Design, fabrication and characterization of a narrow band microwave photonics beamformer in Silicon-On-Insulator

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***Abstract*—A novel microwave photonics beamformer device concept, for Single Side-Band modulated signals, is presented. The core of the beamformer is a phase-shifter and a channel demultiplexer. Design, fabrication in Silicon-On-Insulator and characterization are reported.**

I. INTRODUCTION

Microwave photonics is a well established discipline where the processing of high frequency microwave signals is done completely in the optical domain, with a considerable number of applications[1]. Amongst them, photonic beamforming is of great interest and different implementations exist [2], [3]. Those addressed with integrated optics devices commonly employ ring resonators (RR), due their versatile amplitude and phase response, which in turn can be tuned as reported extensively in the literature (see for instance [4]). In this work we propose an architecture for a beamforming network employing a comb laser [5] as optical source, with Single Side-Band (SSB) modulation scheme, where the central element (the phase shifter) is a tunable all-pass RR (ring side coupled to a waveguide, APRR) and an Arrayed Waveguide Grating (AWG). The fabrication and characterization of a 4x4 AWG with an APRR on each output in Silicon-On-Insulator (SOI) are reported.

II. BEAMFORMER CONCEPT

The beamformer concept is depicted in Fig. 1 and consists of a comb laser which is externally modulated by a dual-drive Mach Zender Modulator (MZM), and next demultiplexed by an 1xN channels AWG. Then each channel is filtered with an APRR and finally photodetected, before an antenna element. The phase required for each antenna element in the beamformer can be selected by tuning the corresponding ring in the range allowed by the passband of the AWG. The photodetected phase will be then proportional to the phase difference between the optical carrier and the SSB RF subcarrier, as reported in [6].

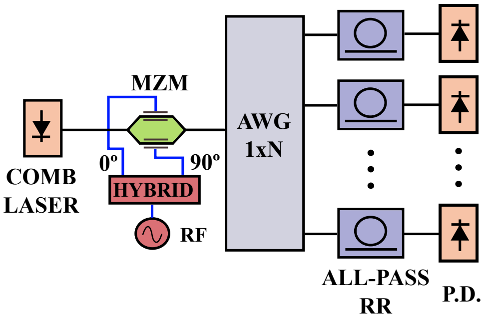

Fig. 1. Schematic of the beamformer device.

III. DESIGN AND FABRICATION

The cross section of the waveguides is height 220nm x width 450nm and the simulated group index for these waveguides is around 4.5. The APRR has been designed to have a free spectral range (FSR) of 0.75nm at a wavelength of $1.55\mu m$ and a coupling constant of $\kappa = 0.5$. The RRs have a perimeter of $711\mu m$ and a straight coupling section of $15\mu m$. The gap between the ring and the access waveguides is 200nm. The coupling constant together with the expected propagation losses (around 3dB/cm) will define the spectral width of the notch in resonance and the $\Delta\lambda_{FWHM}$.

This values have been calculated accordingly to have a $\Delta\lambda_{FWHM}$ and a phase transition that allows to accomplish the maximum phase shift required by design between the optical carrier and the RF subcarrier. At the same time, the on-resonance notch depth has been minimized to avoid extra insertion losses. The beamformer has been designed to introduce a maximum phase shift of 270 degrees for SSB modulated signals up to 40GHz.

The AWG has been designed with 4 input and 4 output channels. The adittional channels at the input side are used for testing purposes. The AWG channel spacing has been set to 3.2nm and with a Gaussian response. The FSR of the AWG has been set to 22.4nm, that is 7 times the channel spacing. This increased FSR will reduce the imbalance between channels in

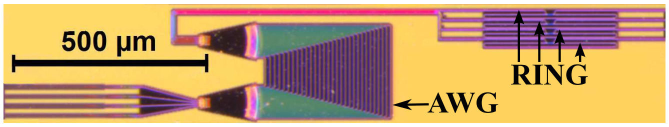

Fig. 2. Micrograph of the fabricated device.

the AWG, at the expense of an increased footprint. With this channel spacing at least 4 resonances of the RR are located within the passband of the AWG.

The devices were fabricated in a 200mm SOI wafer with a Silicon layer thickness of 220nm on top of a $2\mu m$ BOX employing 193nm deep UV lithography. The waveguides, the RRs and the AWG's star couplers have been defined with a deep etch process (220nm). For the input/output grating couplers and for all the waveguide apertures to the slab region of the star couplers in the AWG, an extra shallow etch process (70nm) has been employed to reduce the insertion losses [7]. The AWG footprint is $250\mu m$ x $515\mu m$ using $5\mu m$ waveguides bends. Fig. 2 shows a micrograph of the fabricated device. The inputs and outputs are routed from/to a grating coupler (GC), not shown in the figure, to couple light into/out of the device. The fabrication process did not include thermo-optic heater, hence the APRRs in this device cannot be individually tuned.

IV. CHARACTERIZATION

The chip was tested using standard monomode fibers positioned at 80° angle of the chip surface, aligned to the GCs. The GCs have an efficiency of about 30%. A tunable laser was used to measure the transfer function of the AWG+APRR. All the measurements are normalized to the measurement of a reference straight waveguide on the same chip. Hence the results do not include the GCs losses and represent on-chip figures. Fig. 3 shows the power transfer function for each channel. The on-chip insertion losses are below 3 dB in the four channels and the non-uniformity between channels is 1 dB. The crosstalk in the worst case is 20 dB. In every passband of the AWG, at least four resonances of the APRR can be appreciated.

Fig. 4 shows a single channel characterization with the spectral and phase response. The phase characterization has been carried out with the modulation phase shift method [8]. From Fig. 4-b a 360° phase shift on every resonance of the APRR can be observed. With the current FSR, a maximum SSB RF modulation frequency of 40 GHz can be employed, achieving at most 270° phase shift between the optical carrier and the SSB RF sub-carrier.

V. CONCLUSIONS

A beamforming architecture based in a comb laser and all-pass RR has been presented. The AWG-based demultiplexer and the phase shifting sections have been fabricated and characterized. The measurements show a good agreement between design and fabrication. Future work will include integrating more components of the architecture in SOI by means of modulators and photodetectors

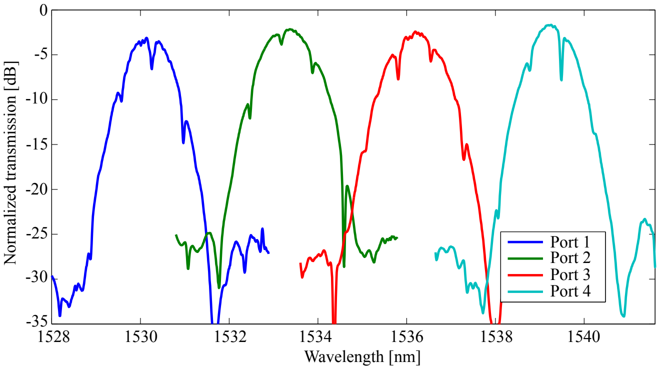

Fig. 3. AWG and all-pass rings combined spectral response

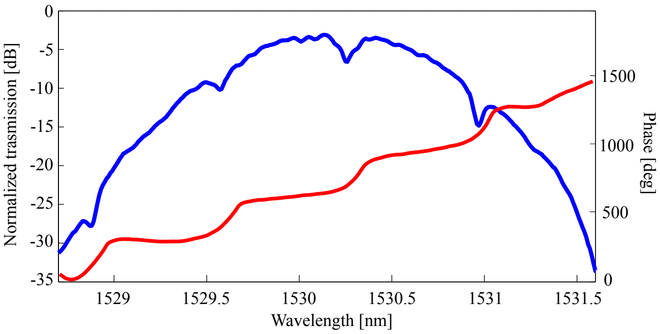

Fig. 4. Amplitude and phase response in a single channel of the device.

ACKNOWLEDGMENT

This work has been funded through the Spanish MICINN project no. TEC2008-06145/TEC and by the GVA through project no. PROMETEO/2008/092. J.D. Doménech acknowledges the FPI research grant no. BES-2009-018381.

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