Multi-Wavelength Filtering Wideband by Cascade Bragg Reflectors in Optical Waveguides

Kamal Ghoumid, Imen Elhechmi, Slimane Mekaoui, and Tijani Gharbi

Abstract—**A double filtering function has been obtained by realization of a double Bragg gratings (BGs) structure based on titanium-diffused optical waveguides in lithium niobate Ti:LiNbO3 has been reported. Focused Ion Beam (FIB) technique is being used in order to obtain homogeneous periodic microstructures. This double structure (D.S.) is characterized by wavelengths reflected around the bands 1203*nm* and 1527*nm* with a coefficient of about 96% and Full widths at half maximums are in the vicinity of 50 and 56*nm*. Experimental results agree well with the results of the simulations. As a perspective, an improvement in the bandwidth of this structure is considered so that it can find its application in coding/decoding optical CDMA is discussed.**

Index Terms—**Optical communications, optical device for signal processing, bragg filter, wavelength filtering devices.**

I. Introduction

The implementation of all-optical circuits for optical processing of information could overcome the speed limitations associated with classical electronics components [1]-[3]. All-optical technology is presented as a potential alternative to achieve these goals. For this purpose, photonics equivalents of fundamental devices that form basic building blocks in electronic circuits would need to be designed and implemented [4], [5]. Filtering is among the most frequently used functions in the signal processing.

The optical filtering wavelength allows the selection of wave- lengths from the total spectrum while blocking the remainder. It plays an important role in several areas. Otherwise, despite decades of progress in microelectronics technology, the dem- and of optical filtering performance in civilian and military applications continues to stress. Moreover, its miniaturization in integrated circuit provides the way of many applications. This miniaturization is the result to the significant advancement in the nanotechnology domain, because it is possible to achieve high integration of several electronic components in a very narrow space. More at the nanoscale, size of component and the etching of hole presents a fundamental challenge to the fabrication process and its usage for wide spectral range [6], [7] which is essential for several applications.

Building on prior our work [8], [9], [10] our motivation is then oriented to the experimental realization of a double optical filtering element engineered specifically as a building block for this task.

An experimental demonstration on component containing two BGs in cascade writing directly in a waveguide Ti:$LiNbO_3$ obtained by FIB milling is presented in this paper. This component leads to the realization of the dual function with double filtering in wavelength around 1203 and 1527*nm*.

The principle of the cascade two Bragg filters is in accordance with that presented in reference [11], [12]. We then obtain, in the spectrum two peaks centered on two wavelengths.

The preliminary results that we have got show that there isn't any impact or any kind of influence from a spectral response on the other one in the case that the reflected bandwidths are sufficiently apart. This can induce overlaps between the bandwidths whatever be their nature reflected or transmitted. This overlapping can infer other phenomena (resonances, beatings, ...). That's why we have deliberately chosen to work with wavelengths which are far apart.

In addition, we note that such a component perspective with several narrow bands (N bands) can find application in several areas especially for optical code division multiple access (CDMA) [13]. The latter is attractive for optical broadband access network. It is very interesting to use the superstructure fiber Bragg grating based en/decoders to construct a wavelength-division-multiplexing (WDM) compatible OCDMA system [14]. In this structure, these networks require simple encoders/decoders enabling the integration of optical devices for further development, using waveguide BG devices to demonstrate compact and versatile [15].

II. Model Description

The double structure presented in this paper is illustrated in Fig. 1. The wave is confined in the layer whose refraction index is n_2 with a depth d representing the optical waveguide Ti:$LiNbO_3$. Whereas, the adjacent two other layers are those of the lithium niobate (L.N, $LiNbO_3$) whose index is n_1 which represents the substrate and the air layer whose index is n_3. Since its propagation in the central layer, the wave will on his path be in contact with two different index corrugation types having different characteristics. The first index modulation represents the first BG_1 with a period of Λ_1, an

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engraving depth of l_1 and a period number N_1. Whereas the second index corrugation is that which represents the second BG_2. The later, is characterized by a period of Λ_2, an engraving depth l_2 period number of N_2. With these parameters, each Bragg grating has a length $L_1 = N_1 \times \Lambda_1$ for the first BG and $L_2 = N_2 \times \Lambda_2$ corresponding to the second BG.

For each injected wave at the double structure input correspond two wave types, one reflected at the input of the cascade structure and the other transmitted to be recovered at the waveguide output.

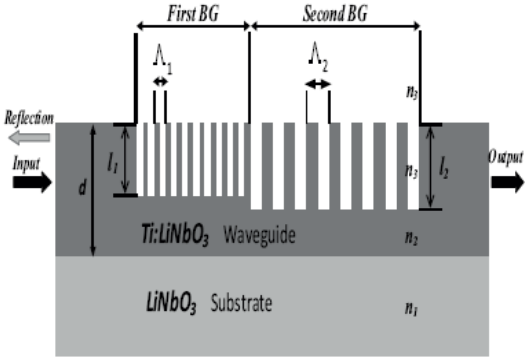

Fig. 1. Basic scheme of the cascade structure engraved in a Ti:LiNbO$_3$ waveguide: each BG$_{1;2}$ is characterized by a period $\Lambda_{1;2}$, an etching depth $l_{1;2}$ and the periods number $N_{1;2}$.

Fig. 2 illustrates the simulations results of both BGs couples chained in cascade and respectively denoted first and second couple. These theoretical curves show the reflectivities versus the wavelength for both considered couples. For the first one, we have obtained two bandwidths centered around 1100 and 1500 *nm* with reflective coefficients whose order is about 99%. Whereas, for the second couple, the two bandwidths are centered around 1200 *nm* and 1700 *nm* with reflective coefficients whose order is about 99%.

III. Fabrication Process

Sub-micrometric photolithographic technique is most commonly used during the fabrication of periodic perturbation of the index on lithium niobate. In our paper, we report the technique of engraving by FIB. The chips are fabricated on a 0.5*mm* thick X-cut $LiNbO_3$ wafer. During the design of the waveguide Ti:$LiNbO_3$, evaporative deposition of a layer of titanium over the entire substrate was undertaken followed by lift-off technique which results in titanium ribbons of width $W = 7\mu m$ and thickness $\tau = 0.08\mu m$. Spacing between the ribbons has the value $100\mu m$. Thermal diffusion has been undertaken in the next step at 1020^0C for 9 *h*. Authors have chosen X-cut, Y-propagation and TE polarized sample of lithium niobate. With these parameters, it is possible to realize extraordinary index $n_e(\lambda = 1203nm) \approx 2.149$ and $n_e(\lambda = 1527nm) \approx 2.138$ with the effective index is $n_{eff}(\lambda = 1203nm) \approx 2.151$ and $n_{eff}(\lambda = 1527nm) \approx 2.140$.

For the experiments, authors have used dual beam Orsay Physics Canion 31 / LEO 4400 FIB. Beam deflection has been carried out by Raith Elphy Quantum 4.0 driver. The current and ions energy values used for the $LiNbO_3$ sputtering are 300 *pA* and 30 *keV*. Initially, metallization of the waveguide by depositing a layer of chromium of thickness 10 *nm* has been obtained followed by designing of both BGs by etching FIB.

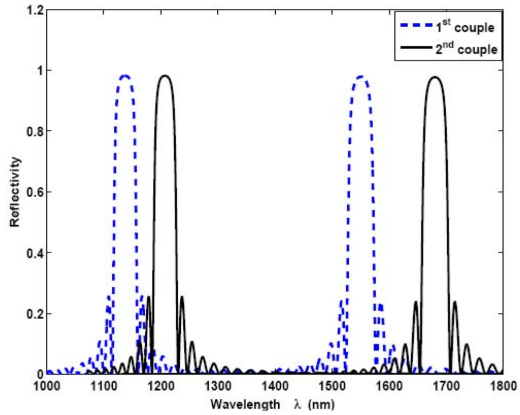

Fig. 2. Reflectivities simulation results versus the wavelength for both considered couples.

Both BGs have the periods (Bragg order $m = 5$) $\Lambda_1 = 1.40$ μm and $\Lambda_2 = 1.81$ μm and a total number of periods $N_1 = N_2 = N = 100$. According to the results obtained by simulations, and by taking into account the coordinates of the maxima corresponding to the optical field in the waveguide, we have to decide about the value of the depth etching for both BGs i.e. depths etching $l_1 = l_2 = l = 2.4$ μm.

Fig. 2 shows the top view of the DS with 7 μm width of the waveguide and lengths of each BG $L_1 = 140$ μm and $L_2 = 181$ μm respectively, elaborated by FIB in a sample of lithium niobate of type X-cut, Y-propagating and TM polarization.

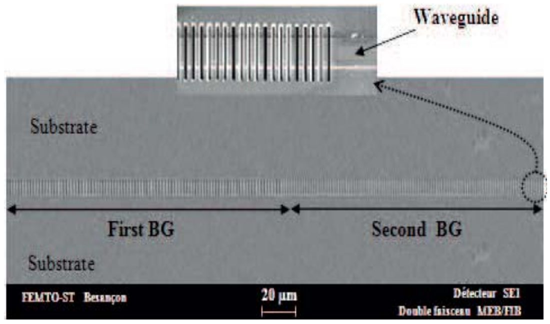

Fig. 3. FIB view of the first and second BG cascade etched into Ti:LiNbO$_3$ waveguide.

IV. Results and Discussions

As we mentioned above, the preliminary results that we have got show that there isn't any impact or any kind of influence from a spectral response on the other one in the case that the reflected bandwidths are sufficiently apart. Hence the justification of our choice of the two bands reflected with wavelengths which are far apart.

The experimental setup used to evaluate the spectral response of the D.S. is analogous to those presented in [8], [9]. A continuous spectrum source with a wavelength range of nm is launched at the coupler input. This continumlaser uses a strong nonlinear effect induced by a picosecond pulse (1064*nm*) injected in a photonic crystal fiber specially designed [10]. It allows to obtain radiation with a flat broadband spectrum.

Fig. 3, shows the reflectivity curve versus wavelengths measured at the output of the waveguide. It shows both bands Reflected for an input signal in the range {850 – 1750} *nm*.

The coefficient of reflection obtained is about 96%. The two bandwidths measured at half maximum of the D.S are respectively in the order of 50*nm* and 56*nm*, which are centered respectively on 1203*nm* and 1527*nm*.

It should be noted the existence of various types of losses which is related to: the injection and alignment process, material absorption and engravings of two BGs of the D.S corrugations. These different types of losses were detailed in [10]. In this configuration the losses are estimated at about 8 *dB*.

Finally, it is worth noting that these experimental results depicted by the curve in the Fig. 4 perfectly confirm and are in good agreement with theoretical predictions and simulations.

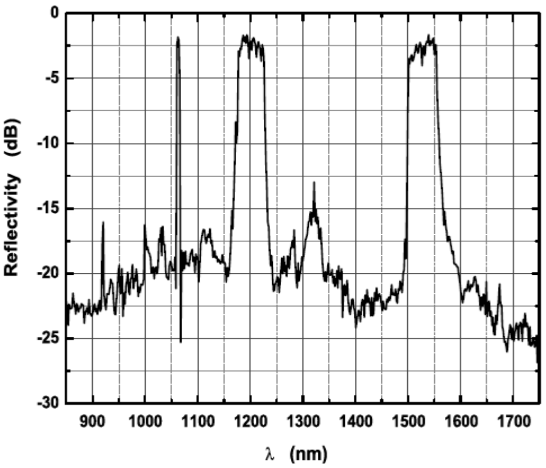

Fig. 4. Reflectivity versus wavelength measured at the output of the $Ti:LiNbO_3$ waveguide. The peak at 1064 *nm* corresponds to the pump of the white laser employed to provide the wide spectrum at the waveguide input. The wavelengths reflected around the bands 1203 *nm* and 1527 *nm* with Full widths at half maximums are in the vicinity of 50 and 56*nm* respectively.

V. Conclusion

Authors have explored the feasibility of working with a double structure combining two BGs etched by an FIB technique. This technology can also be used to realize optical waveguide reflectors and development of precise optical filters with specific spectral response characteristics. Success has been achieved in obtaining a double filtering function in wavelengths around the bands 1200 *nm* and 1550 *nm* with reflectivity as high as 96%. This technique may open the way of *N* filtering function in wavelengths using *N* combined BGs with *N* different periods.

In our objectives and perspectives we are thinking about reducing sufficiently on a similar structure the band pass so that this application can be used in the optical transmissions that involve the CDMA coding/decoding.

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