Integrated Wavelength Filter on thin-film Lithium Niobate for a Photonic-enabled Radiometer

(Student paper)

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This paper presents the first results in the development of a monolithically integrated photonic-based millimetre-wave radiometer for satellite payload weather monitoring sensor. Key photonic components to be integrated in a thin-film Lithium Niobate (LN) platform have been designed and fabricated. In this paper we present our results for an asymmetric Mach-Zehnder Interferometer (AMZI) for required optical wavelength filtering functionality. The AMZI Free Spectral Range (FSR), defined by a path length imbalance of 250 µm, is around 5 nm (625 GHz).
Keywords: *Lithium Niobate, Asymmetric Mach-Zehnder Interferometer, Wavelength Filter*

INTRODUCTION

Recent interest in the study of the Cosmic Microwave Background (CMB) and earth observation for weather monitoring has motivated the development of space missions capable of detecting signals at millimetre and sub-millimetre wavelengths [1][2]. However, the weak intensity of those signals (comparable to the thermal radiation generated by the receiver itself) makes it necessary to use very low-noise receivers. Conventional low-noise receivers require cryocooling, which increases the size, power consumption and cost of the receiver.

A novel photonic-based millimetre and sub-millimetre receiver architecture, capable of operating at room temperature, was recently presented [3][4]. In this photonic-based radiometer, the millimetre wave signal is upconverted into the optical domain modulating an optical wavelength in a low-loss nonlinear crystal [5][6] where detectors are less susceptible to thermal noise at room temperature.

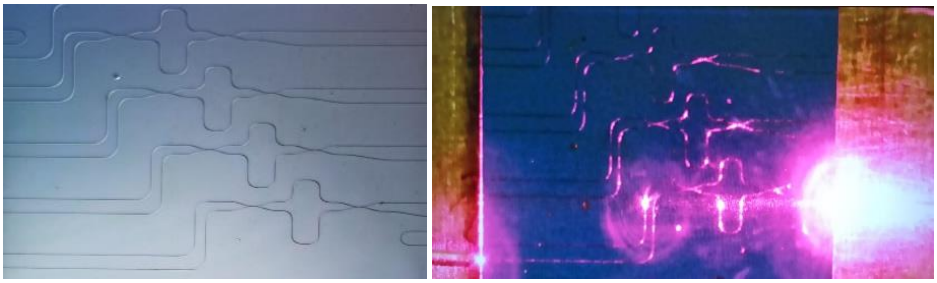
Our goal is to develop such architecture into a Photonic Integrated Circuits (PIC), achieving size and weight reduction critical for the intended satellite payload application. In this paper, we present the design and characterization of a key component for this application, an integrated wavelength filter based on an asymmetric Mach-Zehnder interferometer (AMZI). Due to the need of nonlinear characteristics of the chip, this has been fabricated on a thin-film Lithium Niobate (LN) substrate, which unlocks high-Q resonators.

Thin-film LN-on-insulator has proven to be an integration technology that offers large Pockels electro-optic efficiency [7], low propagation loss and high Q-factor ring resonators [8]. The devices studied here are realized by direct etching by 325 nm into the 600 nm LN layer and cladding with 1.4 µm of silicon dioxide as describe in [7] and are characterized by a large index contrast and strong mode confinement. Losses of 2.7 ± 0.3 dB/m for straight waveguides and 9.3 ± 0.9 dB/m were demonstrated in [8].

RESULTS and DISCUSSION

We report the characterization of 4 different AMZIs designs, all with the same optical path length imbalance between the arms (250 µm), but different waveguide gap in the directional couplers (DC) of the AMZIs. The goal of this work is to determine the directional coupler parameters, and determine the fabrication specifications to achieve 50/50 splitting ratio. The different values for the DC gap that have been tested are 0.65 µm (AMZI 1), 0.55 µm (AMZI 2), 0.45 µm (AMZI 3) and 0.35 µm (AMZI 4). The structures under test are presented in Fig. 1(a), which has been characterized using the Component Analyzer feature of the High-Resolution Optical Spectrum Analyzer from Aragón Photonics. The light is injected and collected through edge coupled optical waveguides, using lensed fibers as shown Fig. 1(b).

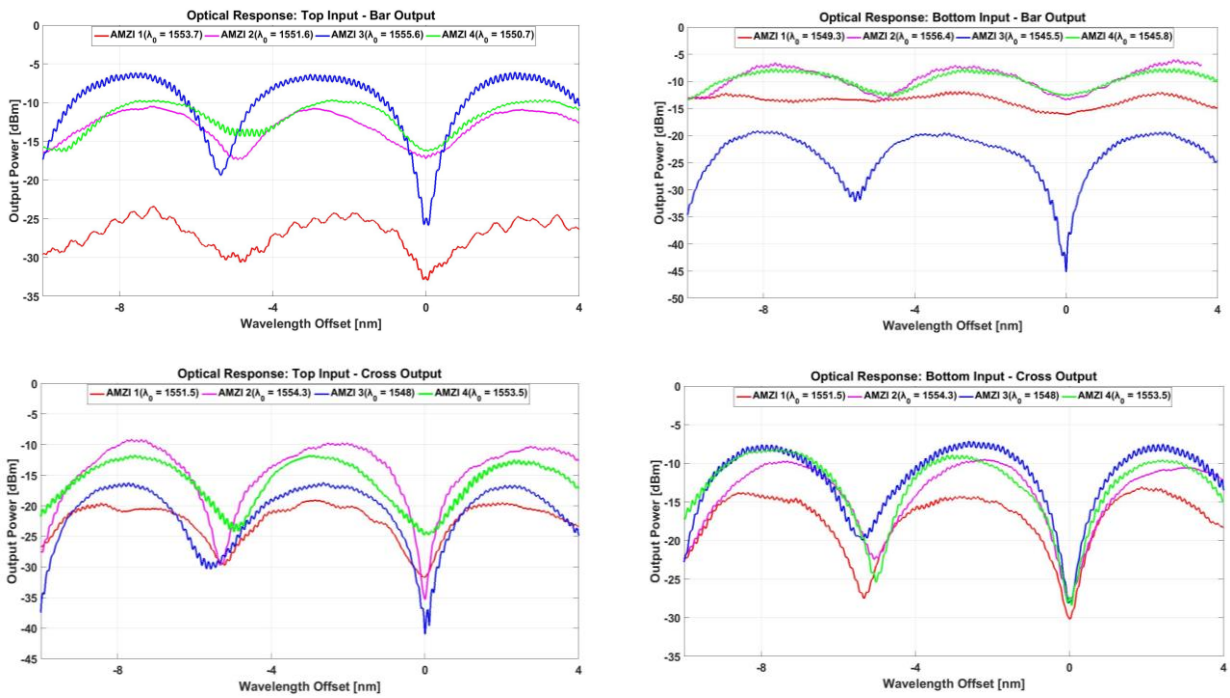
The device characterization was performed injecting the Component Analyzer source into the top arm of the AMZI and collecting the light from the top (BAR port) and bottom (CROSS port) arms of the output directional coupler. Then, the input fiber is moved to the bottom arm of the input directional coupler and the light is again collected from the two corresponding output waveguides of the AMZI under test. The results from these measurements are shown in Fig. 2.



(a) *(b)*

Fig. 1. Microscope image of (a) the 4 AMZIs structures (b) AMZI #4 during fiber-to-chip coupling.

Each graph in Fig. 2 contains the results for the four different AMZI (each with different spacing at the directional couplers). The wavelength axis has been normalized, representing the wavelength offset to the value where the absolute minimum in the optical response is achieved. The insertion loss measured at each facet, working with a lensed fiber of 2 µm spot diameter and 1.8 µm wide waveguides, was found to be around 5.5 dB.



(a) *(b)*

Fig. 2. Optical Spectrum of the response of each structure when (a) light is injected for the Top input waveguide of the DC, (b) light is injected for the Bottom input waveguide of the DC.

When light was injected to the top arm of the input directional couplers, the optical extinction ratio that we achieved at the bar output waveguide of the different samples was 8.5 dB for AMZI 1, 6.5 dB for AMZI 2, 19.5 dB for AMZI 3 and 6.5 dB for AMZI 4. This seems to point to AMZI 3 as being closer to the desired 50/50 splitting ratio. If we now turn to the cross output, the results that we obtain give an extinction ratio of 12.5 dB for AMZI 1, 25.3 dB for AMZI 2, 25 dB for AMZI 3 and 13 dB for AMZI 4 [Fig. 2(a)]. These results are in line with the conclusion from the bar measurements.

If we now turn to the bottom arm of the input directional couplers, the results for the corresponding outputs were: 4 dB for AMZI 1, 6.5 dB for AMZI 2, 25 dB for AMZI 3 and 5 dB for AMZI 4, while for the cross output the results were 17 dB for AMZI 1, 18 dB for AMZI 2, 20.6 dB for AMZI 3 and 19 dB for AMZI 4 [Fig. 2(b)].

The wavelength spacing between the maximum and the minimum transmittance is defined by the path length imbalance (ΔL) between the two arms of the AMZI as:

$$\Delta\lambda = \frac{\lambda_1 \lambda_2}{2 * \eta * \Delta L} \quad (1)$$

where η is the refractive index of the waveguides. The Free Spectral Range (FSR) is then given as 2* $\Delta\lambda$. For all four AMZI structures, as they were designed with the same ΔL, the FSR was found to be around 5 nm (625 GHz).

As mentioned before, the different structures were designed and fabricated for the calibration of the directional couplers splitting ratio as function of the different gaps to find the optimum gap for the 50/50 DC. The suppression of the unwanted signal at each output port will be higher as closer to 50/50 is the splitting ratio of the DC and, from the results presented in Fig. 2. It can be observed that AMZI 3 is the structure that provides the maximum suppression at both output ports when light is coupled to any arm of its input DC.

CONCLUSION

In this paper we presented a monolithically integrated wavelength filter that forms part of a novel radiometer architecture for space applications that eliminates the need for cryostats, reducing the impact of the payload in the satellite. A maximum 25 dB of suppression was achieved with AMZI 3 when injecting light in either of the two arms of the input directional coupler. Therefore, we can also conclude that the DC gap that offers the splitter ratio closer to the desire 50/50 is 0.45 µm. The FSR of the filter can be adjusted by changing the path length imbalance of the AMZI. Furthermore, from the results we can also infer that the highest level of suppression with each structure is obtained when the output is collected at the cross arm of the output directional coupler with respect to the arm of the input directional coupler where light is injected. More extensive work will be carried out to study this behavior.

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References

[1] PRISM collaboration, “Prism (polarized radiation imaging and spectroscopy mission): an extended white paper,” J. Cosmol. Astropart. Phys. 2014
[2] A. R. Cooray and Origins Space Telescope Study Team, “Origins Space Telescope,” in American Astronomical Society Meeting Abstracts #229, 2017
[3] G. S. Botello, L. E. G. Muñoz, et al., "Sensitivity limits of millimeter-wave photonic radiometers based on efficient electro-optic upconverters," Optica 5, pp. 1210-1219, 2018
[4] L. E. G. Muñoz, G. S. Botello, et al., "Room temperature radiometer based on an up-conversion process for CubeSats applications", invited paper, Proc. SPIE 11348, Terahertz Photonics, 2020
[5] A. Rueda, D. V. Strekalov, et al., "Efficient microwave to optical photon conversion: an electro-optical realization," Optica 3, pp. 597-604, 2016
[6] G. S. Botello, Z. Popovic, L. E. G. Muñoz, et al., “Sensitivity and noise in THz electro-optic upconversion radiometers”, Scientific Reports 10, 2020
[7] C. Wang, M. Lončar, et al., "Nanophotonic lithium niobate electro-optic modulators," Opt. Express 26, pp. 1547-1555, 2018
[8] M. Zhang, Marko Lončar, et al., "Monolithic ultra-high-Q lithium niobate microring resonator," Optica 4, pp. 1536-1537, 2017