Periodically Poled Lithium Niobate Waveguides for Quantum Frequency Conversion

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Abstract

Optical frequency conversion based on nonlinear optical interactions in periodically poled lithium niobate (PPLN) is finding widespread application in the burgeoning field of quantum information processing. Second harmonic generation in PPLN can be used to convert between the 700 - 800 nm wavelength band where single-photon emitters and detectors are most effective and the 1550 nm band for minimum transmission loss over optical fiber. Spontaneous parametric down-conversion (SPDC) in PPLN can be used to generate polarization-entangled photon pairs for quantum key distribution and other applications.

Design of PPLN waveguide-based devices for quantum frequency conversion (QFC) requires highly accurate calculation of the waveguide dispersion relation in order to determine the proper poling period, Λ, from the relation (for SHG):

$$\Lambda = 1/(n_2/\lambda_2 - (2n_1)/\lambda_1)$$

Where λ_1 and λ_2 are the fundamental and harmonic wavelengths and n_1 and n_2 are the corresponding effective mode indices. In contrast to etched ridge or step-index waveguides, the diffused waveguide technology that is used in $LiNbO_3$ poses particular modeling challenges that can be addressed through multiphysics modeling in COMSOL Multiphysics® software.

This paper presents techniques for modeling of annealed proton exchange (APE) and reverse proton exchange (RPE) waveguides in lithium niobate through a combination of time-dependent diffusion modeling and electromagnetic mode analysis using the COMSOL RF Module. Prism coupling data are used to refine the model, and calculated PPLN periods are compared with measured results. Multi-mode effects and operating temperature dependence are incorporated into the model and compared with experimental trends.

Figure 1 shows the computed impurity concentration distribution for an APE waveguide, along with the computed fundamental optical modes at 775 and 1550 nm. Figure 2 shows calculated and measured room-temperature SHG spectra. Remaining discrepancies between calculated and measured SHG spectra and possible solutions will be discussed.

Figures used in the abstract

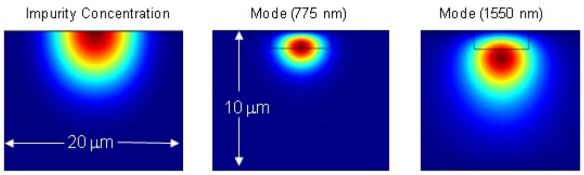

Figure 1: Computed impurity concentration distribution (left) and fundamental mode profiles at 775 (center) and 1550 nm for APE waveguide.

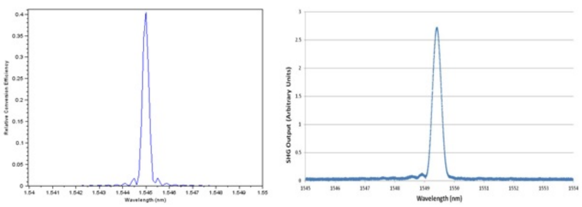

Figure 2: Computed (left) and measured second harmonic generation spectrum.