Opto-electronic wavelength tracker in Silicon-on-Insulator

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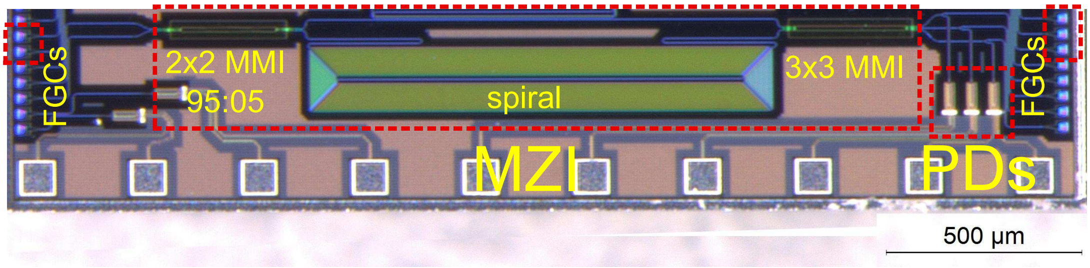
Abstract

In this paper the experimental demonstration of a Silicon-on-Insulator opto-electronic wavelength tracker is reported. The device consist of a 2x3 Mach-Zehnder interferometer with 10 pm resolution and photo-detectors integrated on the same chip. The design provides three complementary, with 120° phase relations, responses. Optical input/output responses exhibit rejection as good as 15 dB, thanks to asymmetric design for the input coupler. Synchronized recorded DC electronic responses for the three photo-detector outputs reproduce the MZI de-phased characteristic, allowing for monitoring wavelength changes with sign.

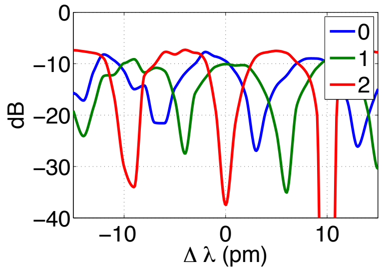
Wavelength tracking (WVLT) devices are of application in the fields of optical communications, instrumentation and sensing. These devices allow for monitoring changes in the wavelength of an optical signal caused by different phenomena, such as strain, temperature and humidity, among other. There have been a significant number of WVLT implementations with discrete components, [1] [2] are good examples, and most of the commercial implementations use such assemblies. A versatile well known layout for a WVLT makes use of an imbalanced Mach-Zehnder interferometer (MZI), where each arm of the interferometer has a different length. The imbalanced MZI has a periodic power spectral response that follows a cosine square expression (see theory in [3]). The spectral period, commonly named free spectral range (FSR) is inversely proportional to the length difference between the two arms of the MZI. To be precise, FSR = $\lambda^2/(n_g \Delta L)$., where λ is the operating wavelength, n_g is the group index for, and ΔL is the length difference between, the arm waveguides. Furthermore the MZI can be integrated on a photonic chip, with photo-detectors. MZI based WVLTs can make use either of 2 or 3 complementary outputs. The former usually provides outputs with a phase relation of 180°, whereas the latter are commonly designed for the optical outputs to have phase relations of $\{-120°, 0°, 120°\}$. While both configuration allow for monitoring the change in wavelength through the relative power change between the output signals, the 3 output port configuration enables to determine the sign of change as well. Integrated WVLT MZIs based on Multimode Interference (MMI) couplers have been reported in different technologies, and a remarkable layout for Silicon-on-Insulator (SOI) technology is proposed in [4], where Harmsma and co-workers made a 2x3 MZI SOI device with 0.55 nm FSR. In this paper we report on the experimental demonstration of a WVLT photonic chip based on a 2x3 MZI with integrated photo-detectors (PDs) in SOI technology. The device has a FSR of 10 pm and a footprint of 2.5x0.5 mm^2.

The devices were designed for, and fabricated in, a multi-project wafer technology by the OpSIS platform at IME Singapore [5]. The process allows for passive and opto-electronic active areas, as p-n junction modulators and photo-detectors. An optical microscope picture of the device is given in Fig. 1-(a). The device is composed of a 2x2 MMI input coupler and a 3x3 MMI output coupler. The couplers are designed in a shallowly etched areas, and designed following the rules in [6]. The output coupler has a 33:33:33 coupling ratio. The inputs/outputs to the couplers are tapered and all the dimensions were numerically optimized using a Beam Propagation Method (BPM) commercial software [7]. The two outputs of the first coupler are connected to the top and bottom inputs of the output coupler with strip waveguides of 450 nm width. One of the connections is a straight waveguide, whereas the other is a spiral waveguide of 56 mm, which for a group index of 4.25 corresponds to a FSR of 10 pm. The input coupler is designed to have a 95:05 coupling ratio, so as to compensate the large loss imbalance between the short and long arm, in order to attain the maximum rejection in the MZI spectral response. The output coupler outputs are connected to Y-branches. One output of each Y-branch is connected to a PD, and the other is used as test optical output. Focusing grating couplers (FGCs) are used as light input/output structures.

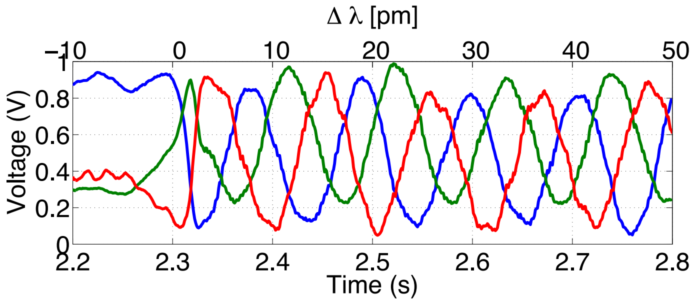
The chip was held in a vacuum chuck, whose temperature was kept to 25° C using a temperature controller (TEC). Fibers, at angle of 74° from the chip normal, were aligned to the input/output FGCs using motorized translation stages. Firstly, the spectral response of the MZI was measured. A tunable laser source synced with an an Optical Spectrum Analyzer (OSA) was used to acquire traces with 1 pm resolution. The traces, normalized with respect of a straight waveguide, are shown in Fig. 1-(b) for a wavelength interval around 1549.83 nm for the three outputs labeled 0, 1 and 2 in the figure. The spectral displacement between the traces correspond



(a) Optical microscope image of the fabricated devices



(b) Optical I/O MZI response



(c) Opto-electronic synchronized response

Fig. 1. Optical microscope image of the fabricated device (a) MZI I/O spectral traces with respect of 1549.83 nm (b) and synchronized electronic traces (c) for the three WVLT channels.

approximately to one third of the FSR, in agreement with the designed phase relations for the output MMI coupler. Despite the chip temperature was controlled, we observed spectral drifts of ±1 pm in the measurements from a nominal position, in the scale of several tens of seconds, which we attributed to the limited resolution of the TEC. The rejection ratio attained in all the responses , defined as the difference between maximum and minimum value in a period, is at least around of 15 dB, thanks to the asymmetric input MMI coupler.

Secondly, the setup was conditioned to measure the opto-electronic response of the WVLT. Probes were used to contact the PD pads, Fig. 1-(a) lower right corner. Each probe was then loaded with a 10 kΩ resistor, and the PDs were biased at -2V. In absence of optical input we observed a dark current of 2 μA. The three resistors where then probed and connected to three channels of a data acquisition (DAQ) card, which allows for recording simultaneously the voltage corresponding to the current change in the three PDs. A tunable laser (TL) was then used as input, to be swept in steps of 1 pm. Furthermore, LabView^{TM} programs were deployed to control simultaneously the TL sweep and the DAQ recording, in order to obtain synchronized data at all the outputs. The results are shown in Fig. 1-(c). They correspond to smoothed data using a moving average of 10 points. The TL start and end wavelengths were set to 1550 nm and 1550.090 nm respectively, and the sweep was started iteratively. The traces in (c) are shown in a given time where, on the left hand side, the currents acquired have random value, since the TL is returning to the start wavelength. After this period of time (around 2.3 s in the figure) the sweep starts and the voltages recorded reproduce the sinusoidal variation of (b), with a one third period de-phased relation as well. Panel (c) top axis shows the sweep time translated into wavelength change from 1550 nm (negative values are arbitrarily labeled to represent the TL return time).

In conclusion, we have reported the experimental demonstration of a SOI opto-electronic wavelength tracker. The device is based in a 2x3 Mach-Zehnder interferometer, with 10 pm resolution, equipped with photo-detectors. The optical transfer function exhibits the phase relations of one third of the FSR, as expected from the design of the output MMI coupler. The optical rejection attained is at least as good as 15 dB. The opto-electronic transfer functions, recorded synchronously at the photo-detectors, reproduce the targeted tracking responses. Finally, we acknowledge funding from the Spanish CDTI NEOTEC, MINECO TEC2010-21337 & TEC2013-42332-P, FEDER UPV 10-3E-492 & 08-3E-008, FPI BES-2011-046100 and FPU AP2010-1595.

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