Analysis of Stress-induced Pockels Effect in Silicon Waveguides

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Abstract

Introduction:

In recent years, strain engineering is emerging as a new frontier in Silicon Photonics. Pockels effect has been experimentally measured in strained silicon, making it a promising candidate material for realizing optical modulators and switches. In this paper we will investigate the electro-optic effect induced by applied strain gradient in silicon optical waveguides.

Use of COMSOL Multiphysics®:
In order to properly investigate and quantify the electro-optic effect in silicon waveguides, we demonstrated that to properly describe the second order dielectric susceptibility a combined optical modal and mechanical analysis is needed The cross-section of the silicon waveguide under investigation is schematically reported in Fig. 1. Our model, starting from symmetry arguments, provides an expression for the effective second order susceptibility of the form: χ (ω)=ci ζi(ω) where the coefficients ci have been calculated by fitting experimental data available in literature [1] and ζi(ω) are the overlap integrals between the strain gradient profile and the optical mode calculated with COMSOL Multiphysics.

The use of COMSOL Multiphysics was fundamental in this study, giving us the possibility of effectively linking the solid mechanics analysis to the modal analysis. The results of electromagnetic mode analysis are shown in figure 2, while the most significant strain components are reported in figure 3. The deformation of the silicon waveguides in presence of a stressing silicon nitride layer has been computed assuming 1 GPa compressive stress as the initial condition for the silicon nitride layer, and taking into account the orthotropic model for Young's module, Poisson's ratio and shear modulus.

Results:
After an accurate selections of the most important overlap integrals, we estimated the (numerical values of the) corresponding c_i by fitting the experimental data reported in ref .1 and obtained the successful comparison shown in Fig. 4.

Conclusions:
We pointed out that modelling the extraordinary second order non-linearity in strained silicon

requires the combination of optical modes and mechanical stress analysis.
The simple relation obtained for the effective susceptibility provides a powerful design and optimization tool for Pockels effect based strained silicon electro-optic modulators, reducing the computation of the electro-optic effect to standard mechanical and optical waveguides analysis.

Reference

1. B. Chmielak et. al. "Investigation of local strain distribution and linear electro-optic effect in strained silicon waveguides," Optics Express, vol. 21, 2013.

2. M. A. Hopcroft et. al. "What is the Young's modulus of silicon?," IEEE Journal of Microelectr vol. 19, 2010.

Figures used in the abstract

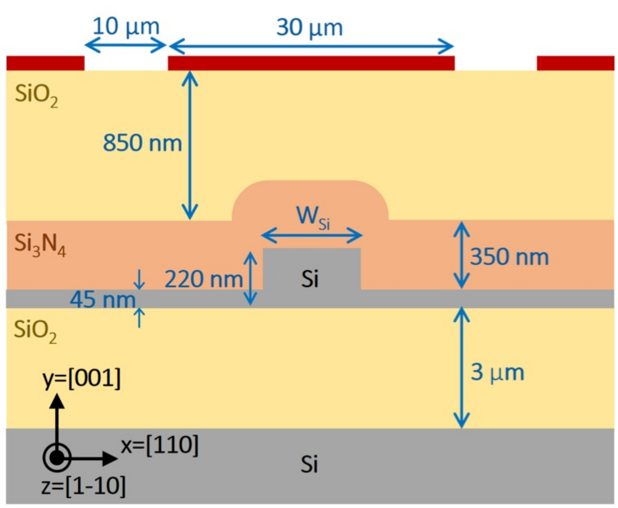

Figure 1: Cross section of the silicon waveguide in ref. 1

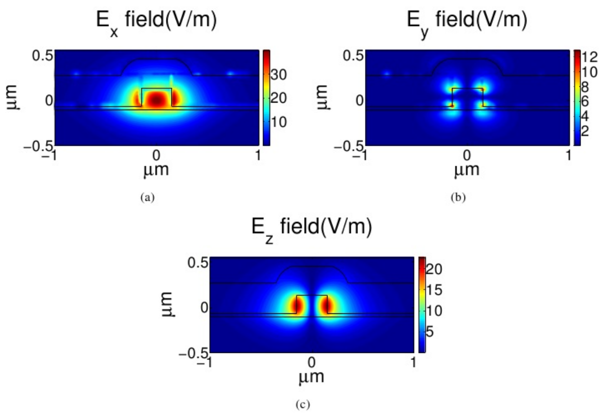

Figure 2: Electric field profile for the silicon waveguide in ref. 1.

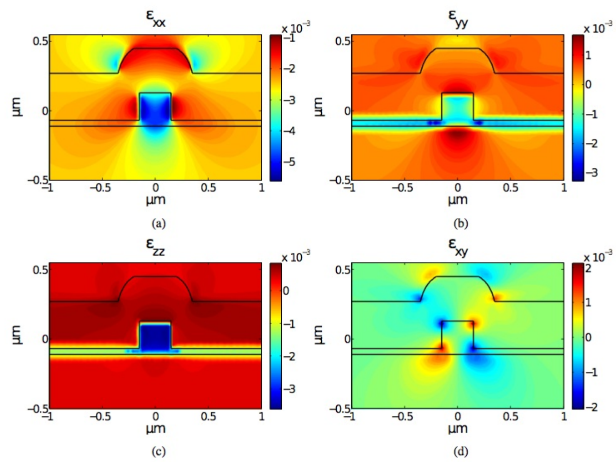

Figure 3: Principal strain profiles in the silicon waveguide in ref. 1.

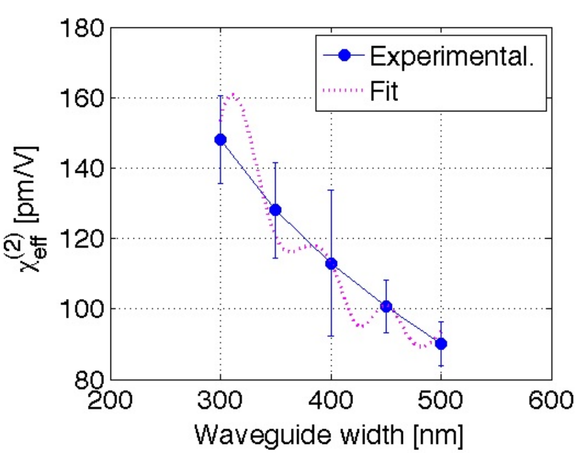

Figure 4: Comparison between experimental results in ref 1 and our fit