Characterization of monolithically integrated lithium niobate ring resonator for a high sensitivity room temperature radiometer

Jessica César Cuello[*1], Alberto Zarzuelo[1], Robinson C. Guzmán[1], Luis Gonzalez-Guerrero[1], Gabriel Santamaria[2], Enderson Falcón-Gómez[1], Luis E. García[1], and Guillermo Carpintero[1]

***Abstract*—Radiometry in the sub-millimeter and THz region is required for applications as spectroscopy, earth observation, space missions and radio astronomy. A high sensitivity room temperature radiometer, based on the upconversion of the RF signal to the optical domain, has been already proposed. High-Q resonators, made of nonlinear crystals, are require for realizing such upconversion process. Since small physical footprint and low power consumption is necessary for space applications, the miniaturization of the components becomes relevant. In this work we present the study of an integrated ring resonator (RR), the first step of the integration, in a Photonic Integrated Circuit (PIC), of the upconversion radiometer. The device was fabricated in a thin-film lithium niobate PIC.**

Keywords—photonic integrated circuit, lithium niobate ring resonators, radiometer

I. Introduction

Upconversion of millimeter-wave or THz signals to the optical domain, where room temperature photonic detectors are highly sensitive, is a novel detection approach proposed in [1]. In this approach, a laser pump is modulated by millimeter-wave or THz signal in a high-Q whispering-gallery mode resonator (WGMR), which is used as an efficient electro-optic modulator (EOM), upconverting the signal detected by the antenna to optical sidebands. Detection can be then performed with conventional photodetectors in a direct or coherent detection scheme. For this approach, using a high-Q resonator as the EOM is necessary to critically couple the pump mode, enhancing intracavity power and thus photon conversion efficiency, leading to a radiometer sensitivity comparable to conventional cooled receivers while working at room temperature as described in [2].

Our goal is to develop such architecture [1] into a photonic integrated circuit (PIC) to achieved low size, weight and power consumption (SWaP), three critical parameters for a satellite payload application. In this work, we present the characterization of a key component for this application, an integrated Lithium Niobate (LiNbO3) resonator. The transmission spectrum of the resonator, and several figures of merits, are obtained. Due to the need of nonlinear characteristics of the chip, the device was fabricated on a thin-film LiNbO3 substrate. The conclusions obtained from this work have been used as input for the development of a second PIC, where the complete photonic-based radiometer architecture is being fabricated.

[1]University Carlos III of Madrid, Leganes, 28911, Spain; [2]University of Colorado at Boulder, Boulder, CO 80309, USA

[*]jecesarc@ing.uc3m.es

II. Device Description

Thin-film Lithium Niobate-on-insulator (LNOI) has emerged as a promising material platform for different applications due to its high refractive index, large piezoelectric response and large Pockels electro-optic efficiency [3]. Furthermore, two of the advantages that makes LNOI suitable for the develop of our photonic integrated circuit is its low propagation loss and high-Q on-chip ring resonators [4].

The integrated system is shown in Fig. 1. The upconverter is based on a WGMR for optical upconversion and an asymmetric Mach-Zehnder interferometer (AMZI) to increase the upconversion bandwidth [5]. By phase matching the optical carrier and the signal detected by the antenna inside the resonator, the upconversion of the RF signal to the optical domain is achieved, generating two optical sidebands around the laser pump v_p by sum-frequency v_s and difference-frequency v_d generation. These optical sidebands represent the signal that we want to detect. The detection can be performed with conventional photodetectors in a direct or coherent detection scheme.

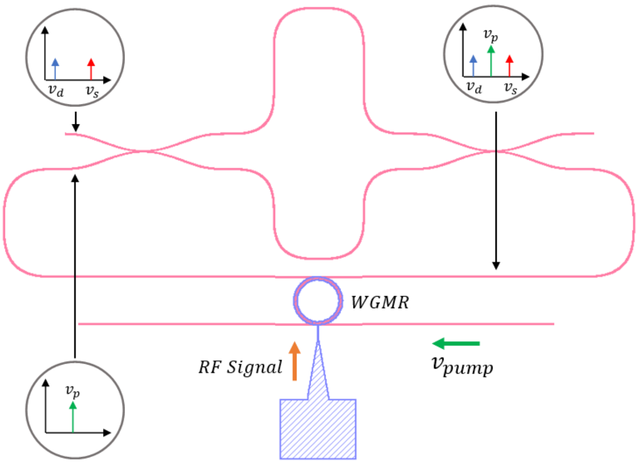

Fig. 1. Integrated photonic-based radiometer architecture.

For testing purposes, a first set of devices was fabricated to individually characterize the WGMR and AMZI. The physical footprint of the PIC is 10 mm x 4 mm. A microscope image of the structures under test is presented in Fig. 2.

To study the influence of the separation between the bus waveguide and the resonator on the transmission spectrum of the resonator, eight structures with different separation (gap) were fabricated. The gap values are: 1.4 µm (RR1), 1.26 µm (RR2), 1.11 µm (RR3), 0.97 µm (RR4), 0.829 µm (RR5), 0.686 µm (RR6), 0.543 µm (RR7), and 0.4 µm (RR8). A resonator radius of 50 µm was used for all eight structures.

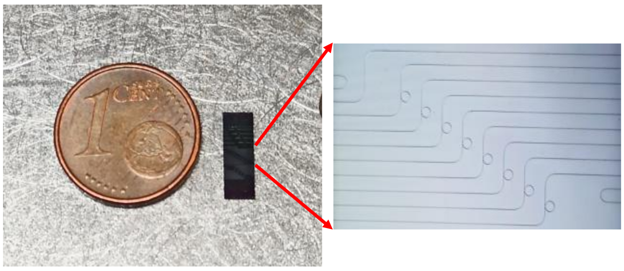

Fig. 2. Image of the physical footprint of the photonic integrated circuit (PIC) and a microscope image of the LiNbO3 resonators.

III. Experimental Results

The characterization of the structures was performed using the Component Analyzer feature of the High-Resolution Optical Spectrum Analyzer (BOSA) from Aragon Photonics. The light is injected and collected through edge coupled optical waveguides, using lensed fibers. 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.

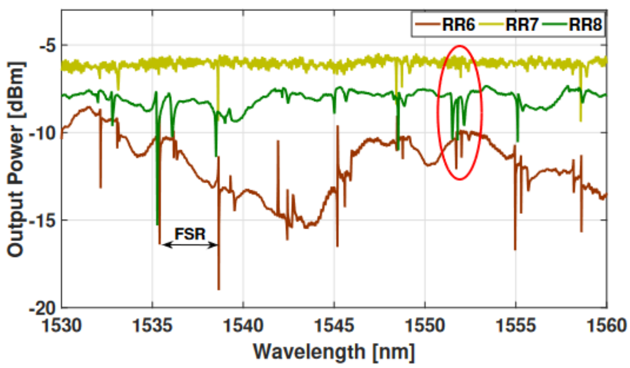

Fig. 3. Transmision spectra of RR6, RR7 and RR8.

After testing all the structures, we observed that resonances begin to appear on RR6, which suggests that for waveguide gaps larger than 0.7 μm there is no appreciable coupling between the access waveguide and the resonator.

The transmission spectra of RR6, RR7 and RR8 are presented in Fig. 3. In the transmission spectrum, three different sets of resonant modes are identified, each with similar Free Spectral Range (FSR) around 3.2 ± 0.2 nm (400 ± 25 GHz).

A modulation of the optical spectrum was also observed in the transmission response of all the structures resulting from the Fabry-Perot cavity created between the facets of the PIC, which can be reduced by using anti-reflection coating at both edges of the chip.

From the transmission spectra we can define that the optimum waveguide-ring resonator gap for the final radiometer design is around 0.543 μm (RR7), due to the flat response of its spectrum. By fitting the experimental results of the under-coupled RR7 (Fig. 4), we estimate a loaded quality factor of $0.8x10^5$. The intrinsic Q-factor (Q_i) of the resonator is related to the measured loaded Q-factor (Q_L) by:

$$Q_i = 2Q_L/\left(1 \pm \sqrt{T_0}\right) \tag{1}$$

where T_0 is the normalized transmission value and + and - correspond to under- and over-coupled regimes, respectively. At critical coupling regime, $T_0 = 0$ corresponding then to an intrinsic Q-factor $Q_i = 2Q_L$.

The measured intrinsic Q-factor of the monolithically integrated LiNbO3 ring resonator is not as good as the state-of-the-art demonstrations on the same platform [4] due to the additional bending loss added by working with a smaller resonator radius.

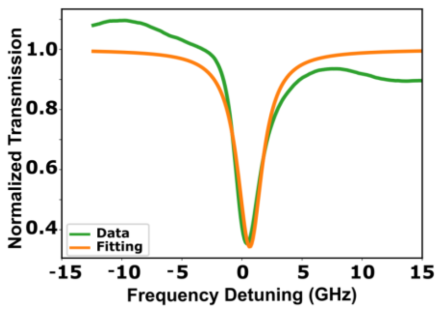

Fig. 4. Fit of the resonance dip to Lorentzian function at wavelength of 1551.5 nm

IV. Conclusions

In this work we have presented the characterization results of a Lithium Niobate ring resonator to be part of a Cubesat payload radiometer. For waveguide/resonator gaps larger than 0.7 μm, almost no light is coupled to the resonator. High-Q LiNbO3 resonators have been demonstrated, with an intrinsic Q-factor of around $1x10^5$ in the best structure (RR7). It is expected that the quality factor of the resonators will increase in future fabrication runs by increasing the radius of curvature of the rings to reduce losses.

Furthermore, photonic integration has allowed the reduction in terms of size, weight and power consumption of the photonic-based radiometer for satellite payload, and the LNOI platform has proven to be the right choice for the development of our high-Q WGMR. The power consumption of the integrated radiometer, associated to the electronic part of the final system, is expected to be around 6W.

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