Monolithic integrated tunable transmitters

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Abstract: Monolithic widely-tunable transmitters are key enablers in reducing the component size, power consumption, and simplifying DWDM network provisioning. We discuss design and performance of monolithic transmitters based on SGDBR laser and electroabsorption or Mach-Zehnder modulators.
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1. Introduction

A compact, high-performance widely-tunable integrated laser/modulator chip is a key component of a tunable transmitter that can dramatically lower the barriers to deployment and operation of high capacity DWDM networks. Optical networking applications for tunable, modulated, lasers range from one time wavelength provisioning and sparing to dynamic wavelength provisioning in re-configurable optical add/drop multiplexers, photonic cross-connects, and all-optical regenerators. Transmitters with full band coverage (C or L) enable wavelength-agile networking concepts in addition to simplifying provisioning and inventory control. Telecom applications impose stringent requirements on transmitter tuning range, wavelength stability, output power, side-mode suppression ratio (SMSR), linewidth, extinction ratio, chirp, tuning speed, and reliability. The application of monolithic tunable transmitters will be limited unless all of the requirements listed above are met.

In this paper, we present details of the design and performance characteristics of widely-tunable monolithic optical transmitters based on Sampled-Grating Distributed Bragg Reflector (SG-DBR) laser integrated with Semiconductor Optical Amplifier (SOA) and electroabsorption (EA) or Mach-Zehnder (MZ) modulators. We demonstrate that these chips fabricated using simple manufacturable offset quantum well technology meet stringent system requirements across 40 nm wavelength range at 2.5 and 10 Gb/s.

2. Device design

As illustrated in Fig. 1, the device consists of a four-section SG-DBR laser, an SOA, and an EA or MZ modulator, all integrated on the same InP chip. The SG-DBR laser includes gain and phase sections positioned between two "sampled grating" distributed reflectors. This laser architecture described in details in [1] utilizes Vernier enhanced current injection tuning mechanism and combines the advantages of wide tuning range (>40 nm), fast tuning (a few tens of nanoseconds), and simplicity for integration with other components. For optical networking applications, lasing on an absolute discrete frequency grid is achieved through calibration at the time of assembly. Employing an integrated SOA for power control allows the gain section current to be held constant across channels, allowing the laser to be biased far enough above threshold to ensure adequate spectral properties and also eliminating a source of parasitic thermally-induced wavelength tuning. The SOA also allows for additional functionality, such as variable optical attenuation (VOA) and beam blanking during wavelength switching.

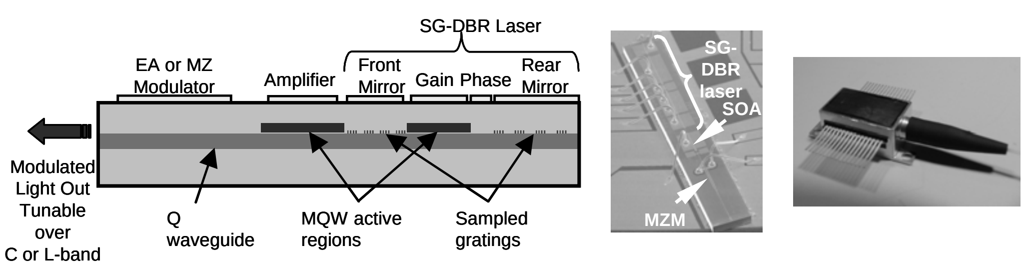

Fig. 1. Schematic crossection of an SG-DBR laser integrated with SOA and EA or MZ modulator; SEM of an SGDBR-SOA-MZM chip mounted on ceramic carrier, and optical image of a packaged integrated optical transmitter.

The chip-scale integration of a widely tunable SG-DBR laser with an SOA and a modulator is accomplished using the same offset quantum-well structure and fabrication technology as used for manufacturing of an SG-DBR alone. In this simple integration technology the active region of the modulator uses the same bulk quaternary waveguide as the tuning sections of the laser. The composition, doping, and thickness of the bulk waveguide can be optimized to achieve high tuning efficiency for the laser and a target extinction ratio for EAM or desired V_π for MZ modulator over the wide spectral bandwidth. The footprint of the monolithic transmitter chip is compatible with packaging into standard hermetic butterfly module (Fig. 1) or transmitter optical subassembly (TOSA).

3. Performance characteristics

Figure 2a) presents typical CW characteristics of an SGDBR-SOA chip. The output power in excess of 80 mW and SMSR better than 40 dB can be maintained across 40 nm tuning range. For the EA-integrated devices modulated time-averaged powers in excess of 5 dBm and *RF* extinction ratios > 10 dB across a 40 nm tuning range have been achieved (Fig. 2b). Fig. 3 shows filtered back-to-back eye diagrams and bit-error-rate (BER) characteristics for several representative channels across the C-band at 2.5Gb/s. Error-free transmission at 2.5 Gb/s has been demonstrated for 350 km of standard single mode fiber. This transmission distance is limited by transient chirp of the bulk EA modulator which remains slightly positive at the used operating conditions.

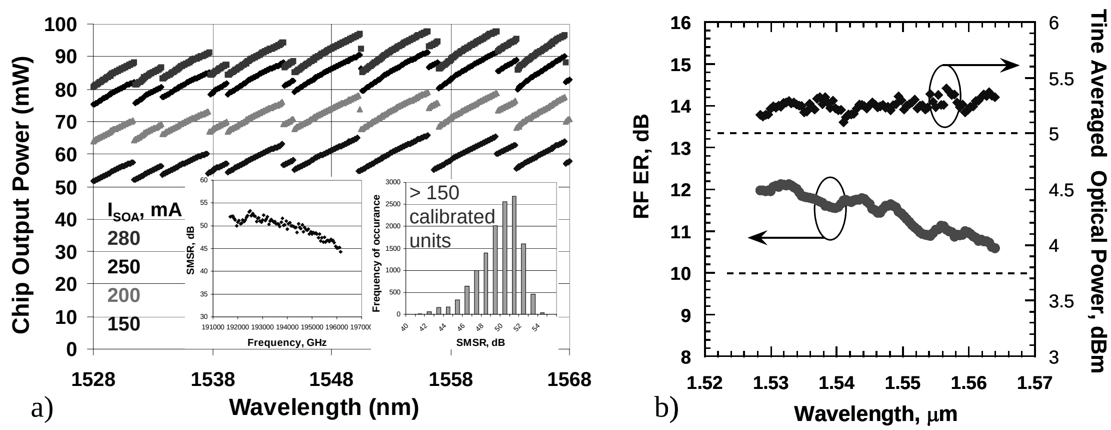

Fig. 2. a) Output power of SG-DBR-SOA chip at several SOA currents; gain section current is 150 mA. The inserts show SMSR as a function of lasing frequency measured with 0.1 nm resolution bandwidth and distribution of SMSR measured for more than 150 calibrated tunable transmitters. b) RF ER and time-averaged fiber-coupled output power for EAM modulated transmitter at 2.5 Gb/s.

The output power vs. wavelength for an SGDBR-SOA-MZM chip is shown in Fig. 4a). For this measurement the nominally π-phase shifted MZM is biased to produce differential phase shift of 0 radians between the two arms. The integrated chips are capable of producing more than 20 mW of power across 40 nm tuning range in the C-band. The insert in Figure 4a) shows normalized transfer function for a packaged SG-DBR-SOA-MZM chip at three wavelength across C-band. DC ER in excess of 20 dB is achieved with less than 3.3 V. The key for achieving uniform transmission performance of the integrated SG-DBR-SOA-MZM transmitter over wide wavelength range is in eliminating optical and electrical crosstalk and precise control of the transient chirp of the modulator. For a π-shifted MZM the dual-drive condition results in "zero" chirp configuration, while single-ended operation results in "negative" chirp. In single-ended drive configuration RF ER of 12 dB was measured across 40 nm tuning range with less than 4 V peak-to-peak modulation voltage (Fig. 4b). The output eye diagrams at 10 Gb/s shown in Figure 5a) pass mask test with 10% margin. The BER data presented in Fig. 5b) for three representative channels shows error free transmission for 1600-1800 ps/nm dispersion for 1535-1563 nm wavelength range.

4. Summary

In summary, widely-tunable SG-DBR lasers are well-positioned for next generation DWDM transmission systems. Compared to their fixed-wavelength counterparts, they exhibit comparable performance characteristics and reliability, with the additional functionality of full band coverage tunability. Simple, robust manufacturing technology has been developed for integration of widely-tunable SG-DBR lasers with SOAs and modulators. The monolithic widely tunable transmitter chips meet stringent system requirements at 2.5 and 10 Gb/s. The developed chip-scale integration technology is compatible with further enhancement of the performance characteristics (power, tuning range, bit rate) and provides essential building blocks to realize various photonic circuits with increased functionality.

5. References

[1] V. Jayaraman, Z.-M. Chuang, L. A. Coldren, "Theory, Design, and Performance of Extended Tuning Range Semiconductor Laser with Sampled Grating", *IEEE J. of Quantum Electron*., 29, pp. 1824 –1834, 1993.

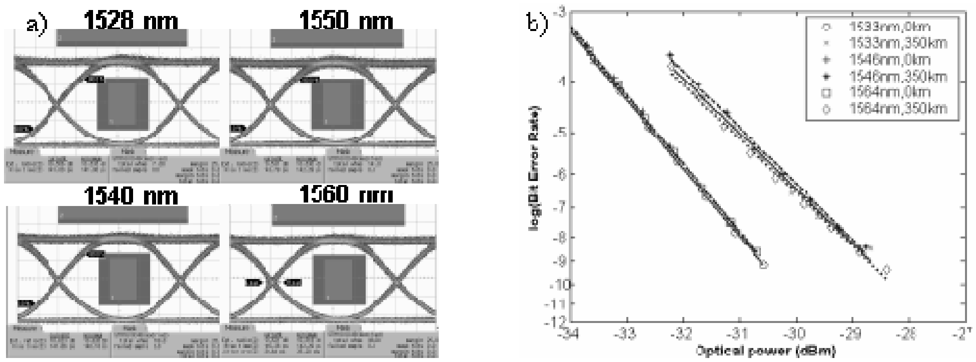

Fig. 3. a) Output eye diagrams of SG-DBR-EAM optical transmitter for several representative wavelength channels at 2.5Gb/s (PRBS 2^{31}-1); overimposed is SONET mask with 25% margin. b) BER curves measured BtB and after 350 km of standard single mode fiber.

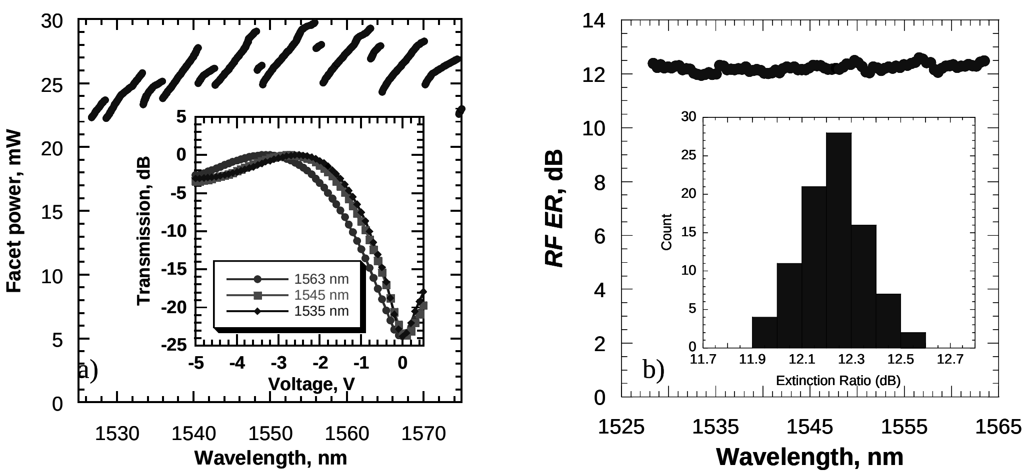

Fig. 4. a) Output power of an SGDBR-SOA-MZM chip as a function of wavelength; the insert shows normalized MZ transfer function at three wavelength. b) RF ER at 10 Gb/s as a function of wavelength measured for 88 ITU channels.

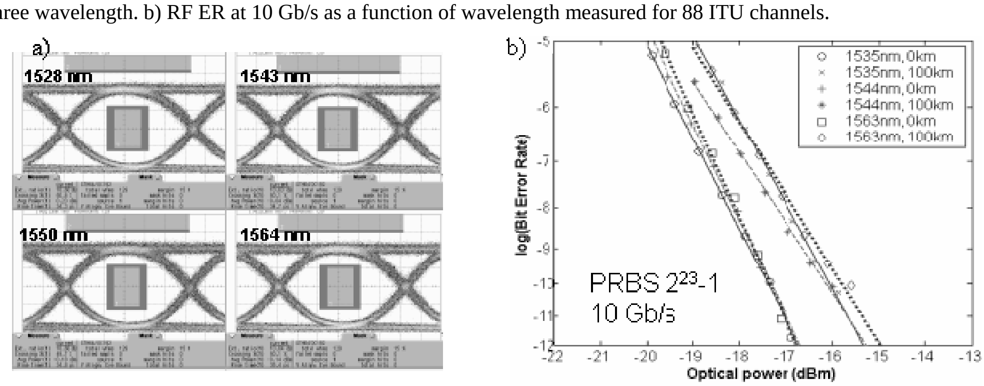

Fig. 5. a) Output eye diagram of an SGDBR-SOA-MZM transmitter at 10 Gb/s. b) BER curves measured BtB and after 100 km of standard single mode fiber.