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Near and Mid Infrared Lithium Niobate based Integrated Optics Interferometer based on SWIFTS-Lippmann

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Abstract: High resolution spectrometers are nowadays achievable in compact devices using integrated optics. The approach developed here consists in obtaining a static interferogram by means of a Fresnel reflection at the waveguide output (Lippmann interference between forward and backward beams) and then sample the fringes by periodically etching the waveguide with transverse nano-grooves, that will collect a negligible part of the flux. We present the first SWIFTS-Lippmann interferometer in the near and mid-infrared, thanks to high form factor grooves obtained by focused ion beam in lithium niobate, which opens the way to electro-optic modulation of the interferogram and thus, sampling on-chip, without any moving part.

Introduction: High resolution integrated spectrometers are an active field of research, thanks to progress in microtechnologies and materials research, aiming at miniaturization and access to different spectral windows [1, 2, 3, 4, 5, 6]. We present in this work the developments of SWIFTS-Lippmann integrated interferometer based on lithium niobate (LN) waveguides in the near and mid-infrared. SWIFTS is the acronym for Stationary Wave Integrated Fourier Transform-Spectrometer [7], where a high resolution integrated optics spectrometer can be obtained by periodically sampling the stationary wave obtained by superposition of direct and backward guided optic beams, using evanescent out-coupling thanks to nanodots or dielectric discontinuities periodically distributed along the surface of a waveguide [8, 9]. In order to sample the stationary wave, we use Focused Ion Beam technology (FIB) to realize high aspect ratio grooves perpendicular to the waveguide and use the diffused energy to sample the optical field. Here we present the realization of high form factor FIB grooves in a LN channel waveguide, its near- and mid-infrared characterization and the application to measurement of effective refractive index of the waveguide and high resolution spectroscopy. The use of an electro-optical material such as LN opens the way to internally scan the fringes under the grooves in order to improve sampling, or shift the wide-band interferogram towards the desired sampling region (i.e. avoiding bad sampling centers) by using a phase modulation stage prior to the Lippmann interference.

Theoretical Model: In a SWIFTS-Lippmann configuration, the superposition of forward and backward reflected beams in a channel waveguide (X-cut, Y-propagation) is given by:

$$I(\lambda, y, E) = I_0\, e^{-\alpha y}\left[1 + R\, e^{-4\alpha(L-y)} - 2\sqrt{R}\, e^{-2\alpha(L-y)} \cos\left[\frac{2\pi}{\lambda} n(\lambda, E) 2(y-L)\right]\right] \qquad (1)$$

Where $n(\lambda,E)$ is the effective refractive index of the fundamental mode and R is the Fresnel reflexion intensity coefficient of LN waveguide/air interface. The period of the static interferogram is given by $i=\lambda/2n$. At a fixed position y (i.e. at a given diffusion center) the intensity of the radiated signal oscillates with wavelength. The period of this signal is given by, in terms of wavenumber:

$$\Delta\sigma=\Delta\lambda/\lambda^2=1/2ny \qquad (2)$$

, where y is the distance to the waveguide facet. By measuring the period of the fringes at different (but very close) wavelengths at a given position y, one can recover the effective refractive index of the waveguide.

Fabrication: We firstly produced the optical waveguides for X-cut $LiNbO_3$ wafers, through diffusion of 180-nm thick 12 μm wide ribs of titanium at 1030°C for 50 hours. Then, we realized the grooves, perpendicular to the waveguide direction, by Focused Ion Beam. The FIB grooves where realized at FEMTO-ST Beam (FIB Dual Beam FEI Helios 600i) in four hours with a probe current of 24 pA, a step size of 12 nm, and a dwell-time of 0.1 ms. We realized 50 grooves, 170nm wide, 633nm deep, with a period of 10 μm, giving a total sampling length of 500 μm (see fig.1).

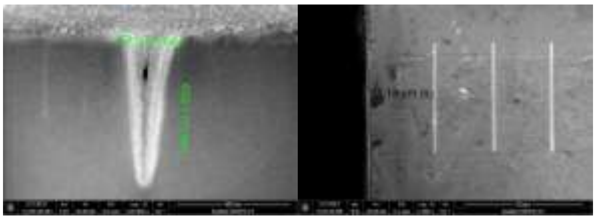

Figure 1: Left: MEB image of groove, showing typical dimensions (170nm long, 633nm depth). Right: Periodicity of the grooves, transverse to the waveguide, and distance from the edge.

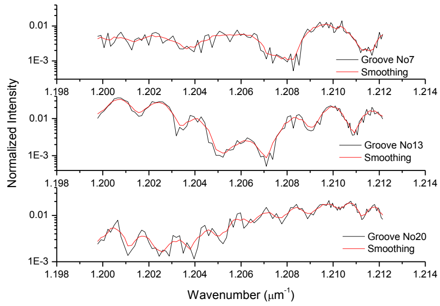

Figure 2: Normalized intensity diffused by different grooves depending on the distance y to the edge (see eq.2). (up): 7,81 μm; (middle): 141μm and (bottom): 211 μm.

We have used a minimum sampling period of 0.1 nm and focused on the first 25 diffusion centers. Theoretical values for spectral resolution, S.R., and spectral window, $\Delta\sigma$, are S.R.=$2nL/\lambda$ and $\Delta\sigma=1/4n\Delta L$ [7]. With L=500 μm (length of the sampling region), n=2.26 the effective refractive index and λ=0.85 μm, we expect S.R.=2350, which is insufficient to resolve the Sacher Laser Diode linewidth (500 kHz), but gives an idea of the spectral resolution we can obtain in this simple device. The spectral window is $\Delta\sigma$=0.0125 μm^{-1} with ΔL=10 μm the distance between grooves.

Results: Using a Sacher tunable source, we scanned the wavelength from 825 to 833 nm, while observing the signal diffracted by the grooves. As given by eq. 2, at a given position y (i.e. observing the light diffused by a given groove), the intensity oscillation varies more and more rapidly as we move away from the waveguide edge (as y increases). The first images of sampling where obtained by using a Sacher tunable source, that allowed us to scan between 825 - 833 nm with a step of 0.1 nm. The results are shown in figure 2. Studying the first 25 grooves, we obtain the period of the sampled signal for different sampling centers as a function of their distance to the edge and can extract the effective refractive index of the fundamental mode of the waveguide with high accuracy.

Results in mid IR as well as simulations on the radiated field as a function of the grooves form factor will also be presented.

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