

# 100 GHz Spaced 10 Gbit/s WDM over 10 °C to 70 °C using an uncooled DBR laser

C. C. Renaud, M. J. Fice, I. Lealman\*, P. Cannard\*, L. Rivers\*, A. J. Seeds

*Dept. of Electronic & Electrical Eng., University College London, Torrington Place, London, WC1E 7JE, United Kingdom.*

*Tel: +44 (0)20 7679 7928, Fax: +44(0)20 7388 9325, email: a.seeds@ee.ucl.ac.uk*

*\* Centre for Integrated Photonics, Martlesham, Ipswich, IP5 3RE, United Kingdom*

**Abstract:** 100 GHz spaced 10 Gbit/s (NRZ, PRBS  $2^{31}-1$ ) WDM transmission is demonstrated with an uncooled DBR laser. The wavelength of the laser was stabilised within 2 GHz from 10 °C to 70 °C using a predicting algorithm.

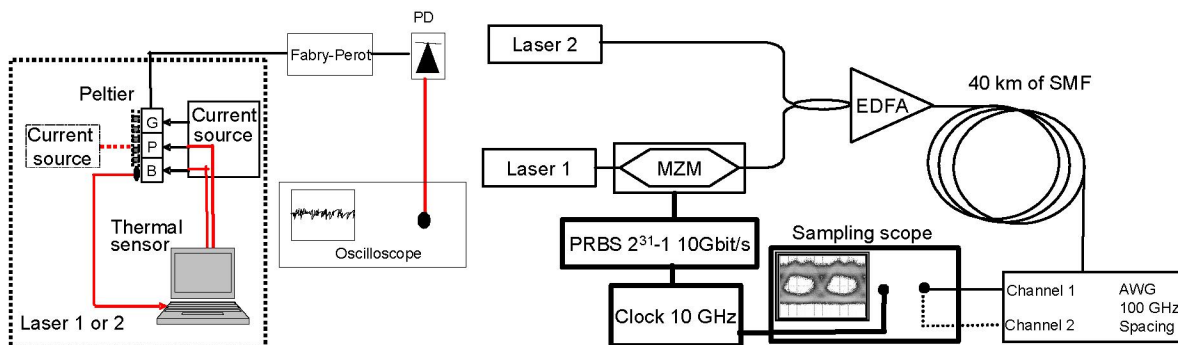
©2004 Optical Society of America

**OCIS codes:** (140.3600) Lasers, tunable; (060.4510) Optical communications

## 1. Introduction

In a more and more cost driven telecommunications industry the cooling system for the lasers is a prime target as shown by the strong growth in coarse wavelength division multiplex (CWDM) [1-2] network standards [3]. This technology uses uncooled lasers, widely spaced channels (20 nm) and simple filters. Thus the cost of WDM networks with modest channel number is greatly reduced. The success of CWDM has started a growing interest in uncooled lasers for closer channel spacing using programmed control loops monitoring the laser wavelength. Recently, uncooled operation with high side mode suppression ratio (SMSR) of a sampled-grating-distributed Bragg reflector (SG-DBR) laser from 10 °C to 60 °C was demonstrated for standard WDM application with 100 GHz spacing where the optical filter components are still relatively inexpensive [4].

This paper reports the first demonstration of 10 Gbit/s transmission over the commercially important 10 °C to 70 °C temperature range using an uncooled laser in a control system which by monitoring the temperature of the laser only, stabilises its output wavelength with an error <2 GHz. The control loop was based on a predicting model of the laser behaviour using as input the measured temperature and the desired wavelength. The uncooled laser was a distributed Bragg reflector (DBR) laser with a long phase section to allow for multiple axial mode cavity length tuning. This laser was used to demonstrate 100 GHz spacing WDM transmission at 10 Gbit/s,  $2^{31}-1$  Pseudo Random Bit Sequence (PRBS), over 40 km of fibre with comparable results to a temperature controlled laser.



**Fig. 1:** Left: Uncooled laser system where the phase and DBR sections are controlled using a predicting algorithm. The laser stability is measured using a Fabry-Perot interferometer (125 MHz resolution). Right: Transmission system at 10Gbit/s. Laser 1 and Laser 2 can both be operated uncooled system or with standard TEC control.

## 2. Experimental systems

Figure 1 shows the experimental system used to test the stabilised laser. The stabilisation is made by measuring the temperature and correlating this measured value with the desired wavelength and the operating currents of the phase and grating sections. The correlation is derived from an algorithm based on basic rate equations and coupled equations for the thermal behaviour of the different sections [5]. To calibrate the algorithm the linear behaviour of

the device as a function of temperature and current is measured by checking the peak wavelength of the Bragg grating when the temperature or the current varies. The laser gain section current was fixed at 50 mA to give an output of 2 dBm at 10 °C. The two other sections (the grating and phase sections) were driven by a multiple channel GPIB controlled current source. The current source and the thermal sensor embedded in the laser package were connected to the computer containing the stabilisation programme. In order to change the laser temperature over a large range, the Peltier cooler in the packaged laser was connected to a separate current source, allowing independent control of the laser temperature.

Wavelength stability monitoring was carried out using a Fabry-Perot interferometer set at half the maximum transmission for the desired wavelength to offer a frequency sensitivity of 125 MHz. To test the uncooled laser system for transmission we used two lasers which were either an uncooled DBR laser with stabilisation enabled or not or conventional temperature controlled (TEC) tuneable laser. The two lasers wavelengths were spaced by 100 GHz. Laser 1 was then externally modulated with an NRZ, 10 Gbit/s PRBS  $2^{31}-1$  signal generated by a LiNbO<sub>3</sub> Mach-Zehnder modulator. Its output was combined with the laser 2 output and amplified to up to 0 dBm optical power per channel with an erbium doped fibre amplifier (EDFA). The signal was then transmitted over 40 km of standard single mode fibre (SMF) and each channel was separated by an arrayed waveguide grating (AWG-100 GHz spacing). The resulting eye diagram for channel 1 (laser 1) was then displayed on a sampling oscilloscope.

### 3. Experimental results

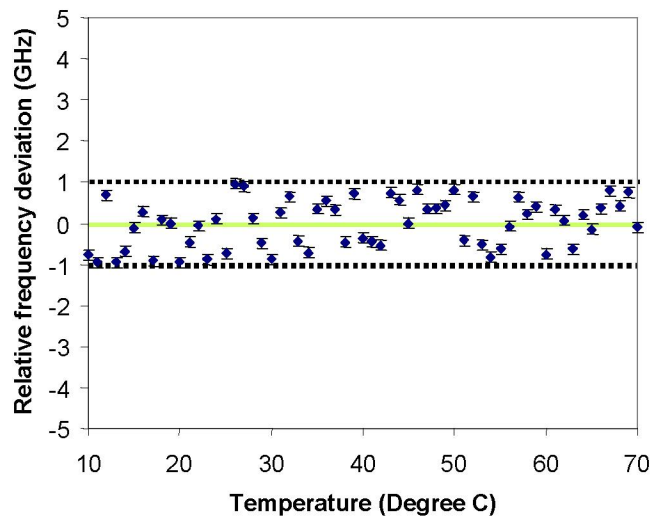


Fig. 2: Wavelength stability of the laser output as a function of the laser temperature. The measurement was made using a Fabry-Perot interferometer with a resolution of 125 MHz.

Figure 2 shows the stability performance of the DBR laser from 10 °C to 70 °C (laser chip temperature). The frequency deviation from the desired wavelength remained within +/- 1 GHz which is comparable to a laser with TEC (typically 2.5 GHz precision of the peak wavelength). Over this range the SMSR remained constant with detailed performance similar to that described in [4].

Figure 3 shows three sets of eye diagrams recorded after transmission of the two channels over 40 km of SMF. Figure 3a shows the eye diagram when channel 1 (Laser 1) is selected, and Lasers 1 is operated uncooled but with the stabilisation circuit enabled, laser 2 is operated with conventional TEC control. Laser 1 temperature was varied from 10 °C to 70 °C. Little degradation of the received signal is observed over the full temperature range. The eye diagram was still clearly open when the laser temperature was 70 °C. The extracted Q-factor varies from Q=7.1 (10 °C) to Q=6.4 (70 °C) (the back to back measurement on Laser 1 with TEC or uncooled gave Q~8). The degradation was caused by the fact that at this high temperature the laser output power had dropped by 5 dBm and the EDFA being close to saturation this resulted in a small drop in transmitted power. This could be compensated by integrating a semiconductor amplifier at the output of the laser to equalize the output power.

Figure 3b shows the eye diagram when channel 1 (Laser 1) is selected, and Laser 1 is operated uncooled but without the stabilisation circuit and Laser 2 is operated with conventional TEC control. Laser 1 temperature was varied from 10 °C to 18 °C. As expected in this case, as the temperature increases the peak wavelength drifts and when this drift is sufficient (>100GHz) no light is transmitted through the filter and the signal is lost.

Finally, Figure 3c shows the eye diagram when channel 1 (Laser 1) is selected, and Laser 1 is operated with conventional TEC control and Laser 2 is operated without the stabilisation circuit. Laser 2 temperature was varied from 10 °C to 18 °C with Laser 2 set to the shorter wavelength channel. The eye diagram of the TEC controlled laser is identical to the one for the uncooled system (Figure 3a) both have an extracted  $Q \sim 7$ , and as expected when Laser 2 drifts sufficiently it starts to interfere with channel 1 and the eye diagram starts to close. When the drift is close to 100 GHz ( $\sim 18$  °C) the eye is completely closed.

As expected from the stability measurements the uncooled laser gives comparable performance to a TEC controlled laser for transmission over 40 km of SMF when its temperature was varied from 10 °C to 70 °C.

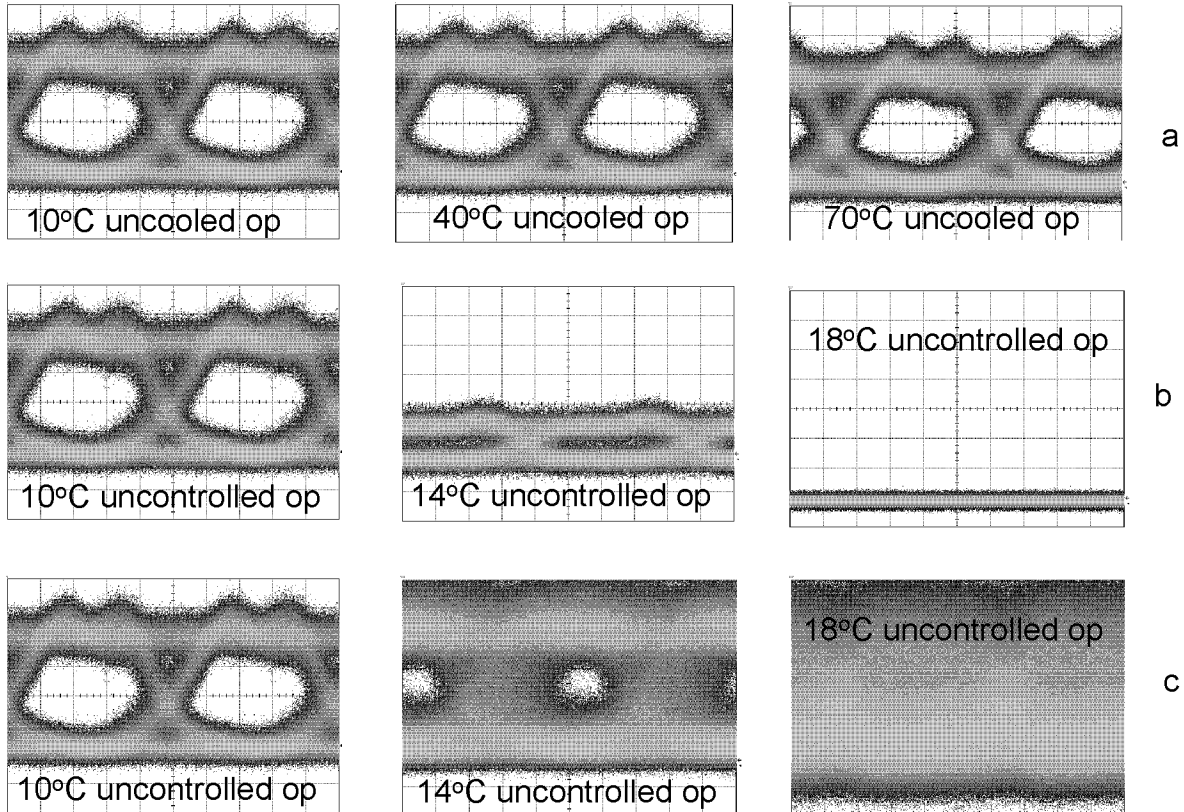


Fig. 3: All eye diagrams are extracted from Laser 1 (Channel 1). Top (a): both lasers in stabilised uncooled operation (temperature of Laser 1 shown). Middle (b): Laser 1 uncontrolled; Laser 2 uncooled stabilised operation (temperature of Laser 1 shown). Bottom (c): Laser 1 TEC controlled, Laser 2 uncontrolled (temperature of Laser 2 shown).

#### 4. Conclusion

The operation of an uncooled stabilised DBR laser was demonstrated from 10 °C to 70 °C. The control of this laser was performed using for the first time a predicting algorithm based on basic rate equations and simple calibration measurements. This stabilised uncooled laser offered similar performance in stability to a TEC controlled laser (2 GHz frequency stability). As expected it also demonstrated similar performance to a TEC controlled laser when modulated at 10 Gbit/s PRBS  $2^{31}-1$  in a 100 GHz spaced WDM system and transmitted over 40 km over SMF over a laser temperature range of 10 °C to 70 °C. Such stabilised lasers offer a route to low cost uncooled dense WDM operation.

Future work will concentrate on extending the predicting algorithm to more complicated tuneable lasers such as an SG-DBR, and studying direct modulation of the DBR laser with an integrated (faster) control system which will also compensate for the direct modulation.

- [1] J. A. Richard, *Photonics Spectra*, vol. 37, pp. 62-64, 2003
- [2] K. Kincaid, *Laser Focus World*, vol. 39, pp.91-100, 2003
- [3] ITU G 694.2
- [4] C. C. Renaud et al., *IEE electron. Letters*, vol 41, pp.127-128, 2005
- [5] M. Teshima, *IEEE J. of Quantum Electron.*, vol. 31, pp. 1389-1400, 1995