Integrated Microwave Photonic Receiver for Radar Applications

Student paper

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Two fully integrated and packaged photonic-based RF receivers based on silicon-on-insulator technology have been proposed and experimentally demonstrated. Technological solutions are implemented to enhance the power handling capacity of the PIC. The frequency agility makes these architectures suitable for radar applications.
Keywords: *microwave photonics, photonic integrated circuits, silicon-on-insulator*

INTRODUCTION

The large degree of flexibility and reconfigurability inherent in photonics-based radio frequency (RF) receivers strongly enhances the range of radar applications [1]. Recent advancements in the maturity of the photonic integrated circuits (PIC) technology have enabled the realization of fully integrated microwave photonic receivers [2]. In particular, frequency down-conversion is an important operation that allows the intermediate frequency (IF) signal to be processed after an analog to digital converter (DAC) stage. The operating band of a photonics-based downconverter can be strongly enhanced by making use of an optical frequency comb (OFC). Based on this approach, two down-converter architectures, labelled as "basic" and "advanced", have been designed and implemented in Silicon-On-Insulator (SOI) technology platform. The PIC is designed in order to support large levels of the input power, for mitigating the RF-to-IF convertion loss of the receivers. Both architectures are subsequently fully packaged and experimentally characterized by measuring the convertion loss, spurious-free dynamic range (SFDR) and the RF frequency response.

INTEGRATED PHOTONIC RECEIVER ARCHITECTURE AND DESIGN

The core concept of the proposed architectures relies on the modulation of an OFC by an incoming RF signal. In this way, one of the beatings at a subsequent photodiode will fall within the comb spacing, designed to be less than the typical bandwidth of the ADC. In this work, the optical comb is generated by an integrated Mode-Locked Laser (MLL), which is reported in [3]. In the "basic" architecture, shown in Fig. 1(a), the comb is modulated by the RF signal from the antenna by means of a dual-drive travelling wave electrode Mach-Zehnder modulator (DDMZM) realized using high-speed pn-junction phase shifters. To maximize the modulator extinction ratio (ER), limited by the deviation of the input multi-mode interference (MMI) splitter from the ideal 50/50 splitting ratio, a variable optical splitter (VOS), implemented as a balanced Mach-Zehnder Interferometer (MZI), is used at the modulator input. A large ER is indeed reflected in an improved dynamic range of the receiver. After modulation, several frequency replicas of the input RF signal for each comb line are created in the optical domain. The two out-of-phase modulator outputs are sent to a SiGe balanced photodetector (BPD), where the beating process between the input signal sidebands with the MLL lines generates a down-converted version of the RF input signal at an IF. Using balanced detection maximizes the PIC output RF power while providing large common noise rejection. One of the shortcomings of this basic architecture, while simple and effective, is that the signal bandwidth is limited to half the MLL frequency spacing which in our work is 3.5 GHz. Additionally, in this "basic" scheme an electrical band-pass

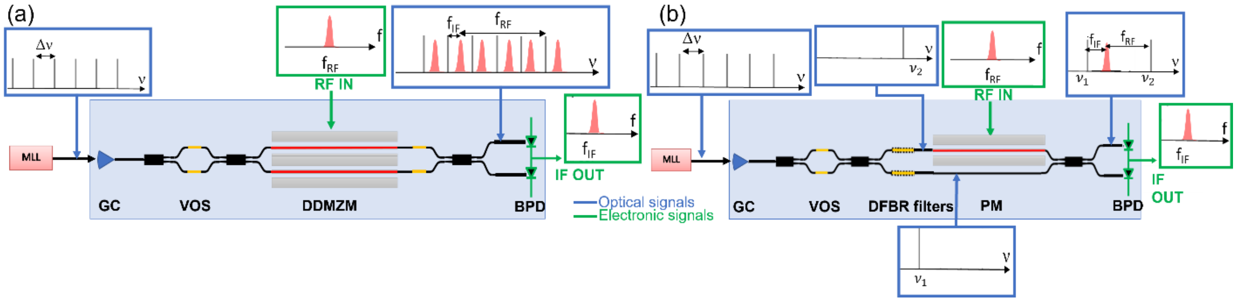

Fig. 1. Schematic layout of the "basic" (a) and "advanced" (b) architectures.

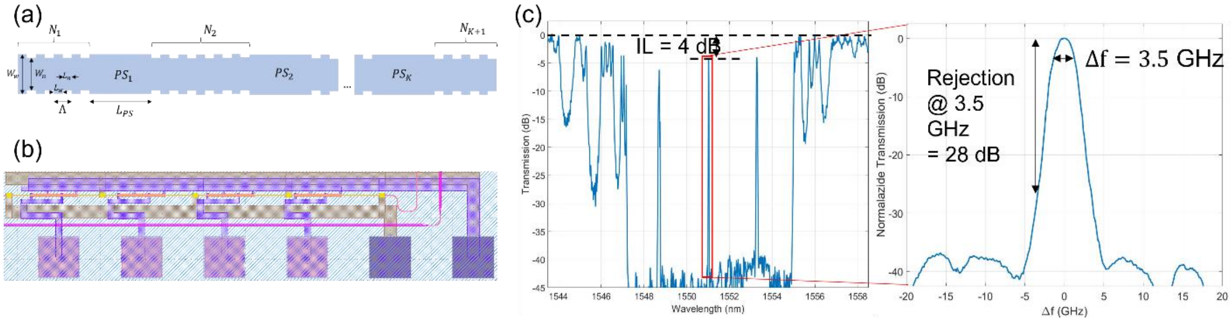

Fig. 2. DFBR optical filter structure (a), mask layout (b) and transfer function (c).

filter (BPF) is required after the BPD to select the desired IF frequency. The "advanced" architecture, illustrated in Fig. 1(b), proposes to overcome such limitations by introducing two optical BPFs which select and separate two different MLL modes. One of the selected tone is subsequently modulated by the RF signal through a phase modulator (PM). At the BPD, the beating between the unmodulated MLL line, that acts as the local oscillator (LO), and the modulated RF signal generates the IF frequency, removing the need of an electrical BPF. Selecting a line within an optical frequency comb with a 3.5 GHz frequency spacing needs filters with very stringent requirements. In this work, 4th-order distributed feedback resonator (DFBR) optical filters are implemented by placing four phase sections (PS) between five sidewall-corrugated waveguide Bragg grating mirrors, as shown in Fig. 2(a). Because of the extremely small fractional bandwidth, active tuning of the PSs through local micro-heaters is required to align the multiple resonances [4]. In addition, the two filters central frequencies need to be centered to an exact frequency difference, so that an additional active tuning mechanism is required, and a top metal heater has been deposited over the whole structures. This type of filters presents a very compact footprint and can achieve very large stopbands (tens of nm) with extremely narrow passband widths. In particular, the filter implemented in this realization has a 3.5 GHz 3-dB bandwidth and a 28 dB rejection measured at 3.5 GHz far from the center of the passband, as shown in Fig. 2(c). For both implementations, the MLL source is coupled to the PIC through a fiber grating coupler. Because increasing optical power is reflected into a decrease of the conversion loss, defined as the ratio between the RF input power and the IF output power, the PIC has been designed to support high optical intensities without triggering the two-photon absorption (TPA) by defining shallow-etch waveguides instead of strip waveguides The VOSs are also placed immediately after the input grating couplers in order to split the optical power before TPA loss accumulate.

EXPERIMENTAL CHARACTERIZATION

The down-converter PIC module of Fig. 3(a) has then been packaged in a lab-sytle evaluation board, including the gluing of the fiber array, the wire-bonding of the PIC on the PCB, the temperature stabilization by means of a Peltier cell, as shown in Fig. 3(b). The receiver demonstrator has then been implemented, interfacing the down-converter module with the external optical and RF components and instruments. The "basic" architecture has been characterized by performing a two-tone analysis for spurious free dynamic range (SFDR) evaluation, i.e. system linearity, as shown in Fig. 4(a). The RF-to-IF conversion loss turns out to be 48 dB with a SFDR of 79.4 dB*Hz$^{2/3}$. The conversion loss value is in line with state-of-the-art values of microwave photonic transceivers in SOI and is lower than the value obtained in the implementation reported in [5]. Moreover, the frequency response of the down-converter has been tested. In Fig. 4(b) the RF signal frequency ranges from ~ 0.75 GHz to ~ 20 GHz with a step which keeps the IF signal frequency fixed. The behavior of the output power mostly depends on frequency response of the wire-bondings which connect the DDMZM electrodes to the PCB: the power is decreased by 10 dB in the frequency range considered. The IF bandwidth is half the MLL repetition rate. In our characterization of the "advanced" architecture, the two optical filters have been centered in correspondence of two comb lines spaced by 10.5 GHz, as illustrated in Fig. 5(a). In this condition, the measured RF-to-IF conversion loss is 84 dB.

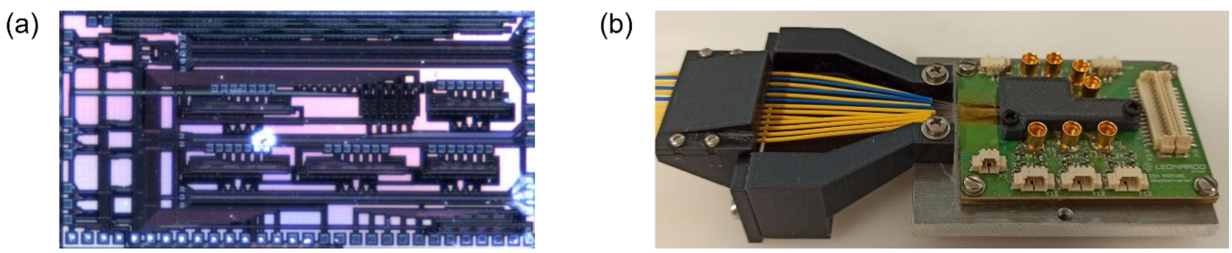

Fig. 3. Down-converter bare PIC picture (a) and packaged PIC (b).

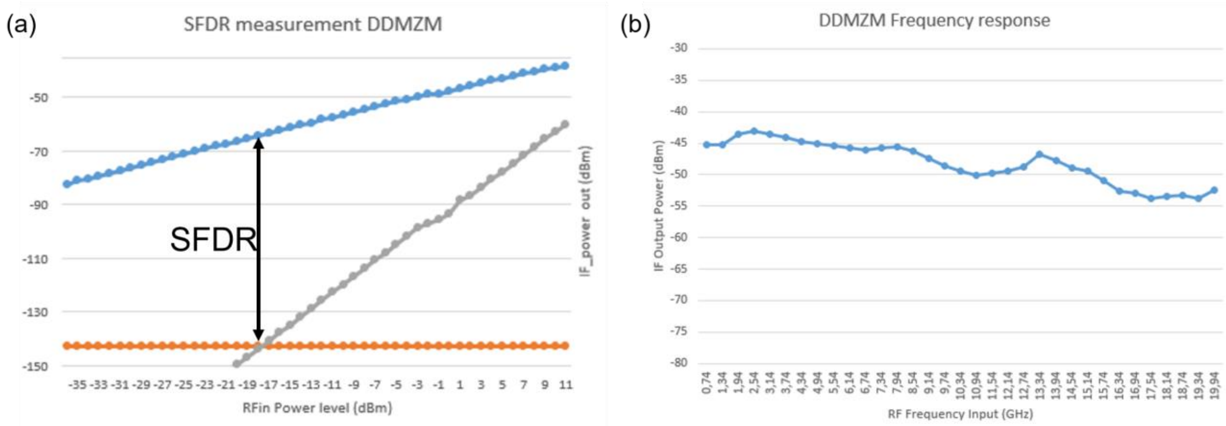

Fig. 4. "Basic" architecture two tone test (a) and RF response (b).

This high loss has been ascribed to the filters which present an insertion loss of ~5 dB and which filter out most of the power coming from the MLL. The RF response, showed in Fig. 5(b), has been observed measuring the conversion loss as the RF frequency varies from 8 to 13 GHz. As the RF signal frequency increases, the conversion loss decreases due to the frequency dependence of the PM. The frequency flexibility demonstrated by both architectures makes them suitable for radar applications. Furthermore, the "advanced" architecture is also suitable for applications where the input signal frequency is unknown, such as defense and multi-protocol communication.

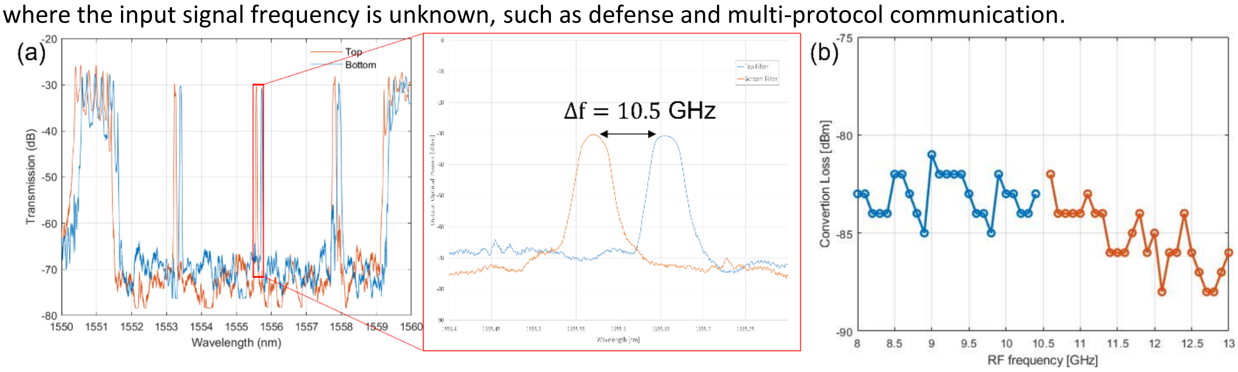

Fig. 5. Transfer function of the two filters (a), "advanced" architecture RF response (b).

DISCUSSION

In this paper, two fully integrated photonic RF receivers have been proposed and experimentally demonstrated. The frequency flexibility exhibited by such architectures makes them suitable for radar applications. The PIC design aims at reducing the RF-to-IF convertion loss exploiting waveguides more resilient to TPA and BPD. The "advanced" architecture is based on two very compact DFBR filters which present a narrow passband of few GHz. In future implementations, III-V/SOI hybrid integrated architectures with semiconductor optical amplifiers (SOAs) on the silicon chip may be considered to minimize the RF-to-IF conversion loss.

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