Studying of multiple-peaked second harmonic generation emission in Silicon waveguide with interdigitated contacts

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In this work we will report on second harmonic generation and on the influence of the variations of the sample geometry in periodically poled silicon waveguides.
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1. Abstract

Nonlinear silicon photonics is emerging in various applications. Notwithstanding, it is strongly limited by silicon centro-symmetry which impedes second order optical effects. Great hopes were placed in the use of strain to break this symmetry in a way that $\chi^{(2)}$ was enabled in silicon. However, as we demonstrated in [1], strain effects are extremely weak in silicon [2] and often masked by charge carrier effects. The charge induced electric field E_{DC} generates an effective second order susceptibility

$$\chi^{(2)} = 3\chi^{(3)}E_{DC},$$

via the third order nonlinear coefficient $\chi^{(3)}$. This was engineered by [3]. In this case, the electric field was generated by lateral *pn* junctions, formed across a waveguide, which induce an electric field when reverse biased. Furthermore, the periodicity Λ of the lateral *pn* junctions can be used to modulate periodically the effective $\chi^{(2)}$ in order to quasi-phase match the pump and the second harmonic modes. Two configurations are available: the single poling configuration where all the p-type doped regions are on one side of the waveguide and all the n-type doped regions are on the other side, and the interdigitated poling configuration where the p-type doped and n-type doped regions are on alternate sides of the waveguide.

We fabricated poled waveguides and found that the interdigitated poling configuration allows to obtain a stronger SHG due to the larger induced $\chi^{(2)}$ modulation. We noted also a multiple-peaked conversion efficiency spectrum. In this work we model the influence on the SHG of the fabrication limited spatial resolution which causes random fluctuations both in the width of the waveguide or in the poling period, as shown in figure (1). These two effects cause a reduction and a splitting of the SHG generation efficiency. In particular, in the undepleted pump approximation, the SH generated power is:

$$P_{SH} = P_p^2 \left|\tilde{\gamma}_{SH}^{(2)}\right|^2 L^2 S$$

where

$$S = \frac{1}{L^2}\left|\int_0^L s(z)\, e^{i\Delta\beta z}\right|^2,$$

$\tilde{\gamma}_{SH}^{(2)}$ is the nonlinear coefficient, L is the waveguide length, $\Delta\beta$ is the optical mode propagation constants difference, which is a function of the effective indices at the pump and at the SH wavelengths, and $s(z)$ is the poling function. Introducing fluctuations in the geometry leads to fluctuations in the effective index for both pump and SH mode. This contribution can be considered introducing a disorder in $\Delta\beta$. In the same way, introducing an error in the poling periodicity means introducing an error in the poling function $s(z)$. Simulations which consider a random Gaussian distribution along the waveguide of both the poling periods and $\Delta\beta$. Agreement between experiments and simulations is found with parameter variations which are compatible with the waveguide process resolutions.

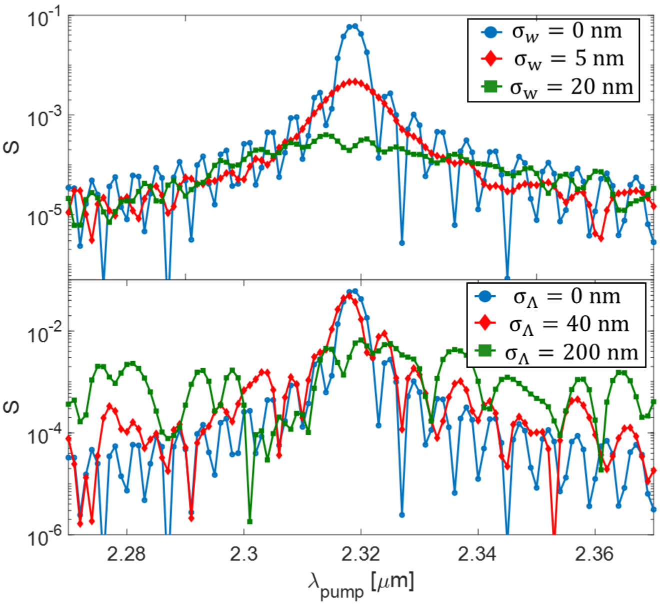

Fig. 1: effect of the disorder introduced in the width of the waveguide (up) and in the poling period (down).

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