Highly confining nonlinear proton exchanged embedded waveguides on z-cut lithium niobate.

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Abstract: In this work, to fabricate highly confining embedded waveguides on LN without degradation of the nonlinear coefficient, we combined a modified direct exchange we call High Index Soft Proton Exchange (HISoPE) and a reverse proton exchange (RPE) processes. The kinetics of the RPE process is discussed, as well as its influence on the index profile. Linear and nonlinear characterizations are performed on a first realization, that illustrates the complexity of the obtained index profile.

Introduction. Fabrication of highly confining nonlinear waveguides on lithium niobate (LN) has always been a challenge. The proton exchange (PE) technique proposed in the 1980's is able to achieve a high value of $\delta n = 0.1$, however such waveguides no longer benefit from the intrinsic nonlinear properties of the substrate.1 Since then, many modifications of the PE process have been tested in order to find a compromise between the confinement and the nonlinearities. Techniques such as Annealed Proton Exchange (APE) and Soft Proton Exchange (SPE) do realize waveguides with preserved nonlinear coefficients but with a rather weak confinement, the value of the index change, being in any cases lower than 0.03 at $\lambda = 1.55 \mu$m.2-5 We have developed a new Proton Exchange process, which allows realizing waveguides on LN with a $\delta n$ of 0.1 and without degradation of the nonlinear coefficient. However, to avoid strains and stresses due to an important lattice parameters mismatch, which is typical for H:LN structures with high concentration of protons, we reconstructed the LN substrate near the surface using the Reverse Proton Exchange (RPE) process.6 Embedding a waveguide in such a way, allows “erasing” the surface layer presenting the higher mismatch and preserving the deeper part of waveguide whose index increase is at least equivalent to SPE waveguides. However, this approach is difficult to control, as the kinetics of RPE depends on the crystalline phase of the initial proton exchanged LN.7 In the present work, we discuss the main problems that one can meet during the fabrication of nonlinear waveguides using a combination of PE and RPE processes.

Planar waveguide fabrication and characterizations. 3" Z-cut wafers were used for the waveguides fabrication. The PE consists in immersing the crystal in a bath of benzoic acid (BA) containing a certain percentage of lithium benzoate (LB), which is chosen low to obtain waveguides with high index change (Fig. 1). But on the other hand this concentration is chosen as high as possible to avoid the degradation of the nonlinearities. Waveguides are fabricated in a hermetically closed and evacuated down to 3 mbar metallic container at a temperature of 300°C. The exchange time can vary from several hours to several days depending on the desired depth of the waveguide. Further characterizations of the waveguides reveals that the index profile is composed of a step section followed by a graded index section (Fig. 2) and that the nonlinear properties are non degraded. We
call them High Index Soft Proton Exchanged waveguides, and X-Ray diffraction characterization indicates that these waveguides are composed of $\kappa_2$ phase and $\alpha$ phase (Fig. 3).

For the RPE process, the crystal is immersed into a melt of KNO$_3$:NaNO$_3$:LiNO$_3$ in the proportions 1:1:0.1 and heated up to 300°C. The study of RPE kinetics indicates that the step portion of the index profile is rather rapidly erased while the RPE seems to be much slower in the graded index part of the waveguide (Fig. 4). This behavior is quite interesting and indicates that the tolerances to produce an embedded graded index waveguide should be quite loose.

Channel waveguides fabrication and characterizations. Contrary to what occurs in planar waveguides, the different kinetics of RPE raise a problem for channel waveguides fabrication. Indeed, the $\kappa_2$ part of the channel waveguide being erased more rapidly by RPE, the resulting waveguide can be quite complicated (Fig. 5). We will see in the following that a profile corresponding to the one sketched in Fig. 5 behave more or less as two highly coupled waveguides.

![Fig. 5. Channel waveguide before and after RPE.](image)

Indeed, measuring SHG as well as SPDC spectra (Figs. 6-7) of embedded waveguides fabricated in the way described above in PPLN, we could observe multiple peaks of phase matching. The distribution of these peaks cannot be explained by a multimode nature of the waveguide, but fits quite well with the assumption that the embedded waveguide behaves like a directional coupler.

Conclusion. The combination of direct and reverse proton exchange we proposed, allows realizing highly confining (up to $\delta n_e=0.1$) embedded waveguides on LN without degradation of the nonlinear coefficient. All the details concerning the first linear and nonlinear channel waveguides characterization will be presented at the conference.

References