Phase modulation in a Compact 8-channel Loop-back AWG based Integrated Comb Processor

Student paper

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For the realization of integrated microcomb-based systems, integrated photonic interposers that connect, operate, and process the optical signals that transit between the many photonic components are needed. In this work, the phase modulation characteristics of an 8-channel integrated comb source spectral processor based on an arrayed-waveguide grating are presented. The phase response of the device is characterized using optical frequency domain interferometry.

***Keywords*:** Microresonator frequency comb, comb processor, silicon nitride, phase modulation, optical frequency domain interferometry

INTRODUCTION

Optical microcombs, generated in micro and nanophotonic resonators, have substantially broadened the reach of applications of optical frequency combs [1]. A variety of applications have been shown to benefit from the use of microcombs [2],[3]. Integrated microcomb-based systems need optical interposer that connect, operate, and process the optical signals [4]. Soliton microcombs can be used in radio frequency (RF) arbitrary waveform generation, which has an ultrahigh analog bandwidth as major advantage. Such a system can be implemented as a photonic integrated circuit [5], where an integrated optical waveshaper, or spectral processor, is used to modulate the amplitude and phase of a soliton microcomb.

In this work, an optical interposer as a spectral processor is presented: an 8-channel loop-back AWG based integrated comb processor (ICP), designed to modulate both amplitude and phase of separated comb lines. The device was introduced in [6], where its amplitude modulation was shown. Here, we present a characterization of the phase modulation of the device using optical frequency domain interferometry (OFDI). Different strategies to characterize the phase response of the ICP may be adopted: firstly, an interferometer with the device under test (DUT) and a delay line can be analyzed using a broadband source and an optical spectral analyzer (OSA). Here, the OSA resolution is a limiting factor and the path length difference (PLD) should be chosen accordingly. On chip a balanced Mach-Zehnder interferometer (MZI) could be created. The balanced MZI can then be used to characterize the ICP phase response by analyzing the amplitude response of this MZI. OFDI, a swept-wavelength technique, allows for the characterization of photonic devices with very high resolution, which makes it suitable for integrated devices. The optical amplitude and phase response of the DUT can be assessed in both the time and the spectral domains [8]. Therefore, as demonstrated in [7] and [8], the technique can be adapted to retrieve the phase characteristics of the ICP.

DESIGN AND MEASUREMENTS

The ICP consists of a 9-channel AWG in loop-back configuration, in 8 the arms of the loop-back symmetrical MZIs are placed, which leaves the 9th channel for the in- and output of the signal. The floorplan of the ICP is shown in Fig. 1 (b). The first sidelobe of the AWG's channels are suppressed 22 dB. Each channel can be modulated in both amplitude and phase employing thermal phase shifters on both MZI arms. The MZIs, tested separately, show a 37 dB extinction ratio when a 37 mA current is applied to one of the heaters, this results in a spectral processor with an amplitude modulation reaching a suppression ratio of up to 22 dB. The chip is characterized by vertically coupling light using grating couplers. The design and amplitude modulation has been demonstrated in [6]. The graph in Fig. 1 (a) shows the transmission of the spectral processor, the peak around 1553 nm is the input channel, which is not controllable in the loop-back. Left to this peak there are 8 channels, controllable in amplitude and phase. The response of the AWG isn't flat and the loop-back configuration doubles that. The response is also slanted due to using the side input of the AWG. The device has been fabricated in a Si_3N_4 platform with SiO_2 substrate and SiO_2 cladding at Myfab Chalmers. The substrate is thermally oxidized silicon. The thermal oxide thickness is 3 µm with a refractive index of 1.4431 at 1550nm, the LPCVD Si_3N_4 is 200nm thick and has a refractive index of 1.99. The top cladding is fabricated as first a layer of 1 µm of LPCVD SiO_2 with a refractive index of 1.4439. On top is a 2 µm of

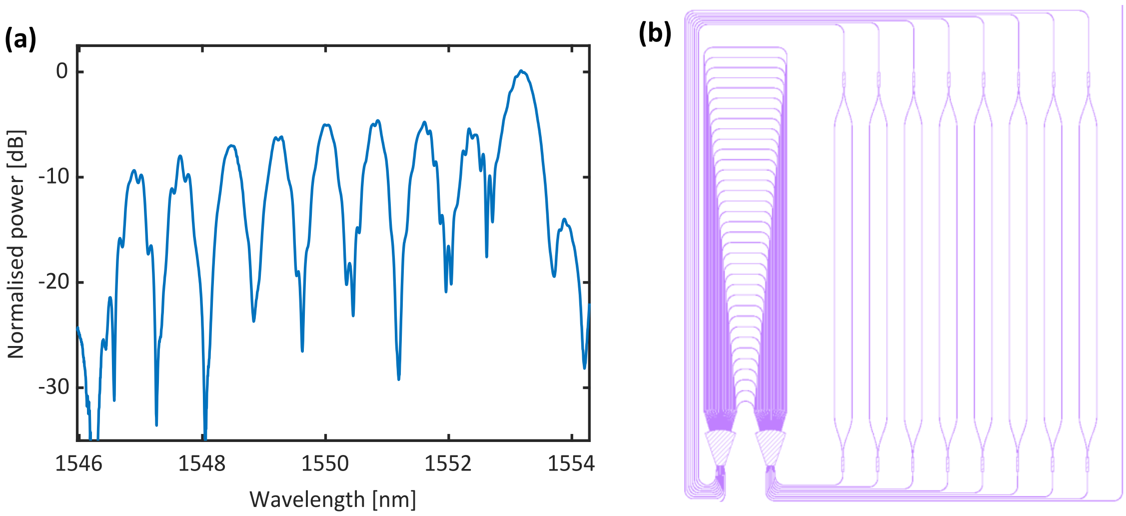

Fig. 1. (a) The transmission response of the spectral processor, the response of the grating coupler has been substracted to show the response of only the processor. From left to right the 8 controllable channels are visible, the highest, 9th peak is the AWG channel used for guiding the light in and out of the loop-back onfiguration. (b) The floorplan of the spectral processor. The total device measures 2.4 mm by 2.7 mm.

PECVD SiO_2 with refractive index 1.4595. The structures are defined via electron-beam lithography using a 500 x 500 µm2 square writing field and are deep etched [6]. The fabrication of the Si_3N_4 structures follows the procedure described in [9].

For modulating the phase in one of the ICP channels, an equal current is applied to the heaters on both arms of the MZIs that are implemented in the loop-back layout. This will induce an equal phase shift in both arms so that after combining the two signals the amplitude remains unchanged. The heaters have a resistivity of 215 Ω each, the amplitude response of the MZI shows the phase tuners reach a π phase shift when a 37 mA current is applied, resulting in a 294 mW power consumption per for a π phase shift.

Although the measured crosstalk in amplitude for the MZIs is negligible, any temperature difference can cause a phase error in the loop-back channels or AWG. For this reason, the phase modulation tests are set up in a way that the same total power is applied to the chip. While in succeeding tests the applied current in one channel is rising till 37 mA, the other channels applied current is lowered in value. In these conditions, two different experiments, A and B, are carried out, by doing increasing / decreasing phase modulation on channels 1 and 4 in case A, and 4 and 8, in B, respectively. Each experiment is divided into 4 tuning steps or iterations, where measurements are performed, sweeping values in the {0,37} mA range. The chip is wirebonded on a PCB, which is placed on a heatsink that is temperature controlled by a Peltier.

In the OFDI setup, the DUT is placed in an optical fiber MZI with a given PLD. A tunable laser wavelength sweep of 100 nm span around $\lambda = 1550$ nm is performed, giving an interference pattern that is photodetected and transformed to digital data. The resulting DUT interferogram is properly linearized in frequency by using a secondary MZI with higher PLD, a common strategy in OFDI.

RESULTS

In Fig. 2 (a), it is shown the obtained interferogram for the first iteration of experiment A. The interferogram is pass filtered to a single central band (shown in blue), where the ICP channels are found. Then, inverse fast Fourier transform (FFT) is applied to obtain the time domain response. The resulting trace in amplitude is shown below, zoomed to the region of interest. The broadened peak at the left corresponds to the remaining direct AWG contribution, while the ICP channels contributions, each of them convolved with the AWG response correspondingly, are superimposed in the second (highlighted in orange) group at the right, where their center positions are indicated with dashed lines. The next processing step consists of applying a window filter to isolate the ICP contributions, and then conduct a trace crop to re-center the trace, individually, to the positions of the channel centers. Under these conditions, ideally, the corresponding spectral phase response plateaus along the corresponding frequency region of the channel. Hence, we proceed accordingly and, once the re-centered traces are available for each of the 8 channels, FFT algorithm is systematically applied to reconstruct the corresponding spectra, obtaining amplitude and phase traces as shown in Fig. 2 (a) for channel 4. As expected, the phase curve, although somewhat affected by adjacent channels, is fairly steady in the region of the channel band. The spectral

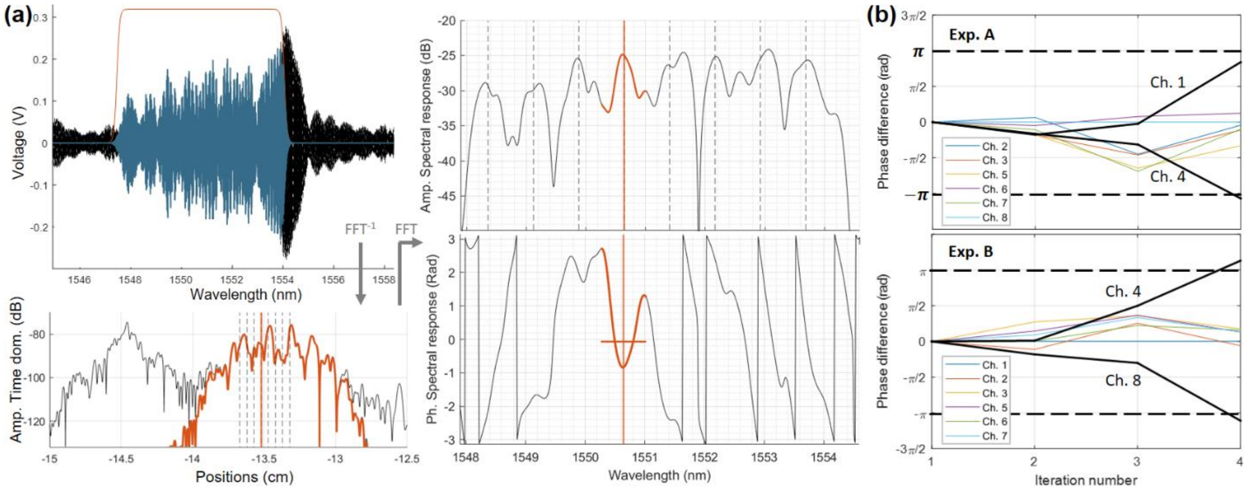

Fig. 2. (a) OFDI processing including DUT interferogram, time domain response, and amplitud and phase spectral response reconstructed from individual channel re-centering process. (b) Phase differences for the two performed experiments.

amplitude is also shown above, where just the 8 ICP channels are visible, having disappeared the direct AWG contribution after its complete removal in the time domain picture. Phase is then assessed in the region of the channel for each case. While these values lack of physical meaning separately, and vary from one measurement take to another in OFDI [8], it does a relative evaluation of them and, accordingly, we calculate the phase differences between each channel and the outer channel, i.e. channel 8 and 1 for experiments A and B, respectively. Since iteration 1 corresponds to the origin of heater tuning, we set this phase difference to zero, as reference, and compute the evolution of this quantity along the electrical tuning iterations. The results for both experiments are shown in Fig. 2 (b) where, as expected, the corresponding traces for the tuned channels (in bold black curves) evolve from 0 to, roughly but clearly, $\pm\pi$, while the unperturbed channels (shown in different colors) maintain a steadier evolution, not exempt from a certain degree of variation.

DISCUSSION

The comb processor presented in [6] has been characterized for its phase modulation capabilities using the OFDI technique as described in [8]. The experimental results show the phase modulation evolution along the tuning in both experiments, and demonstrates the correct functioning of the ICP device. However, some thermal crosstalk between the arms of the loop-back structure, together with channel optical crosstalk originated in the AWG, leads to the slight variation of phase observed for the unperturbed channels. Therefore, the device performance may be improved in future designs by adopting thermal crosstalk reduction strategies, e.g. air trenches to thermally isolate tuner regions, reducing the length of the arms, and also by refinements in the design of the AWG. The ICP could be used as an optical interposer and opens a viable path for on chip RF arbitrary waveform generation. A common Si_3N_4 thickness for broadband comb sources is 790nm, for comb generation and modulation on the same chip, this difference in thickness can be overcome with use of photonic interposers [4].

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