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# Frequency Drift Reduction in a Four-Laser Array for TWDM PON Applications

Mathilde Gay, Laurent Bramerie, Christophe Peucheret, John O'Carroll, Richard Phelan, Michael Gleeson, Diarmuid Byrne, Brian Kelly, Marta Nawrocka, and Fabienne Saliou

**Abstract**— Burst-mode operation of laser arrays suitable for next generation passive optical networks (NG-PON2) employing time and wavelength division multiplexing (TWDM) is impaired by frequency drifts under variable burst duration. In this work, the issue of frequency drifts under burst and wavelength switching operation is addressed in a four-laser array integrated with a multimode interference coupler using a regrowth-free technology. Frequency drifts are shown to be significantly reduced in a TWDM-PON configuration thanks to the introduction of a thermal management technique based on the use of inactive lasers in the array. Thanks to this method, up to 22% drift reduction is obtained under burst and wavelength switching operation.

**Index Terms**—Laser array, TWDM passive optical network, frequency drift.

## I. INTRODUCTION

TIME and wavelength division multiplexing (TWDM) for next generation passive optical networks (NG-PON2) will require wavelength-tunable transmitters supporting burst mode operation at the customer side. Configurations with four pairs of wavelengths have been shown to meet the requirements of NG-PON2 [1]. In this configuration, the transmitter at each optical network unit (ONU) must be tunable to any of the four upstream wavelengths. In this context, laser arrays become attractive solutions combining fast wavelength tuning and cost constraints compatibility.

The frequency drift of lasers under burst-mode operation is a concerning issue, as the laser emission frequency must remain within the multiplexer passband during laser switch-on regardless of the duration of the burst. In a 100-GHz grid scenario, a tolerance of  $\pm 20$  GHz for the laser emission frequency is specified in the standards [2]. Different solutions have been proposed so far for frequency drift reduction in single laser structures. These include integration of a heating element along the laser for counter-heating operation [3, 4], control of the burst ramp [5], sub-threshold heating [6] or engineering of the signal density of the burst preamble [7].

In this work, we present a new transmitter architecture based on an array of four single-mode lasers integrated with a multimode interference (MMI) coupler in a regrowth-free technology that

is compatible with TWDM-PON cost requirements. This transmitter is to be placed at the ONU side to allow fast tunability, thus never emitting simultaneously on two wavelengths. Frequency drift under burst mode operation is addressed by taking advantage of the presence of the inactive lasers in the array that are biased below threshold in order to limit the active laser frequency drift when it is switched on to transmit a data burst. A maximum drift excursion below 20 GHz was measured for the lasers of the array thanks to the introduction of our proposed thermal management leading to 17% drift reduction. The drift under burst and wavelength switching operation is furthermore assessed for the first time to our knowledge with a measured drift reduction of 22%.

## II. TRANSMITTER DESCRIPTION

Each laser of the array structure (represented in Fig. 1(a)) is based on the discrete-mode laser technology [8] in which ridge waveguide Fabry-Perot lasers are fabricated using a regrowth-free AlInGaAs/InP technology. Single-mode operation is achieved by introducing index perturbations distributed along the waveguide laser cavity leading to more than 40-dB side-mode suppression. The laser structures are combined to a common output waveguide thanks to a  $4 \times 1$  multi-mode interference (MMI) coupler. At this stage of the fabrication process, the lasers are biased with direct current only and no data transmission is permitted.

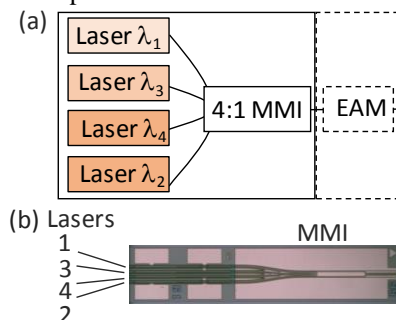


Fig. 1. (a) Schematic representation of the 4-laser array structure. Only the part of the device within the solid box was implemented in this work. (b) Microscope picture of the device.

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Since for the ONU transmitter in a TWDM PON context only one single wavelength is used at any given time, external modulation can be performed thanks to a single common external modulator. An electro-absorption modulator (represented within a dashed box in Fig. 1(a)) will be included in the next generation of devices. It is however important to notice that external data modulation performed in this way will not modify the frequency drift. This early stage prototype is hence fully suitable for the proposed burst operation study. The 4×1 MMI structure, made from the same layer stack as the lasers, needs to be biased for transparent operation. A microscope picture of the device is shown on Fig. 1(b).

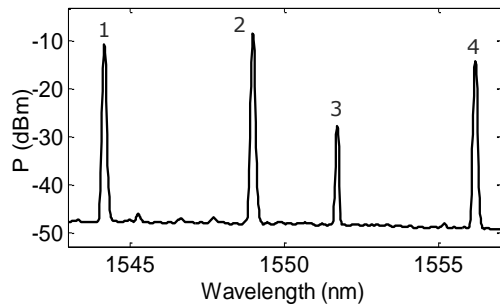


Fig. 2. Spectrum at the output of the laser array when all lasers are biased at 80 mA.

The spectrum measured at the output of the MMI when all four lasers are biased with a current of 80 mA is represented in Fig. 2. Four signals with wavelengths of 1544.2 nm, 1549 nm, 1551.7 nm and 1556.2 nm are emitted with respective output powers of -1.25 dBm, 0.25 dBm, -17 dBm and -5 dBm. The respective lasing thresholds are 30 mA, 35 mA, 30 mA and 35 mA. The origin of the lower power of channel 3 at 1551.7 nm is some sub-optimum implementation of the MMI coupler. The channel spacing was not a key parameter in this early stage prototype for frequency drift study and the chip was not designed with 100 GHz channel spacing. The laser array was placed in a butterfly package including a Peltier element to maintain the temperature at 25 °C. Finally, a four-laser driver board was developed, leading to a 10 to 90% switch-on rise time of 20 ns when the bias is changed from 0 to 70-mA.

### III. BURST MODE OPERATION AND FREQUENCY DRIFT MANAGEMENT

We study the frequency drift of the transmitter when each laser is individually switched on between 25 mA and 70 mA bias, for a standardized burst period of 125  $\mu$ s and for a burst duration varying between 1% and 99% of the period. The frequency drift is measured using a method developed for time-resolved frequency chirp measurement based on the use of a Mach-Zehnder interferometer (MZI) as an optical frequency discriminator [9]. In this experiment (Fig. 3 (a)), the transfer function of an MZI with 200-GHz free spectral range is emulated using a programmable optical filter, thus providing enhanced stability compared to traditional fiber-based MZI implementations.

The frequency drift measurement method relies on the measurement of the intensity of the filtered signal for three different relative detunings of the emulated MZI transfer function with respect to the laser frequency. The laser

frequency drift is converted to power fluctuations by the MZI transfer function, which will add to the laser emitted power variations in different ways, depending on the biasing of the MZI. Thanks to measurements of the power of the filtered signals at the three detunings corresponding to points A, B and C in Fig. 3(c), the time varying phase can be separated from the time-varying intensity. The frequency drift can then be calculated from the retrieved time-varying phase. In our implementation, the signal is detected by a 15-GHz photodiode (PD) and acquired in a real time oscilloscope (3 GHz bandwidth, 5 GS/s).

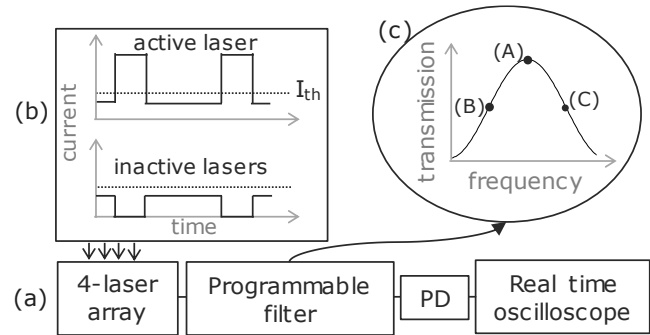


Fig. 3. (a) Experimental setup for the measurement of the frequency drift. (b) Laser driver chronogram. (c) Emulated filter transfer function and tuning positions for frequency drift measurement.

In a TWDM context, where thermal effects are under consideration, the laser frequency reference should be defined during the first emitted burst, which happens during the ONU initialization phase (ranging). During this phase, a short burst (preamble followed by a few bytes) is transmitted and the carrier frequency is tuned to the center of the passband of the multiplexer channel. In this study, the laser nominal center frequency is thus determined for a burst duration of 1% of the cycle (1.25  $\mu$ s). Fig. 4(a) presents the measured frequency drift with respect to the nominal frequency of laser 1 when the burst duration varies. The longer the burst, the stronger the heating compared to the reference case of 1% burst duration and the larger the frequency drift, with a maximum drift of -22.6 GHz

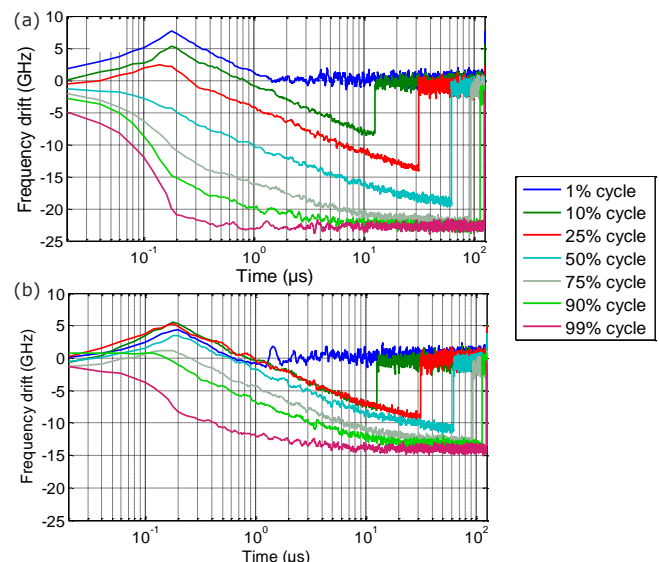


Fig. 4. Frequency drift versus burst duration of laser 1, (a) without and (b) with the proposed drift management method.

measured for a 123.75- $\mu$ s burst duration (99%).

The inactive lasers of the transmitter were then used as heaters for laser 1. For this purpose, biasing signals complementary to that injected to laser 1 were applied to lasers 2, 3 and 4 with current values just below their threshold currents  $I_{th}$  (between 0 and 25 mA), so that the emitted power ratio between emitting laser (1 in this case) and heating lasers (2, 3 and 4 in this case) is maintained above 30 dB (Fig. 3(b)). Fig. 4(b) depicts the resulting frequency drifts, which remain below 14 GHz. The compensation limits the temperature gradient regardless of the burst duration.

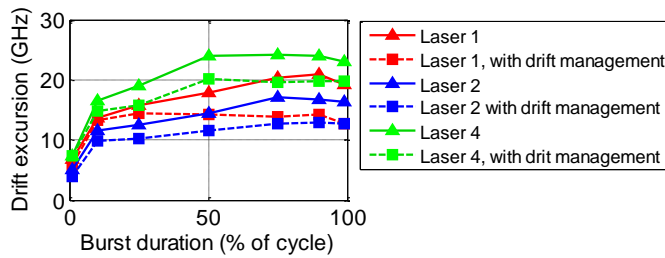


Fig. 5. Drift excursion versus burst duration of lasers 1, 2 and 4 with and without the proposed drift management.

Identical measurements were performed on lasers 2 and 4. The frequency drift of laser 3 was not measured due to its lower output power. The values of maximum drift excursions (drift variation during the burst), with or without drift management, measured as a function of burst duration are summarized in Fig. 5. Laser 4 presents the largest drift, which reaches -24.2 GHz for long bursts. Using the proposed management, the drift is reduced below -20 GHz, making the drift excursion compliant with standard recommendations.

#### IV. SWITCHING BETWEEN TWO WAVELENGTHS

The frequency drift behavior when the transmitter is switched between laser 1 to laser 4 is now investigated. The command signals switch the bias currents of laser 1 and laser 4 between 25 mA and 70 mA with a burst duration of 62.5  $\mu$ s and a burst cycle of 125  $\mu$ s, as illustrated in Fig. 6(a). The frequency drift under this switching operation is represented in Fig. 6(b). The frequency drift of laser 1 is then measured as a function of burst duration when laser 4 burst duration is fixed. Three different cases of laser 4 burst of 1%, 50% and 99% of the cycle duration are considered (Fig. 6(c)). A maximum drift excursion of -27.3 GHz was measured when the burst length is 99% of the cycle duration for both lasers.

Drift reduction by adjusting bias currents of lasers 2 and 3 is now applied. The chronogram of lasers 2 and 3 bias currents is obtained by operating a NOR gate on laser 1 and 4 currents (Fig. 6(a)) with a current excursion between 0 and 25 mA. Using this drift management technique, a 22% drift excursion reduction is obtained, leading to a maximum of -21.2 GHz when the bursts applied to lasers 1 and 4 last 99% of the cycle duration. The study has been performed on laser presenting the largest frequency drift and which is located on the side of the array. A specific design minimizing the distance between lasers could probably enhance the heating effect of inactive lasers and possibly limit even more the frequency drift. Moreover, the

possibility to integrate a semiconductor optical amplifier at the output of the laser was demonstrated in [10]. This would increase the lasers output powers thus allowing to work at lower bias currents and consequently lead to smaller frequency drifts. Let us finally notice that the present study has been performed at 25°C; however, this kind of laser has been shown to operate in a large temperature range from 0 to 85°C. At temperatures where the lasing threshold evolves, the bias current of active and inactive lasers should be adjusted, both to maintain a constant output power of the active laser and to place the inactive lasers just below their thresholds.

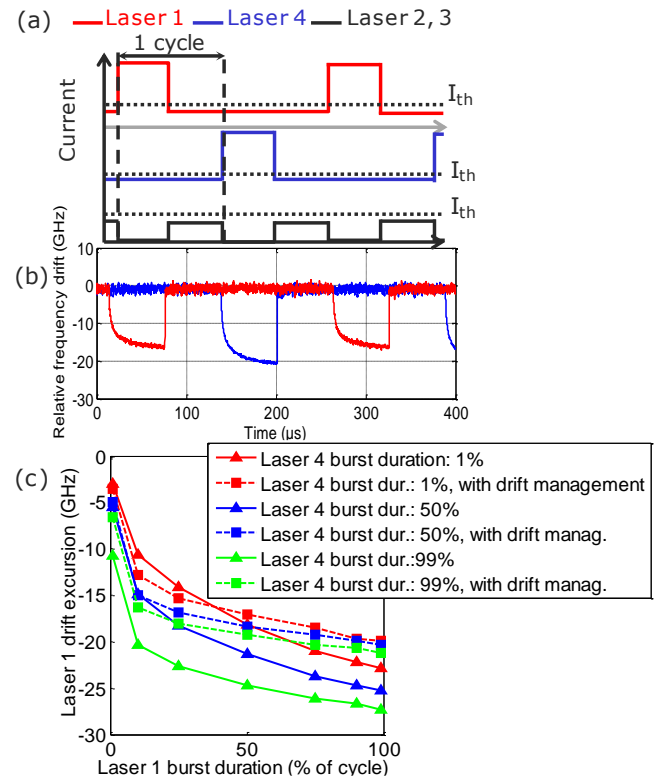


Fig. 6. (a) Laser driving currents chronograms in the case of wavelength switching. (b) Frequency drift excursions of lasers 1 and 4 with respect to their nominal center frequencies. (c) Frequency drift excursion, with and without compensation, of laser 1 as a function of the burst duration applied to this laser for different burst durations applied to laser 4.

#### V. CONCLUSION

The frequency drift of a four-laser array under burst and wavelength switching operation is assessed for TWDM-PON applications. The four-single-mode laser array integrated with an MMI coupler is based on a regrowth-free technology that is compatible with TWDM-PON cost requirements. The use of a laser array offers a double advantage: firstly it limits the required thermal variation for wavelength adjustment (divided by 4 in the case of a 4-laser array); secondly, we take advantage of the presence of inactive lasers in the array to limit the frequency drift of the active laser during burst emission. It results in a maximum frequency drift excursion below 20 GHz, which is compliant with TWDM-PON standards. The implemented drift management under burst and wavelength switching operation allows a reduction of up to 22% of the frequency drift for a laser located at the side of the array.

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