Double polarization active Y-junctions in the mid-IR, based on Ti:diffused Lithium Niobate Waveguides

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***Abstract*—Double polarization active beam combiners have been developed for mid-infrared applications, in particular, in the field of high contrast interferometry in astronomy. As the objective of these beam combiners is to achieve high rejection ratios based on proper recombination of the fundamental modes guided by each arm (better than 40dB at the desired wavelength), we will focus our discussion on the fringe contrast obtained, using a monochromatic source and scanning the dark fringe, by internal modulation. In a second time, white light interferograms will be presented, in order to address the spectral dispersion (chromaticity of the combiners), and the efficiency of the modulator in the wideband regime. We will also show our prototypes for improving the effective electro-optic coefficient, based on the fabrication of photonic crystals inside the waveguides.**

Keywords-electro-optics, interferometry, beam combiners, lithium niobate, mid-infrared, modal filtering

I. INTRODUCTION

The context of this work is the development of integrated optic beam combiners devoted to stellar interferometry [1]. In the run for exoplanet detection, the 2.5-5μm observation window has been identified as an adequate band for planet search science [2]. Besides, for spatial applications, the use of compact and light optical beam combiners ensuring robustness and stability of the interferometric signal is mostly welcome. Thus, the development of materials allowing light confinement in both polarizations, together with a good transparency in the mid-IR and able to achieve electro-optic modulation, in order to finely tune the relative phase of the interacting fields, is knowing a rapid development. Indeed, there are recent publications in active materials like lithium niobate beam combiners centered in K-band (2.2μm) [3] and L-band (3.7μm) [4].

Aside from spectral considerations, several issues are requested from an efficient optical beam combiner: First, the ability to filter out high order modes in the waveguides, thus achieving modal filtering and optimizing the contrast of the interference fringes obtained. As the astronomical models are very sensitive to fringe contrast, modal filtering is compulsory in order to improve the quality of the interference data. Second, active control of the phase in the integrated optic device is needed, in order to limit the signal fluctuations and eventually achieve on-chip fringe scan. This can be done using well known electro-optic materials, as long as they exhibit good transparency in the mid-IR. Another important issue is to ensure that both polarizations are guided, since polarization studies are essential to understood astrophysical phenomena, and most of the astrophysical instruments are not polarisation sensitive, giving only information about the intensity and not the vector direction of the electromagnetic field. Finally, it is important to reduce or at least characterize the spectral dispersion of the combiner over the whole observation band (here, 3.4-4.1μm), which means that special geometries have to be designed (achromatic couplers, low dispersion waveguides).

Thus, we have selected LiNbO3 in order to develop new integrated beam combiners, not only due to its transparency up to 5.2μm, but also for its excellent electro-optic properties, that will allow active control of phases. Focusing on double polarization waveguides like Ti-indiffusion, Sohler group demonstrated a first realization in the mid-IR devoted to Difference Frequency Generation [5] and more recently other groups have been working on mid-IR LiNbO3 interferometers [4, 6].

In this paper, we present our results on active Y junctions working in the L-band (monochromatic and wide-band). We will show how the modal filtering allows to obtain high rejection ratios; we analyze the wide band spectra to recover the dispersion characteristics of the combiner and, finally, will present mono- and poly-chromatic modulation in the L-band obtained in both polarizations (TE and TM) using the electro-optic effect.

II. SAMPLE FABRICAION AND EXPERIMENTAL SET-UP

The junctions were fabricated in X-cut Lithium Niobate substrates by Ti:diffusion for 20h at 1020ºC. The width of the channel waveguides ranged from 12-26μm, allowing to obtain single mode behavior at higher wavelengths with the increasing width. The passive behavior of the channel and Y-junctions, including propagation losses, was discussed in a previous paper [6]. In the present work, we present the electro-optic response of the junctions for the atmospheric window under study, i.e., L-Band. The experimental set-up is shown below:

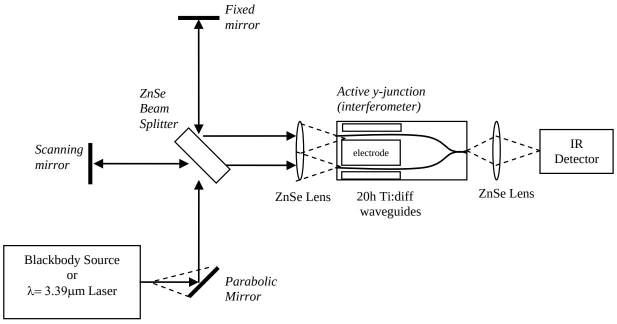

Figure 1. Schematics of the experimental set-up allowing intensity modulation in the mid-IR.

A mid-IR source (either He:Ne λ=3.39µm laser or a Blackbody) is focused on a 20um diameter hole to ensure spatial resolution. Then, the aperture is placed at the focal length (25.4mm) of an off-axis parabola to achieve collimation. The beam passes through a classical Michelson interferometer, using a thick ZnSe plate as beam splitter, allowing lateral separation of two beams to be injected in the waveguide. Injection is ensured by a 25.4mm lens, so that optical power is one, and the numerical aperture matches that of the waveguides. The output field is imaged by a ZnSe lens on the FLIR infrared camera. Modulation is achieved, in this preliminary sample, by electrodes in a push configuration (only one arm under electric field).

III. RESULTS

A. *Monochromatic Fringes*

Light coming from a He-Ne laser at λ=3.39µm was injected at 45º from the vertical X-axis of the waveguide, in order to ensure excitation of both TE and TM polarizations. In the figure shown below, we were able to achieve almost one period scan (OPD 2.96um) while applying a triangle function on the electrodes, obtaining a half-wave voltage of $V\pi=22V$ (or $V\pi L\pi= 55$ V•cm).

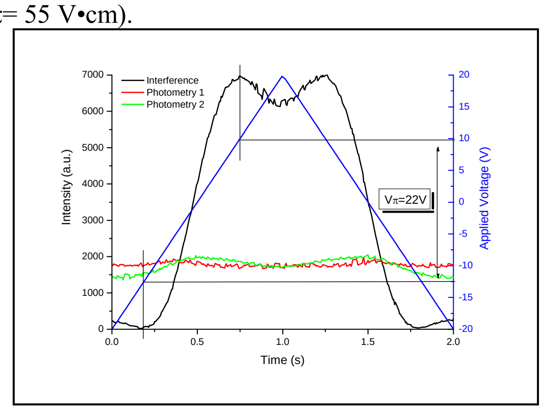

Figure 2. Modulation achieved in the combiner, using monochromatic laser light and a 40Vpp triangular ramp.

Using external modulation, i.e. translating the scanning mirror, we obtained high contrast fringes, showing the filtering capabilities of the system. The average rejection ratio was 300 (25dB), with a best value of 1110 (30.4dB) in a single stage, push type modulator (monochromatic). This is a promising result, but work has still to be done in order to match the 40dB requirements for nulling interferometry.

B. *Polychromatic Fringes*

Injecting light from a Blackbody source, wide band fringes were obtained for TE and TM polarization. We observe that the interference fringes have good contrast (66.8% for a wide band source) and that the waveguide effectively act as a filter since the optical bench (without the waveguide) presents a contrast of 48.0%.

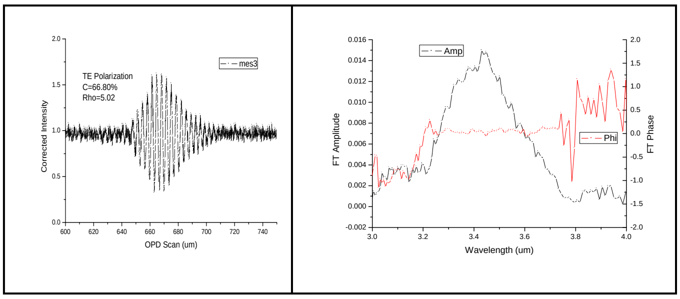

Figure 3. Left: TE wide band fringes. Right: Amplitude and Phase of the Fourier Transform of the wide band fringes.

We notice that the fringes are quite symmetric, which suggests that the combiner is weakly dispersive, as seen in the flat phase spectrum obtained.

Modulation of the central fringe was achieved using the electro-optic effect, and although the modulation amplitude was weaker than in the monochromatic case, we were able to observe it in both polarizations (see figure 4 below, where only TM is shown).

Some polarization issues have to be improved, since we don’t find the expected ratio of 3 between extraordinary and ordinary modulation amplitudes, probably due to a poor extinction of the perpendicular contribution. We are currently working on improving the quality of the polarization selectivity.

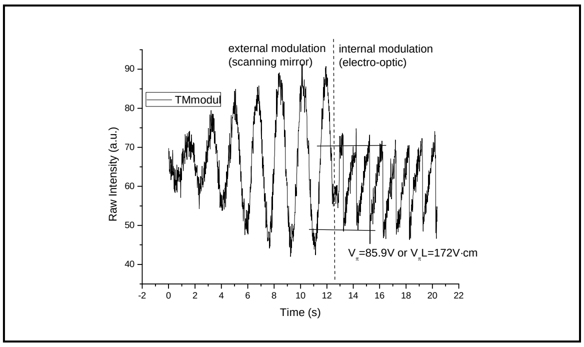

Figure 4. Electro-optic modulation of the wide band fringes in TM polarization. Note that below 13s the fringes are scanned externally.

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IV. CONCLUSION

Active Y-junctions in the mid-IR were obtained and showed filtering and modulation capabilities in both TE and TM polarization. High rejection ratio devices were obtained, showing weak dispersion over the entire L-band. The future devices will include photonic crystals in order to improve the electro-optic response, as well as double stage Mach-Zehnder modulators in order to achieve deeper rejection ratio.

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