Widely tunable lasers for slow and fast switching applications

J. Regan, W. Lynds, L. Coldren

Agility Communications, Adamson House, Towers Business Park, Didsbury, Manchester, M20 2YY, UK

Abstract: This paper will review progress made in SG-DBR Photonic Integrated Circuit based widely tunable cw lasers, integrated transmitters and transponder modules for applications in reconfigurable and packet-switched networks.

Keywords: Tunable laser, SG-DBR, Mach-Zehnder modulator

1. Introduction

Over the last two years semiconductor widely tunable lasers based on the Sampled-Grating Distibuted Bragg Reflector (SG-DBR) have evolved from an interesting technology, into field-deployed products carrying live traffic in Long Haul and Metro networks. This has involved the qualification of these components to Telcordia standards and the establishment of low cost manufacturing methods. The principal driver has been the need to reduce the high inventory costs associated with holding stocks of up to 80 different wavelengths of transmitter throughout the supply chain. However, the move has also been fuelled by the vision of the cost savings and network flexibility enabled by wavelength switchable sources combined with Reconfigurable Optical Add-Drop Multiplexers (ROADM), and the equipment vendors are now bringing such products to market. Meanwhile, research continues into optical packet switched networks for which the SG-DBR represents an ideal fast switching transmitter.

At the same time the component technology has continued to evolve and SG-DBR devices with successively more functions integrated are being developed to reduce the size, cost and enhance the ease of use.

2. Single Chip Transmitter

Figure 1 shows a schematic of the InP-based transmitter.

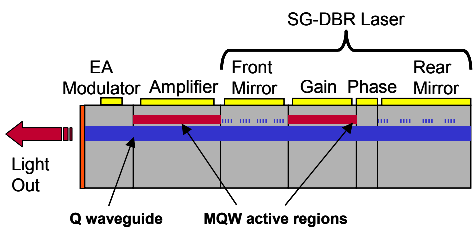

Figure 1 : Single-chip widely-tunable transmitter using a SGDBR laser integrated with an SOA and EAM.

It includes the four-section sampled-grating DBR (SGDBR) laser[1], an integrated SOA, and an electro-absorption modulator (EAM)[2]. A common quaternary waveguide extends throughout the entire device and quantum well gain layers are included at the laser gain and SOA sections. The modulator bias is varied across the 40 nm tuning range to enable efficient modulation across this entire range.

Due to the low switching currents (one tenth of those of a DBR), thermal transients are low, and the chip is capable of channel switching speeds of the order of a few tens of nanoseconds, fast enough to be used in packet switched applications. Figure 2 Shows a histogram of switch times between channels for a packaged SG-DBR[3].

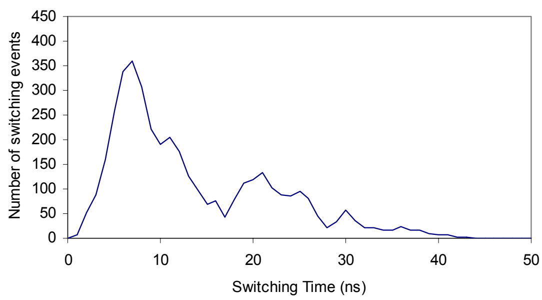

Figure 2 : Histogram of switching times of SG-DBR

In addition to high output powers, monolithic integration with the SOA provides a number of benefits for switched applications. The SOA operates deep in saturation keeping the output constant, independent of channel selected, so that no adjustment of the Gain section is required during a switching transition. Also, if the SOA is reverse biased it absorbs, acting as a shutter to blank the laser output during a channel switch so that no spurious light is seen on intermediate channels.

Figure 3 shows the bit-error rate after transmission through 350 km of standard single-mode fiber for two different wavelengths. The data is applied directly to the EAM of the chip. The average modulated output power is about 3dBm in this case. Error-free operation was observed.

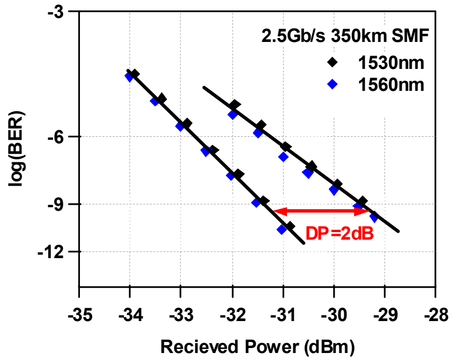

Figure 3 : Bit-error-rate results after tranmission through 350 km of standard fiber at 2.5 Gb/s.

These same chips can be operated as cw sources by keeping the EAM in the on-state. Another Agility product uses this approach by calibrating the output to be 10 mW at each of the 100 channels spaced by 50 GHz across the C-band. Other cw products leave the EAM off for more power out. Packaged as complete modules with wavelength lockers and electronics, these devices switch between locked ITU channels with intermediate blanked output within 10mS, fast enough to enable network reconfiguration within the 50mS SDH protection period.

Relatively high output power has recently been obtained by a slight redesign. Figure 4 shows the cw characteristics of a device that was calibrated for 40 mW into fiber across the entire C-band. Also included are the linewidth, $\Delta\nu$, the relative intensity noise, RIN, and the side-mode suppression ratio, SMSR for all C-band channels.

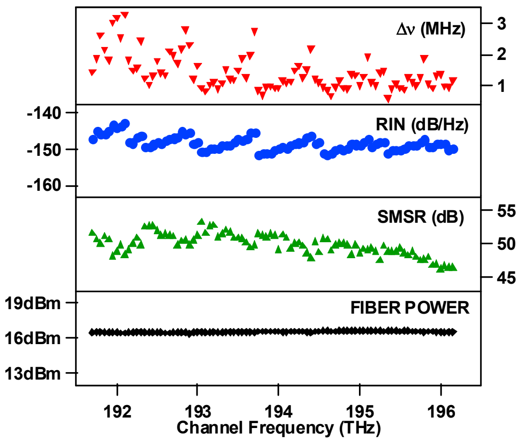

Figure 4 : CW characteristics of SGCBR-SOA device for 100 channels--calibrated for 40 mW of fiber power.

3. Reliability

Figure 5 summarizes some of the reliability data taken on the 10 mW cw product by Agility. Both the integrated EAM transmitter and the 10 mW cw version have undergone complete Telcordia qualification. Because of the InP single-chip architecture, these PICs can be qualified in much the same way as simple laser chips. Such is not the case with other types of widely-tunable transmitters in which separated optical parts are involved in some sort of hybrid package.

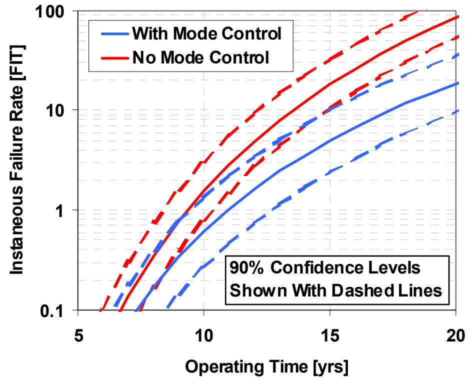

Figure 5 : FIT rate vs. time, assuming both original mirror biases as well as with bias updating.

4. Wavelength switchable Transponders

In response to the demand for transponder solutions, Agility has developed the world's first universal transponder that can operate at any wavelength across the C-band[4]. Figure 6 is a photo of the 300 pin MSA transponder together with eye-diagrams taken at three widely spaced wavelengths.

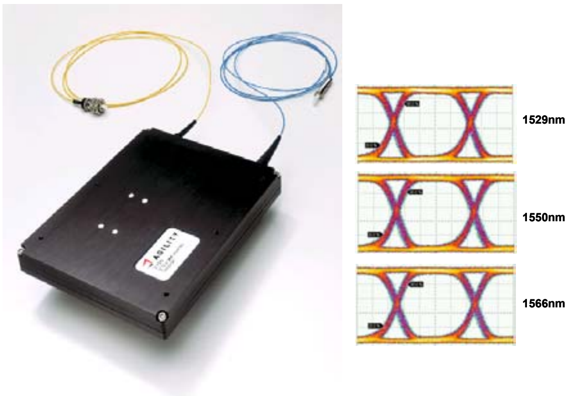

Figure 6 : 300 pin-MSA transponder and 10Gb/s eye diagrams at three widely spaced wavelengths. LiNbO3 external modulator incorporated with 20 mW cw SGDBR.

This incorporates a lithium niobate MZM as is commonly used in the industry. This is coupled to Agility's 20 mW cw widely-tunable laser. Figure 7 shows the BER for 11.1Gb/s data at two widely spaced wavelengths over a distance on 100 km on standard fiber.

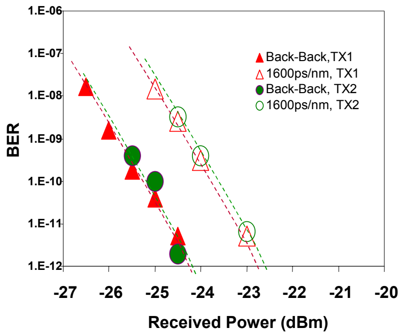

Figure 7 : Transponder bit-error-rate vs. received power comparing back-to-back with 100km transmission at 11.1 Gb/s for two wavelengths. Modulator chirp set to –0.7; APD used at receiver side.

With software selectable wavelength, output power, chirp and bit rate and the ability to switch channels in mS, these transponders represent a universal transceiver for reconfigurable 10G Long Haul and Metro networks.

5. Integrated SG-DBR SOA Mach-Zehnder

Recent work at Agility focusses on the development of a Mach-Zehnder modulator (MZM) integrated on the chip with SG-DBR and SOA, shown in Figure 8.

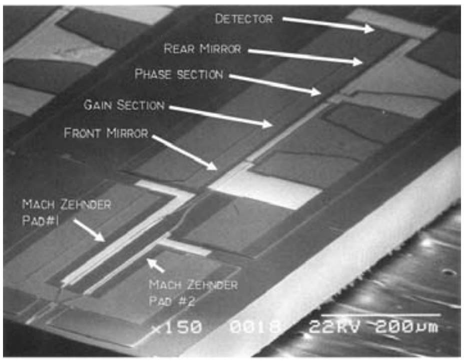

Figure 8 : SEM photo of SGDBR integrated with a Mach-Zehnder modulator.

By monolithically integrating the MZM a much smaller footprint and low power dissipation is possible. In addition, the chirp can be tailored for each channel across the wavelength band by adjusting the biases to the two legs of the MZM as has been done for the EAM case.

Figure 9 shows the 10Gb/s eye diagrams and Figure 10 the Bit Error Rate across the entire C band for the packaged integrated MZM. It exhibits less than 2dB dispersion penalty over 100km (>1600ps/nm) of fibre

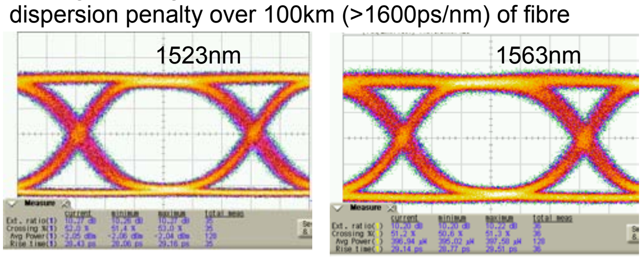

Figure 9 : 10Gb/s eye diagrams of MZM

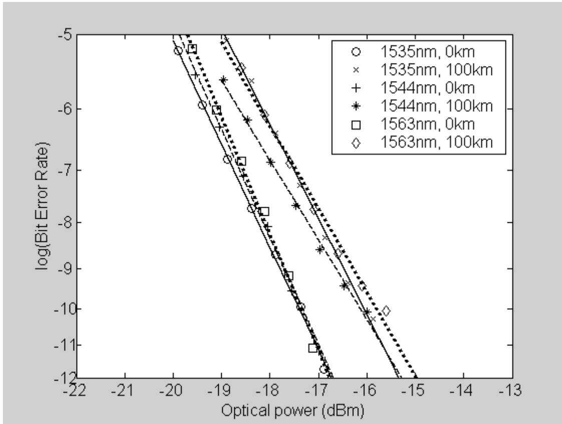

Figure 10 : Bit ErrorRate of MZM over 100km fibre

These SG-DBR SOA Mach Zehnder transmitters will shortly be introduced into new generations of switchable transponder. In addition, combination the nanosecond switch times of the SGDBR with with the 10 and 40Gb/s modulation capability of the MZM in a compact source brings forward the point at which optical fast packet switched networks become economically feasible.

6. Conclusion

We have seen that widely tunable lasers with attractive switching properties have already become a commercial reality. The components are now moving forward to higher degrees of integration, both at the chip level and in terms of the electronics functions included, reducing footprint, power dissipation and cost.

7. Aknowledgment

The authors acknowledge the contribution of their colleagues at Agility to this work, and the contribution from Bell Labs of the fast switching test results.

8. References

[1] L. Coldren, JSTQE, 6 (6) 988, Nov/Dec 2000.

[2] A. Akulova, et al JSTQE, 8, Dec, 2002.

[3] M. Duelk, et al: "*Fast Packet Routing in a 2.5 Tb/s Optical Switch Fabric with 40 Gb/s Duobinary Signals at 0.8 b/s/Hz Spectral Efficiency*", OFC, Atlanta, March 2003

[4] R-C Yu, et al, *APOC'03*, Wuhan, China, Sept. '03

9. Glossary

SG-DBR: Sampled Grating Distributed Bragg Reflector
EAM: Electro Absorption Modulator
MZM: Mach Zehnder Modulator
SOA: Semiconductor Optical Amplifier