Poling free $LiNbO_3$ waveguides for wide bandwidth nonlinear optical frequency conversion

M. Chauvet, A. Zinaoui, N. Courjal, L. Robert, S. Queste, L. Gauthier-Manuel, M. Suarez
FEMTO-ST institute, UMR CNRS 6174, University of Bourgogne Franche-Comté, 15B Avenue des Montboucons, 25030 Besançon, France

$LiNbO_3$ films are at the heart of an intense research activity due to a strong potential for RF components, exploiting piezoelectric properties, and for the development of integrated optical chips, using electro-optical and nonlinear properties [1-3]. Thanks to the latter property, optical frequencies conversion is possible which is a key process in many devices. For example, to realize intricated photon sources for optics, for MIR spectroscopy, and more generally to obtain new wavelengths from existing laser sources.
The most common approach for efficient frequency conversion in $LiNbO_3$ is based on inversing periodically its polarity (PPLN - Periodically Poled Lithium Niobate). Combining this technique with a waveguide with small effective guided mode cross section leads to normalized conversion efficiency as high as 2600 %/W/cm² at telecom wavelengths [4]. However, it is restrained by a short conversion bandwidth, typically of a few nanometers near the central wavelength. One way to increase this bandwidth consists in using tailored aperiodic poling (step-chirped PPLN). For instance, a 100 nm bandwidth has been shown in ref [5] but at the expense of a modest conversion efficiency of 9.6 %/W/cm². These cases display the trade-off between conversion efficiency and bandwidth response.

In the present work, we uncover a configuration for which a tailored high-index contrast $LiNbO_3$ waveguide provides a nonlinear second harmonic generation (SHG) with a record bandwidth response along with a high conversion efficiency. The frequency doubling component, that could also generate intricated photons, is based on a ridge waveguide built in a suspended thin $LiNbO_3$ membrane (Fig.1a). The phase matching between the two fundamental modes TE_{00} (SH) and TM_{00} (pump) is fulfilled thanks to a precisely designed waveguide cross section of few micrometers square. Standard Ti-indiffused waveguide are combined at the input and output of this nonlinear section with adiabatic tapered transition area to form a monolithic $LiNbO_3$ integrated component, as shown in Fig 1b. This arrangement greatly facilitates light coupling in the high confinement nonlinear section with a simple polarization maintaining singlemode fiber giving coupling losses less than 1dB.

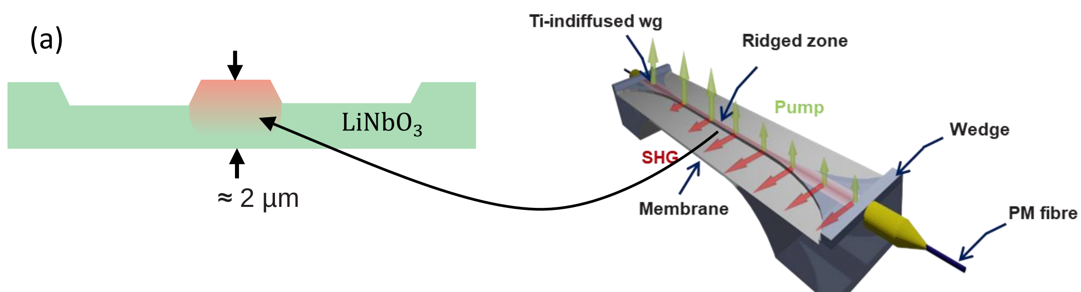

Figure 1: Structure of the nonlinear ridge waveguide membrane (a) and artistic view of the developed suspended nonlinear ridge component integrated with input and output Ti-indiffused tapered regions.

Numerical simulations reveal outstanding SHG characteristics for the integrated component. As an illustration, normalized conversion efficiency versus wavelength is shown in fig. 2 for a ridge waveguide 2µm wide and 2.15µm high and with a membrane 1.35µm thick. At room temperature phase matching is observed for two separate wavelengths centered near 1.4µm and 1.56µm, respectively. At a temperature of 30°C, the device depicts a broadband response exceeding 100 nm with a competitive efficiency approaching 60 %/W/cm² at telecom wavelengths.

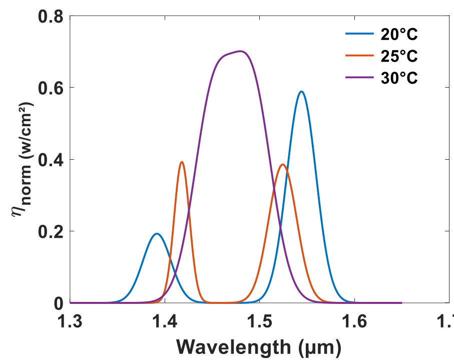

Figure 2 :Calculated conversion efficiency for a ridge waveguide 2µm wide and 2.15µm high in a 1.35µm thick membrane at three different temperature values.

The manufacturing process begins with the deposition of a 6 µm wide titanium ribbon which is further in-diffused at 1050 °C for 10 hours to form a singlemode waveguide at 1.55µm. The central ridge waveguide and the tapered region are then etched by reactive ion etching (RIE). At last a membrane is finally inscribed in the material by dicing-polishing with a precision circular saw (3350 DISCO DAD) at the back side of structure in the non-linear waveguide area. An RIE post-thinning process has been developed to achieve well-calibrated $LiNbO_3$ membrane thickness down to 500 nm still maintaining low propagation losses.
Experimental results in accordance with the predicted performances have been recently obtained and will be presented in details.

Conclusions

We have designed a $LiNbO_3$ waveguide enabling type-I second harmonic generation for the whole C-band telecommunication wavelengths by birefringence phase matching of fundamental SH and pump modes. The nonlinear component is based on a high confinement ridge waveguide made out of a thin $LiNbO_3$ membrane. Ultrawide response over 100nm along with a conversion efficiency near 50% are exposed. The performances extends to a wider range of wavelengths by temperature tuning. In addition, the elaborated device also includes Ti-indiffused standard waveguides that are adiabatically connected with the nonlinear ridge waveguide to provide an efficient and easy light coupling with singlemode fibers. This work uncovers configurations for which tailored high-contrast $LiNbO_3$ waveguides provide nonlinear conversion characteristics that can supplement PPLN structures.

References

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