Novel Frequency Chirp Compensation Scheme for Directly Modulated SG DBR Tunable Lasers

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***Abstract*—The authors demonstrate a compensation scheme to reduce the frequency chirp associated with directly modulated sampled grating distributed Bragg reflector tunable lasers. Experimental results obtained show that the direct modulation of the laser's gain section results in a large frequency chirp of 25 GHz. However, by simultaneous modulation of the laser's phase section this large frequency chirp can be significantly reduced.**

***Index Terms*—Direct intensity modulation, frequency chirp, optical fiber communications, tunable laser (TL), wavelength-division multiplexing (WDM).**

I. INTRODUCTION

WIDELY tunable lasers (TLs) are becoming an essential component for operation of advanced wavelength-division-multiplexed (WDM) systems, packet-switched schemes, and access networks. The sampled grating distributed Bragg reflector (SG DBR) TL has emerged as the most promising candidate for such WDM reconfigurable applications, due to its large wavelength tuning range (40 nm), high output power (>10 dBm), high sidemode suppression ratio (SMSR) (>45 dB), and simplicity of integration [1]. External modulation of TLs is currently the most common method to modulate the light-wave signal. Although this technique provides high-speed and stable data modulation, the large insertion losses of the modulator can prove prohibitive. The extra optical component also adds to the cost and complexity of the tunable transmitter, rendering this technique unsuitable for short reach applications.

Alternatively, direct modulation is one of the most simple and cost-efficient techniques to modulate light-wave signals, providing a low cost, small form factor transmitter. Nevertheless, one of the main drawbacks of this technique is the frequency fluctuation (chirp) imposed on the signal. This frequency chirp can impair the overall performance of WDM systems in two ways, either by drifting out of the receiving filter's bandwidth [2] and/or by drifting into the neighboring channel's filter bandwidth thereby causing cross channel interference. Additionally, the chirped signal would be more prone to dispersion effects in the fiber.

Such impairments would overshadow the advantages of direct modulation and prevent service providers from adopting such a technique. A corrective measure yielding an improvement in system performance could be achieved by reducing the index of modulation which would in effect reduce the magnitude of the frequency chirp. However, this would degrade the resulting on–off contrast ratio indicating that a compromise would have to be drawn between the signal extinction ratio and the frequency chirp.

Previous work in this area has mainly focused on the compensation of thermal transients caused by wavelength switching or transmission experiments using directly modulated sources [3]. Recently, Liu *et al.* reported a 2.5-GHz frequency drift of an uncooled DBR laser, that was directly modulated at 2.5 Gb/s, over an 85 °C temperature range [4]. However, in this letter, we propose a novel scheme that compensates the frequency chirp due to the direct modulation, which could be applied to a number of DBR-based TL structures. It consists of the simultaneous modulation of both the gain and phase sections of an SG DBR laser. The direct modulation of the laser phase section produces a corresponding frequency variation, but more importantly with a sign that is opposite of that produced through modulation of the gain section. This effect can be utilized to reduce the inherent chirp associated with directly modulated lasers. To the best of our knowledge, this is the first time that the chirp caused by the direct modulation of an SG DBR TL has been compensated by the simultaneous modulation of the phase section.

II. EXPERIMENTAL SETUP

The experimental setups used in this work are illustrated in Fig. 1. The SG DBR laser used was a temperature-controlled fiber pigtailed commercially available device contained within a butterfly package. The temperature was set and maintained at 22 °C. The back mirror (I_b), gain (I_g), and front mirror (I_f) currents were initially set at 55.03, 79.29, and 0.53 mA, respectively, which resulted in a lasing wavelength of 1554.5 nm (λc) and an SMSR of 45 dB. Fig. 1(a) displays the setup used to obtain a static characterization of the laser phase section, which was obtained by applying a varied dc bias. The applied current was altered in 1-mA steps and the central lasing wavelength was simultaneously recorded. The corresponding shift in wavelength relative to λc, as a function of phase current, is illustrated in Fig. 2. As can be seen, the wavelength slowly decreases with an increase in the injection current until a longitudinal mode jump is experienced, after which the cycle is repeated. From this result we can see that by biasing the phase section around 15 mA and applying a peak-to-peak modulation

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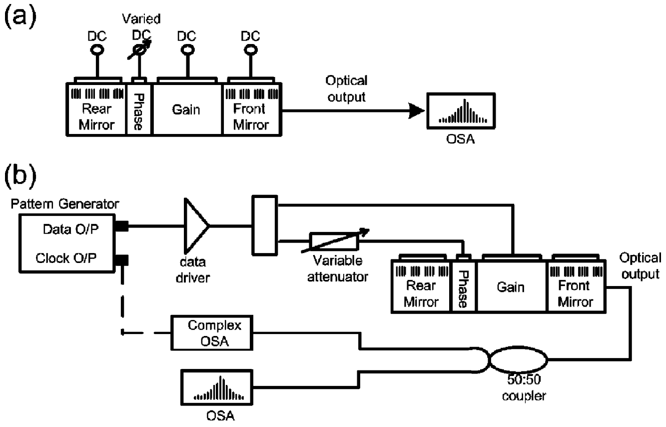

Fig. 1. (a) Setup for static characterization of phase section and (b) experimental setup for frequency chirp compensation scheme.

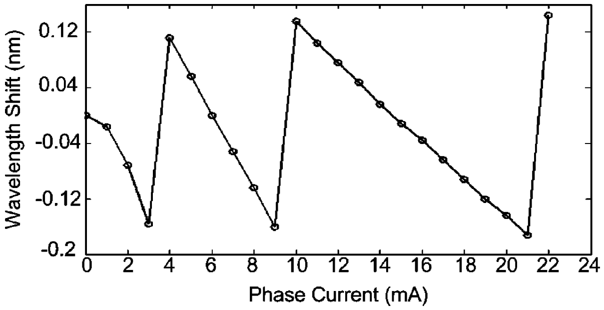

Fig. 2. Wavelength shift as a function of phase current, relative to central wavelength at zero bias (1554.5 nm).

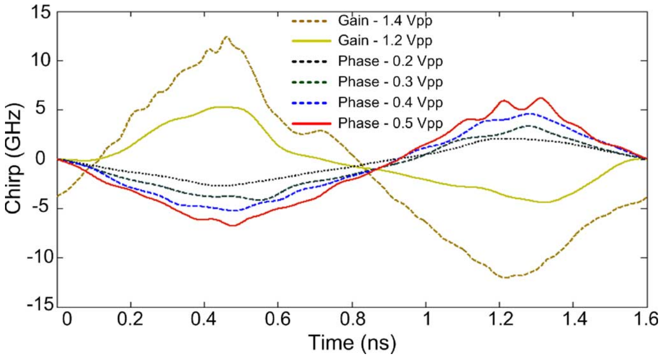

Fig. 3. Chirp profiles of both the phase and gain section for a number of drive voltages.

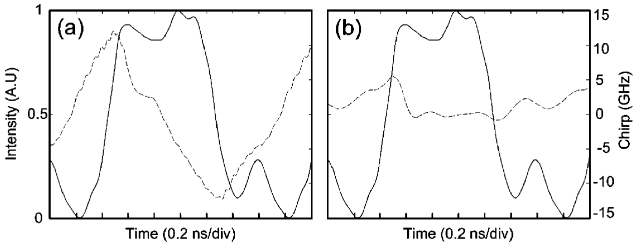

Fig. 4. Intensity (solid line) and chirp (dotted line) profile (a) with only gain modulation and (b) with both gain and phase modulation.

of 10 mA, we can achieve a maximum frequency shift without incurring a mode hop.

In order to obtain a qualitative analysis of the proposed compensation scheme, the direct modulation induced frequency chirp was analyzed for both the gain and phase sections individually. This was achieved, as in Fig. 1(b), by analyzing the directly modulated TL output with the aid of a commercially available complex optical spectrum analyzer (OSA) (AP2443B) that had a spectral resolution of 20 MHz. Using this device, both the intensity and phase information of the signal could be retrieved. However, a requirement for phase measurements on the complex OSA, limited us to using a four bit patterned sequence of 1100 to directly modulate the TL at a clock rate of 2.5 GHz. Additionally, the bandwidth of the laser gain section (~1.5 GHz) also restricted the upper limit of the data rate.

The repeated pattern of 1100 was amplified and split into two paths. One arm consisting of a variable attenuator and a bias tee was connected to the phase section, while the second arm consisting of only a bias tee was connected to the gain section. The frequency chirp due to direct modulation was recorded using the complex OSA when only the phase section was connected, for a number of modulation voltages. This characterization was repeated for the gain section of the device, therefore providing an accurate representation of the chirp magnitude and sign for both sections individually. This characterization enabled the selection of optimal operating conditions for the phase section to achieve complete frequency chirp compensation. For the frequency chirp compensation scheme, both sections of the device are modulated simultaneously. Therefore, the electrical path lengths to both sections of the laser were matched in order to ensure an optimum bit-by-bit compensation. The output of the laser was again monitored with the complex OSA.

III. RESULTS AND DISCUSSION

The initial chirp profiles characterized at a number of peak-to-peak modulation drive conditions are shown in Fig. 3. Here the gain and phase sections were modulated individually with a pattern (1100) clocked at 2.5 GHz. The chirp profile spanning from 0.4 to 1.2 ns corresponds to a time when the two 1-bit symbols are present. By comparing the respective chirp characteristics, an optimum drive voltage for both sections was devised. The compensation scheme is enabled by the fact that the frequency chirps exhibited by both sections have opposing signs when directly modulated by an identical bit sequence. As expected, current injection into the passive phase section leads to a negative change in the refractive index and therefore results in a blue shift in frequency due to the free carrier plasma effect [5]. Conversely, carrier injection into the gain section causes a transient chirp on the leading and trailing edges of the modulated optical signal, with some intermittent adiabatic chirp [6]. However, it is important to note that if the modulation rate is high enough, the transient frequency chirp will dominate, resulting in a frequency chirp opposite to that imposed by the phase section. This is the principle by which this chirp compensation scheme operates.

Fig. 4 illustrates the intensity and chirp profiles of the directly modulated SG DBR laser, measured using the complex OSA, for the two scenarios. First, modulation was applied to the gain section of the device with the phase section dc biased at 15 mA [Fig. 4(a)]. The figure shows two 1-bits corresponding to 800 ps with a large frequency chirp of 25 GHz. Fig. 4(b) displays the intensity and chirp profile of the laser output when both sections are modulated. There is a dramatic improvement in the

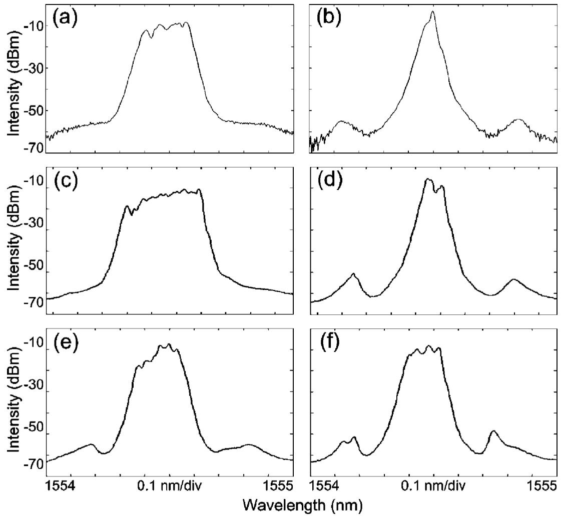

Fig. 5. Spectra of 4-, 16-, and 32-bit patterns for gain modulation (a), (c), (e) and simultaneous gain and phase modulation (b), (d), (f), respectively.

level of frequency chirp and this reduction is due to the gain and phase sections exhibiting opposite chirp profiles when directly modulated. The minor fluctuations are a result of the nonideal matching of the chirp profiles.

The corresponding spectra of the directly modulated SG DBR laser under the two different scenarios are illustrated in Fig. 5(a) and (b). The broadened spectrum in Fig. 5(a) clearly shows the direct modulation induced frequency offset. Fig. 5(b) displays the compensated spectrum, which was achieved with simultaneous modulation of both gain and phase sections. The narrowing in the spectrum mirrors the reduction in chirp illustrated in Fig. 4(b) and reaffirms the frequency chirp compensation technique. The compressed spectrum will dramatically reduce the effect of cross-channel interference and will also ensure that the effects of fiber dispersion are minimized.

To understand the transition from the transient to the adiabatic regime a 16-bit pattern (containing four consecutive “1-bits”) and a 32-bit pattern (containing ten consecutive “1-bits”) were applied to both the laser gain and phase sections at the same clock rate. The corresponding spectra were analyzed using a conventional OSA (due to the pattern limitation of the complex OSA). Fig. 5(c) and (d) illustrates the spectra corresponding to the 16-bit pattern containing four consecutive 1 symbols. Here again there is a large degree of spectral broadening when only the gain section is modulated. However, through simultaneous modulation of the phase section there is still a large reduction in spectral width. The compensation is not as significant as that achieved using the 4-bit pattern as a longer sequence of 1-bits results in an increased adiabatic chirp. Conversely, when the 32-bit pattern was applied to the laser almost, no compensation was realized through simultaneous modulation of the phase section [Fig. 5(e) and (f)].

This poor performance of the frequency chirp compensation scheme is a result of the bit sequence containing a large succession of 1-bits. Hence, the adiabatic chirp is more prominent and modulation of the phase section only results in a minor compensation of the frequency chirp. One way to overcome this problem would be to increase the data rates applied to the laser to 10 Gb/s as in [7], which would generate a bit duration of 100 ps. Such a small duration would result in a transient chirp dominated regime, thus providing the ideal profile for compensation through modulation of the lasers phase section.

IV. CONCLUSION

We have characterized the frequency offset associated with a directly modulated SG DBR TL. A frequency chirp of 25 GHz was recorded through modulation of the laser gain section, which consequently caused severe broadening of the spectrum. A compensation scheme was proposed to reduce this frequency chirp and therefore narrow the laser spectrum. This was achieved by simultaneously modulating both the gain and phase sections of the device. The opposing chirp profiles experienced after modulation, characterized using a complex spectrum analyzer, reduced the exhibited frequency chirp to approximately zero, causing a dramatic reduction in the width of the laser spectrum. This compensation scheme vastly increases the viability of a directly modulated SG DBR TL for implementation in short reach applications.

It is important to note that for complete frequency chirp compensation the chirp profile exhibited by the gain section must be in the transient dominated regime. This may be achieved by increasing the modulation rate applied to this section. Therefore, new device structures are currently being investigated with optimized radio-frequency connections to both laser sections, which will lead to higher modulation rates.

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