INTEGRATED TUNABLE TRANSMITTERS FOR WDM NETWORKS

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(*Invited paper*)

Abstract *The integration of widely-tunable sampled-grating lasers with semiconductor optical amplifiers and either electroabsorption or Mach-Zehender modulators has been successful in creating high-performance optical transmitters. Details of this performance as well as recent advances in this technology will be reviewed in this paper.*

Introduction

The desire to reduce operational costs with a universal WDM source that can access any wavelength channel across the C-or L-bands of a DWDM optical fiber system has provided a growing market for widely tunable lasers. The further desire to have analogous universal WDM transmitters, which integrate such sources with modulators, to enable low cost, low power dissipation, and small form-factor has also provided a market impetus to develop a viable photonic integration platform to provide such products.

Most recently, many customers are expressing a preference to purchase at the transponder level to avoid contact with the optical components entirely. Here especially, a universal, programmable, full-band product is very desirable, and here especially, having small-form-factor, low-power, full-band optical components is very important to enable these characteristics in the universal DWDM transponder. In addition to the inventory issues, such a product will also enable the long anticipated ability to remotely dynamically provision wavelengths in the network.

Past attempts to develop viable integration technologies have largely failed to produce the required performance metrics to compete with the conventional discrete approaches. For past DWDM systems, dozens of different DFB laser codes had to be available, and more importantly, each transmit/receive line card was specific to a particular wavelength, and dozens of these had to be inventoried for rapid replacement of failed parts. This inventory issue appears to have been one of the key issues that led to the virtual collapse of the industry over the past two years.

Photonic Integration platform

Work at UCSB and Agility Communications has aimed to address these issues by developing a low-cost 'platform technology' that is capable of providing a wide variety of PICs without changing the basic manufacturing process. This limits the required capital investment and enables higher volume by sharing the technology across a number of components. Figure 1 shows a photograph of a 2" InP wafer with arrays of seven-section photonic IC transmitters, each consisting of a full-band-tunable sampled-grating DBR (SGDBR) laser integrated with a monitoring detector, optical amplifier, and modulator. The SEM inset shows one of these mounted on a carrier ready to be inserted into a package. It is important to note that the wafer layer structure and processing procedure used is identical to that developed for the SGDBR laser alone. This same structure and processing procedure is also used in the more complex laser PICs to be discussed below. Note also a key advantage of photonic integration--only one optical coupling to fiber is required, as would be necessary for a simple DFB laser alone.

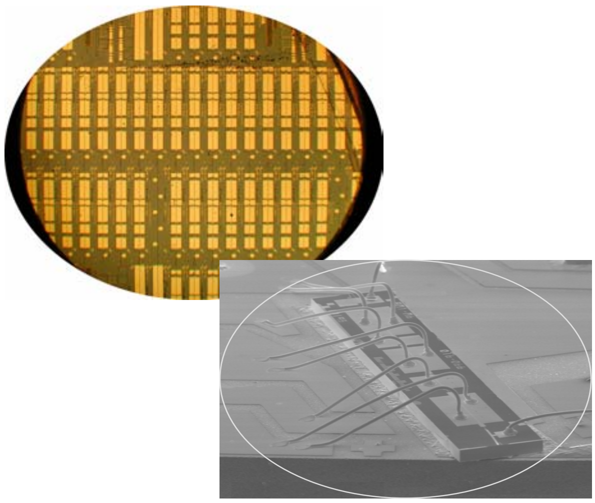

Figure 1. Photo of wafer and SEM of mounted single-chip transmitter.

Single-chip transmitter

Figure 2 shows a schematic of the InP-based transmitter chip[1]. 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[2].

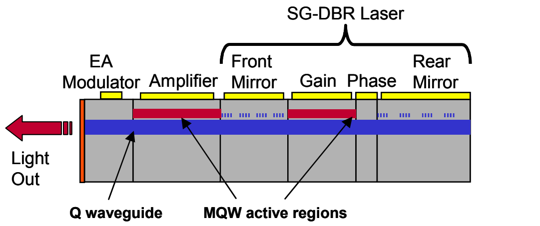

Figure 2. Single-chip widely-tunable transmitter schematic showing a SGDBR laser integrated with an SOA and EAM.

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.

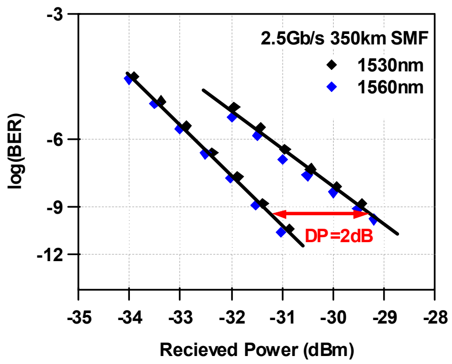

Figure 3. Bit-error-rate results after tranmission through 350 km of standard fiber at 2.5 Gb/s.

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. Figure 4 shows a variety of characteristics for a 20 mW cw product.

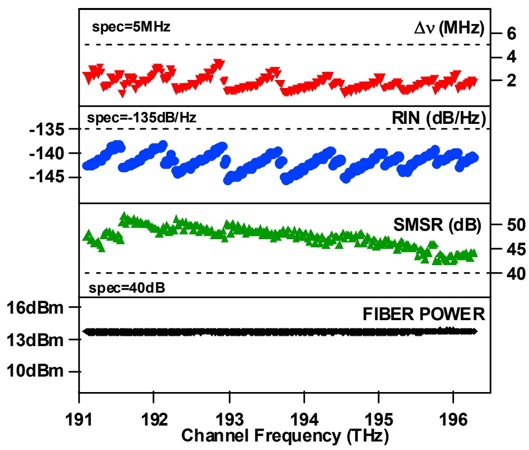

Figure 4. CW characteristics of SGCBR-SOA device for 100 channels--calibrated for 20 mW of fiber power. The linewidth, $\Delta\nu$, relative intensity noise, RIN, and side-mode suppression ratio, SMSR shown for all C-band channels.

Improvements in chirp

The device illustrated in Fig. 2 and characterized in Fig. 3 provides good results at 2.5 Gb/s for distances up to 350 km. However, for longer distances and/or higher bit rates, some sort of chirp control is necessary. Two approaches have been explored. The first is a 'tandem EA' modulator as shown in Fig. 5.

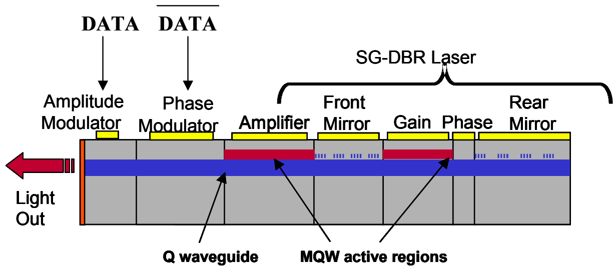

Figure 5. SGDBR integrated with a two-section tandem EAM including inverted data applied to a phase modulator to compensate chirp. Amplitude modulator reverse biased for absorption; no bias applied to phase mod.

The tandem EAM employs a phase section in addition to the electroabsorption section to compensate the positive chirp usually observed. As illustrated, an inverted data signal is applied to the phase section; however as indicated in Fig. 6, unwanted out-of-phase intensity modulation is avoided by reducing the magnitude of the inverted data, keeping the dc bias low, and increasing the length of the phase section in proportion to the reduced data magnitude. The load impedance is simultaneously reduced to provide the same RC bandwidth for the phase section. The circuit shows that this can be done with a simple voltage divider beginning with an inverted drive signal of the same magnitude.

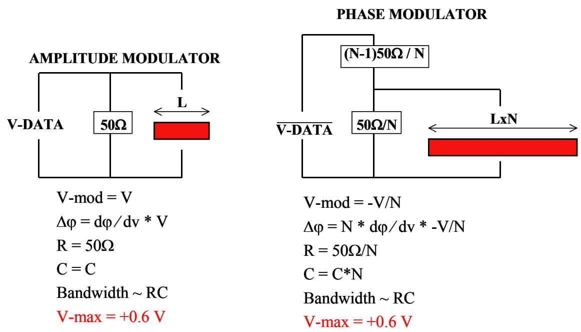

Figure 6. Comparison of section lengths, terminations and drive levels for tandem EAM.

Figure 7 shows the measured chirp from the tandem EAM for three cases—no phase section compensation and compensating phase modulation for either zero or negative chirp. Note that the waveguide material and structure is identical for both, so that this is very easy to fabricate. In this case the RC bandwidths of the amplitude and phase modulation sections were slightly different, so some chirp glitches still exist. Nevertheless, the viability of the novel concept is demonstrated.

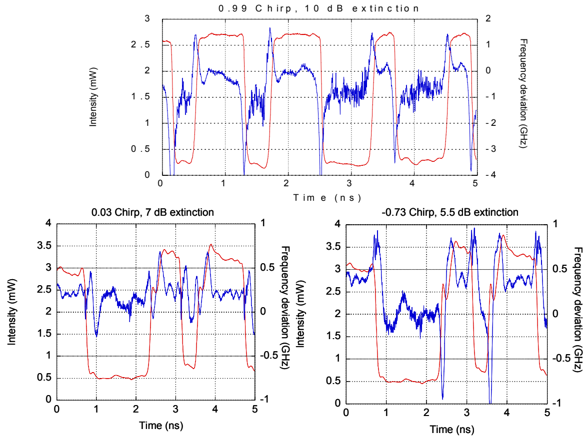

Figure 7. Chirp superimposed on data signals taken from a tandem EAM with a phase section length of 600 μm and an absorption section length of 200 μm—i.e., N=3. (top) no phase signal; (bottom left) V_{ph} = -1/3 V_{amp}; (bottom right) V_{ph} = -1/2 V_{amp}

The second effort to control chirp involves replacing the EAM with a Mach-Zehender modulator (MZM) as shown in Fig. 8. Such modulators have been used widely for long-haul applications, and they allow negative chirp with only one drive signal, although dual drive of both arms of the MZM are necessary for truly programmable chirp. In the past, researchers have had difficulties in integrating such MZMs directly with lasers because of reflections. However, the UCSB-Agility effort appears to have solved these difficulties[3,4].

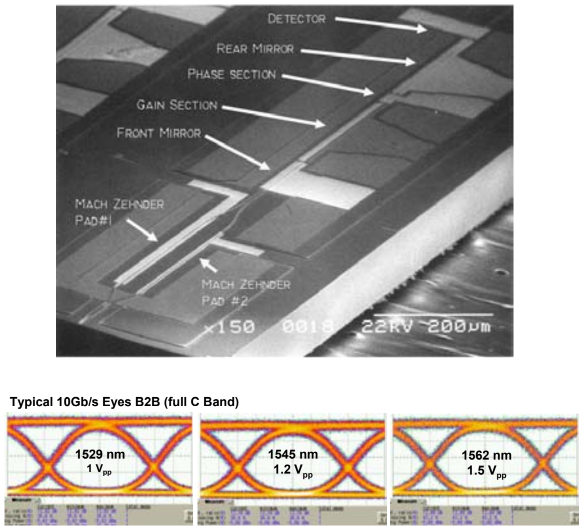

Figure 8. (Top) SEM photo of SGDBR integrated with a Mach-Zehender modulator. (bottom) eye-diagrams at 10 Gb/s for three wavelengths across the band.

By monolithically integrating the MZM a much smaller footprint and low power dissipation is possible as compared to hybrid packaged or fiber-coupled devices. 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. Chirp values from +1 to –1 are readily available. The initial results shown in Fig. 8 illustrate filtered eye diagrams. Error free transmission over 80 km of standard fiber was demonstrated for all channels at 10Gb/s using a negative chirp configuration.

Widely-tunable 'Universal' 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[5]. Figure 9 is a photo of the 300 pin MSA transponder together with eye-diagrams taken at three widely spaced wavelengths.

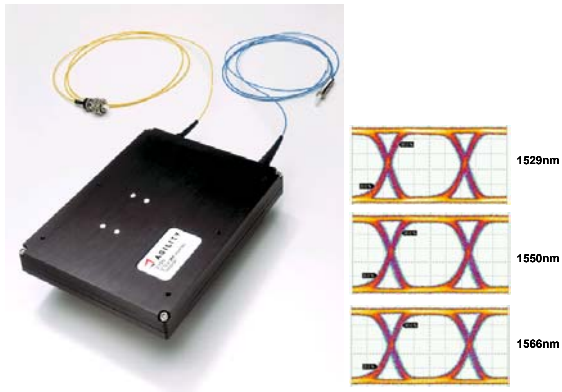

Figure 9. 300 pin-MSA transponder and 10Gb/s eye diagrams at three widely spaced wavelengths. LiNbO3 external modulator incorporated with 20 mW cw SGDBR.

The initial prototype transponders actually incorporate a fiber-coupled lithium niobate MZM as is commonly used in the industry. This is coupled to Agility's 20 mW cw widely-tunable laser. Figure 10 shows the BER for 11.1Gb/s data at two widely spaced wavelengths over a distance on 100 km on standard fiber.

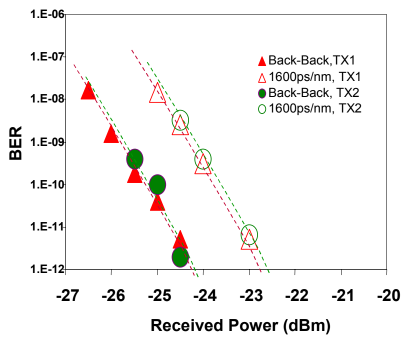

Figure 10. Transponder bit-error-rate vs. received power comparing back-to-back with 100km transmission at 11.1 Gb/s for two wavelengths. Modulator chirp set to –0.7; APD used at receiver side.

Future versions of the transponder will incorporate the integrated MZM with the SGDBR for reduced power dissipation and smaller form-factor. The ability to set the chirp for each and every channel should also enable improved performance and tailorability to the particular properties of any fiber link in which it may be used.

Reliability

Figure 11 summarizes some of the reliability data taken on the 10 mW cw product by Agility[6]. 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.

The data indicate that no updating of mirror currents is necessary for a FIT rate of <20 at 15 yrs. This includes reasonable margins for other device parameters. However, a mirror look-up table updating algorithm has also been developed that both monitors the mirror drift for setting possible alarms as well as updating the table. This improves the FIT rate to <3 at 15 yrs.

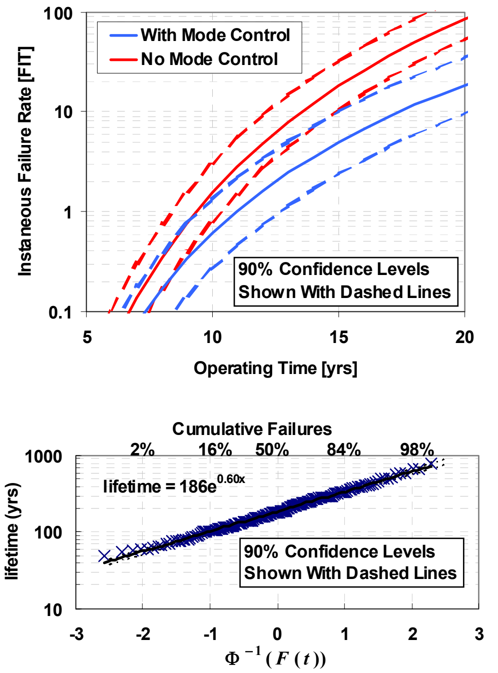

Figure 11. (Top) FIT rate vs. time, assuming both original mirror biases as well as with bias updating. (Bottom) Lifetime distribution of 200 parts tested. Maximum channel currents assumed.

Conclusions

Single-chip widely-tunable optical transmitters have been demonstrated that have performance and manufacturing aspects that are attractive for system insertion. More recent versions include modulators with improved chirp control for long-haul applications. Universal, full-band programmable, DWDM transponders have also been developed. The incorporation of the integrated SGDBR-MZM chips should make such components even more attractive.

References

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