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Highly efficient nonlinear waveguides in $LiNbO_3$ fabricated by a combination of Soft Proton Exchange (SPE) and E-beam writing.

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Using an E-Beam writing process we produced high quality periodical domains in SPE lithium niobate waveguides. In SHG experiment we got up to 47%/W.cm^2 conversion efficiency which is comparable to similar waveguides where the domains are obtained by other techniques.

The samples under investigation is a 0.5-mm-thick Z-cut CLN plates. The SPE process [1] was carried out in benzoic acid diluted with 3.1% of lithium benzoate (LB) at 300 °C for 72 hours, using a SiO_2 mask on Z– polar surface to fabricate the channel waveguides with different width along the X-crystallographic axes. Using a scanning electron microscope (Auriga Crossbeam workstation, Carl Zeiss) equipped with an electron-beam (e-beam) lithography system (Elphy Multibeam, Raith), we produced domain structures with various periods. The maximum length of written PPLN segment was 1.5 mm. Longer segments were obtained by moving the sample and writing several segments. The domain patterns were visualized by piezoresponse force microscopy (PFM) and confocal Raman microscopy (CRM).

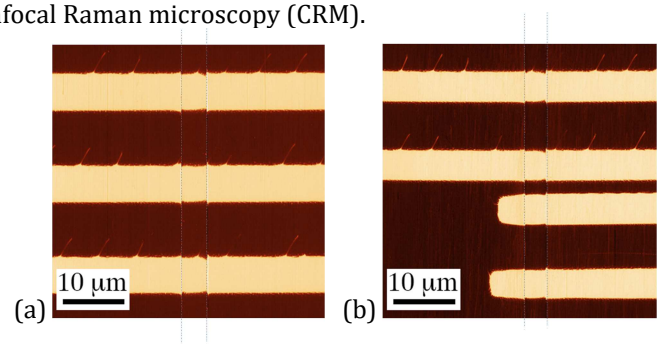

Fig. 1. PFM image of SPE waveguide (vertical) going through periodical domain structure (horizontal): dark – initial state, white – written domain. (a) inside one segment of writing (b) illustration of the stitching error between two written segments when the nonlinear grating is obtained by concatenation of several 1.5 mm PPLN sections.

Typical PFM images of the SPE waveguide going through periodical structure is presented in Fig. 1, which shows that the e-beam poling process is nearly not affected by the presence of the waveguide in contrary to what has been observed for E-field poling [2]. Moreover, we did not observe any nanodomains, contrarily to what we obtained earlier [3]. The other observed features of the written domain patterns

("fingers") can be attributed to highly non-equilibrium switching conditions during e-beam irradiation caused by gradient of spontaneous polarization in SPE layer [4].

For the SHG experiments, we used a TUNICS T100S-HP tunable laser with a fiber amplifier delivering 80mW within the wavelength range 1535 to 1570 nm. The SHG spectrums of waveguides of different widths and a 1.5 mm PPLN section are presented in Fig. 2a. The SHG efficiency was up to 47%/(W·cm^2) as high as what is obtained in PPLN waveguides produced by other techniques. The FWHM of the SHG spectra is in good agreement with the calculated one. The observed wavelength shift corresponds to the influence of the waveguide width on the effective indices of the modes.

We also characterized waveguides going through 6mm PPLN sections (4 writing segments) and presenting some stitching errors (Fig. 1b). In this case we observed a similar conversion efficiency and as expected a narrower SHG spectra but also multiple SH pics which are not completely explained yet (Fig. 2b).

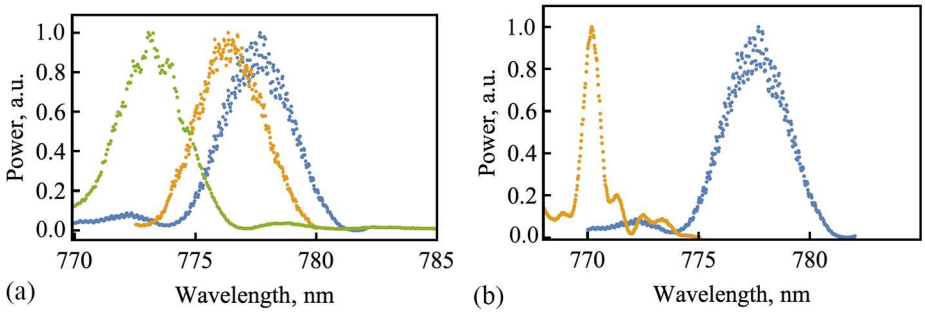

Fig. 2. SHG spectra for SPE waveguides. Parameters: (a) waveguides width 5 μm (green), 7 μm (orange), and 8 μm (blue). Period of pattern 16.2 μm, length of periodically poled section – 1.5 mm. (b) Blue spectrum – the width of the waveguide is 8 μm, the period of PPLN is 16.2 μm, the length of PPLN is 1.5 mm; orange spectrum – the width of the waveguide is 5 μm, the period of PPLN is 16.0 μm, the length of PPLN is 6.0 mm.

In conclusion, this work shows that it is possible to get state of the art SH conversion efficiency by writing the periodic domains after the waveguides fabrication. This is of capital interest for device combining nonlinear section with more complicated circuits.

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