes a lower limit to the achievable packet size. For 80ns tuning time, 10% overhead at 10Gb/s corresponds to a minimum packet length of 7200 bits leading to a requirement for grooming with 40 byte TCP/IP acknowledgements. The presence of the error floor at burst lengths of up to 1s suggests OBS network operation may also be affected by the finite tuning time despite relatively long edge delays of tens of milliseconds.

Acknowledgements

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References

[1] M. Düser and P. Bayvel, "Analysis of a Dynamically Wavelength-Routed Optical Burst Switched Network Architecture," IEEE/OSA J. Lightwave Technol., vol. 20, Apr. 2002, pp. 574-585

[2] C. Qiao, "Labeled Optical Burst Switching for IP-over-WDM Integration," IEEE Commun. Mag., vol.38, Sept 2000, pp.104-114

[3] K. V. Shrikhande, I.M. White, D. Wonglumsom, S.M. Gemelos, M.S. Rogge, Y. Fukashiro, M. Avenarius, L.G. Kazovsky, "HORNET: a packet-over-WDM multiple access metropolitan area ring network," IEEE J. Select. Areas Commun., vol.18, 2000. pp. 2004-2016

[4] R. O'Dowd, S. O'Duill, G. Mulvihill, N. O'Gorman, and Y. Yu, "Frequency Plan and Wavelength Switching Limits for Widely Tuneable Semiconductor Transmitters," IEEE J. Select Topics Quantum Electron., vol.7, Mar./Apr. 2001, pp. 259-269

[5] J.Gripp, M. Duelk, J. Simsarian, S. Chandrasekhar, P. Bernasconi, A. Bhardwaj, et al., "Demonstration of a 1.2 Tbit/s Optical Packet Switch Fabric (32 * 40 Gbit/s) based on 40 Gb/s Burst-Mode Clock-Data-Recovery, Fast Tuneable Lasers, and a high Performance NxN AWG," Proc. ECOC 2001, paper PD.A.1.7, Amsterdam, Sep./Oct. 2001, pp. 58-59

[6] T. Mullane, D. McDonald, T. Farrell, and J. Dunne, "Full-coverage microsecond wavelength switching of a monolithic widely tuneable laser, from any channel to any channel, over the entire C band on the ITU G.682 ITU grid," Proc SPIE Conf. *Opto-Ireland 2002: Optics and Photonics Technologies and Applications*, 2002, vol. 4876, pp. 260-265

[7] J. Dunne, T. Farrell, and R. O'Dowd, "Fast generation of optimum operating points for tuneable SG DBR laser over 1535-1565 nm range," Proc. IEEE Conf. Lasers and Electro-Optics (CLEO 1999), May 1999, pp. 147-148