Widely-Tunable Chip-Scale Transmitters and Wavelength Converters

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Widely-tunable lasers have gained much attention over the past few years as universal sources for dense WDM networks[1]. Interest in the dynamic networking capability enabled by such sources is also of continued interest, although the slow-down in the build out of the telecom infrastructure has slowed the introduction of such architectures. In this paper we will review the current status of InP-based integrated optical transmitters, which are monolithically integrated on a single chip and cover the full C or L-bands, and we will also give an update on the recent application of such devices within monolithically-integrated widely-tunable wavelength converters.

Figure 1 shows a schematic of the transmitter chip. It includes the four-section sampled-grating DBR (SGDBR) laser, 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. Figure 2 shows the bit-error rate after transmission through 350 km of standard single-mode fiber for two different wavelengths. The average modulated output power is about 3dBm in this case.

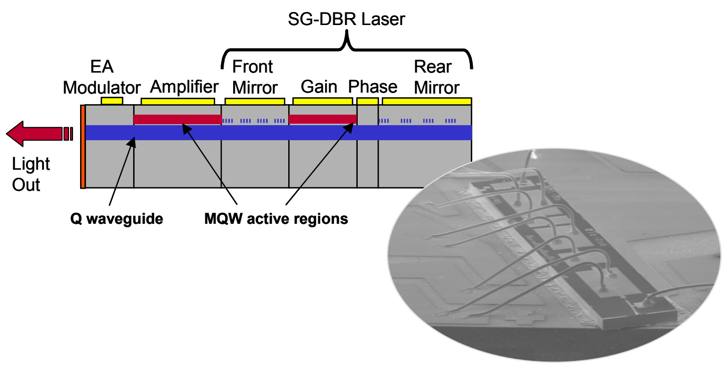


Figure 1. SGDBR laser with integrated SOA and EAM. Inset gives SEM photo of device.

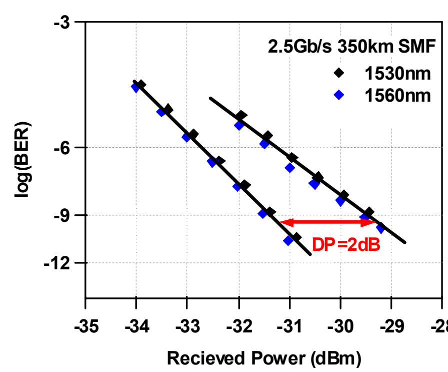
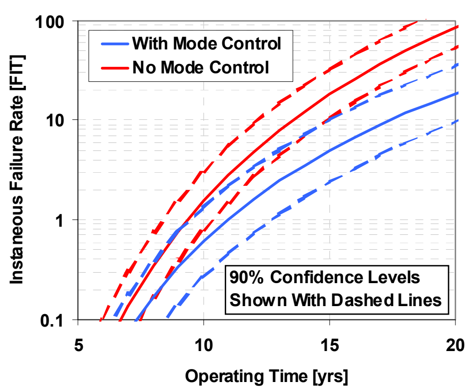


Figure 2. Bit-error-rate results after transmission through 350 km of standard fiber at 2.5 Gb/s.

These lasers can also be operated as CW sources for external modulators by simply setting the EAM for maximum transmission. The standard qualified Agility product is calibrated for 10 mW out in this case. Figure 3 shows results from reliability testing on this laser. The FIT rate is given both with and without 'mode control' in which the mirror currents can be updated over life[3].



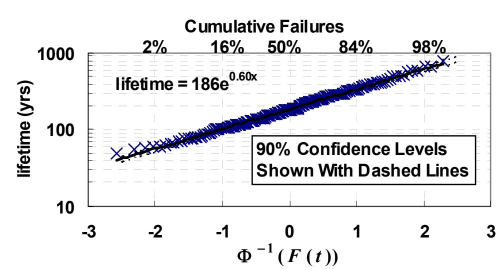


Figure 3. (left) FIT rate vs. time, assuming both original mirror biases as well as with bias updating. (right) Lifetime distribution of 200 parts tested. Maximum channel currents are assumed. FIT rate <2 for average channel.

More 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.

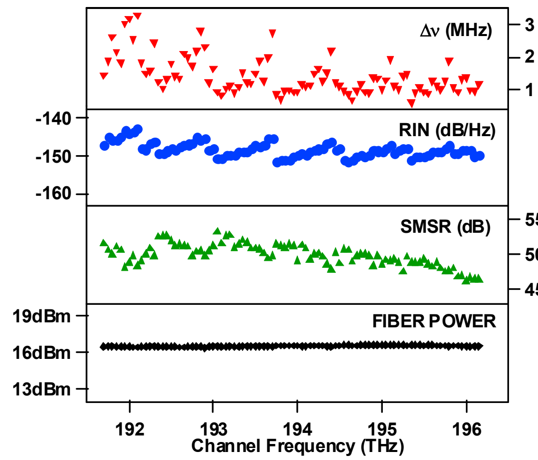
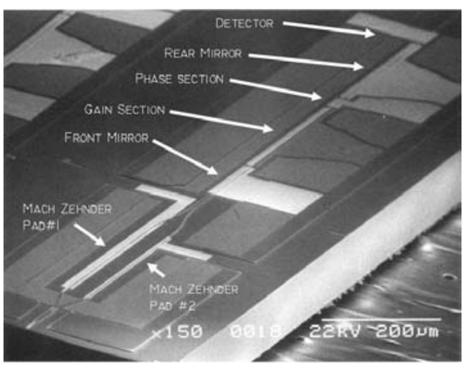


Figure 4. CW characteristics of SGCBR-SOA device for 100 channels when calibrated for 40 mW of fiber power.

Recent work both at UCSB[4] and Agility[5] includes some effort on replacing the EAM with a Mach-Zehender modulator (MZM). This is being done to improve the chirp characteristics for long-haul applications. 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 5 gives an SEM photo of the UCSB device and initial results from the Agility device. Error free transmission over 80 km of standard fiber was demonstrated for all channels.



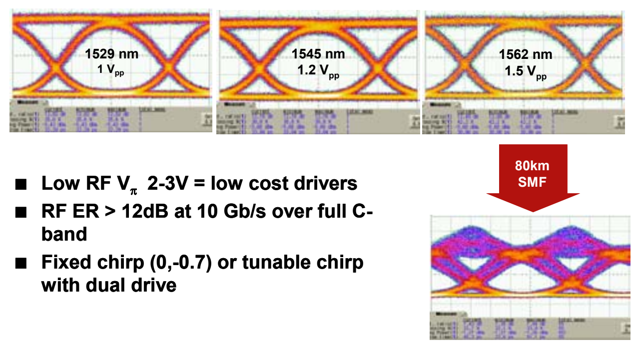


Figure 5. SEM photo (left) and eye diagrams at 10Gb/s across C-band (right) for the monolithically integrated SGDBR-Mach-Zehender modulator. The top three eyes are for launched power and the lower unfiltered eye is for the worst-case channel after transmission over 80km in standard fiber.

One of the components desired for dynamic optical networking is a widely-tunable wavelength converter (WC). Such an element can greatly increase the reconfigurability of WDM networks for reduced operating costs without requiring costly electronic line cards. Work at UCSB is exploring two monolithically integrated WCs that incorporate SGDBR lasers with integrated modulators for full-band reconfigurability. Both require only DC biases to the InP chips. Figure 6 illustrates a Mach-Zehender bridge-type WC[6]. This is very similar to the device of Fig. 5, only in this case the MZM contains SOAs in each of its legs, and one of them is modulated optically by the input optical data via the connections shown in the schematica. The process here is a modulation of the carrier density within the SOA by the incoming optical data. This in tern then changes the gain and phase of this leg of the MZM and modulates the cw light at an arbitrary wavelength from the SGDBR. Results of the wavelength conversion are shown by the eye diagram and BER characteristics for 2.5 Gb/s data in Fig. 6. The finite carrier lifetime provides the low-pass character to the eyes and perhaps the ~2dB of conversion penalty. These characteristics should be improved with increased SGDBR power (only ~ 2mWout in this case) and better SOA design in the future.

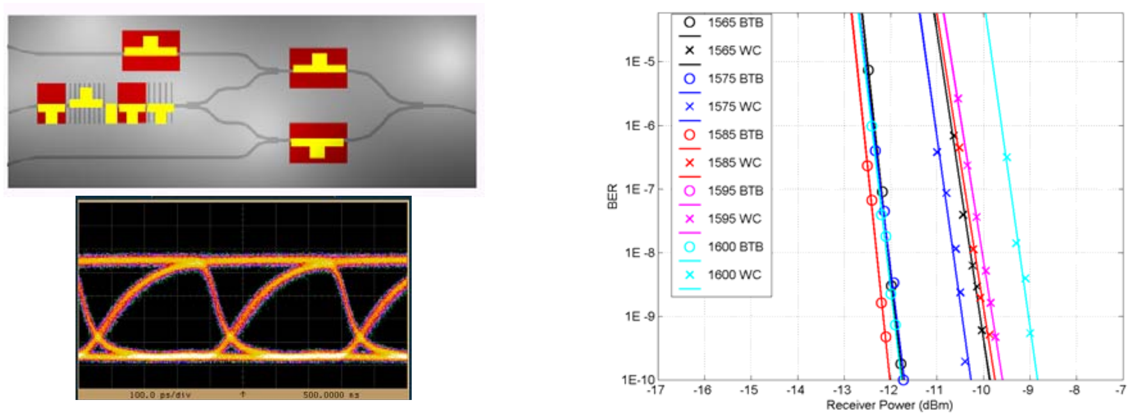


Figure 6. Schematic, eye-diagram, and bit-error-rate characteristic for Mach-Zehender bridge type wavelength converter. Red regions on schematic are gain/SOA regions. Eye is for conversion from 1570 nm to 1545 nm. BTB=> BER with no WC.

The second type of wavelength conversion, illustrated in Fig. 7 uses separated detection and modulation elements. This, in principle enables the separate optimization of the two elements and avoids carrier lifetime effects. As indicated by the equivalent circuit, this OEIC version is illustrated in a direct modulation embodiment in which the photocurrent from a detector directly modulates the drive current to the gain section of the SGDBR laser. Gain is provided by the SOAs to compensate for coupling losses and the differential efficiencies of the detector and laser. In this case the gain is also segmented and the modulation is applied only to the short 'gain-lever' section to enhance the effective laser differential quantum efficiency. Because the detected carriers flow between the separate detector and laser stages, there is a current that can be monitored to enable signal monitoring in this embodiment.

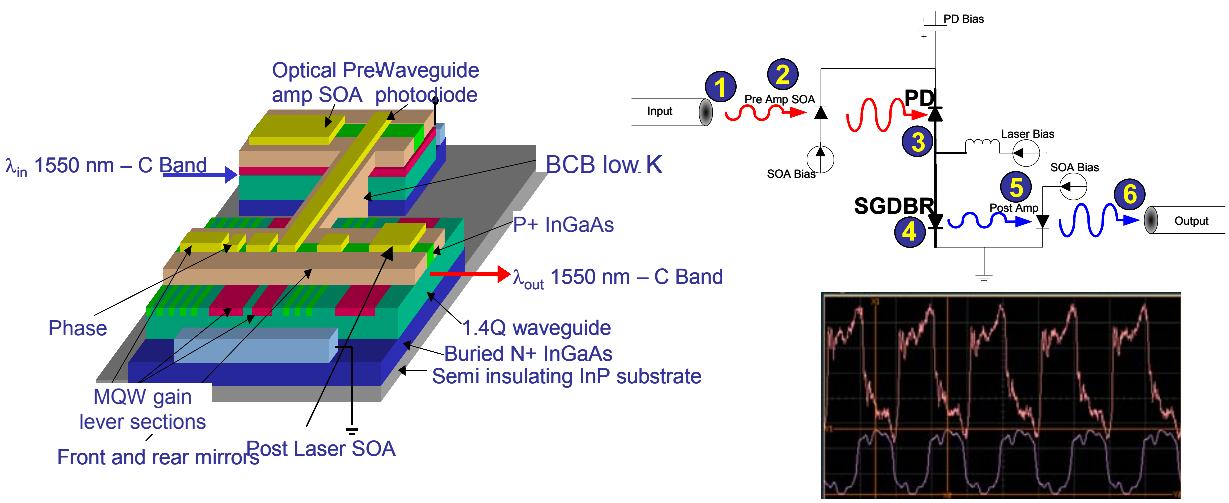


Figure 7. Schematic, equivalent circuit and wavelength conversion results for an integrated detector-laser type device. The data shows wavelength conversion (top) and signal monitoring (bottom) at 50 MHz. The measured WC bandwidth was only 2 GHz due to parasitics in this experiment.

[1] L. Coldren, JSTQE Millenium issue.
[2] Y. Akulova, et al, *J. of Selected Topics in Quantum Electronics*, **8**, Dec., 2002;
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[4] J. Barton, et al,
[5] Agility MZM
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