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Nonlinear Effects in Silicon Waveguides

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Abstract

In this work, we modelled the nonlinear effects in silicon waveguides which are crucial for many applications, including all-optical signal processing, switching, wavelength conversion. I have developed the model for ultrafast all-optical switching using split-step Fourier method and calculated the nonlinear phase shift due to the Kerr effect and including the nonlinear losses (i.e. two-photon absorption, free carrier absorption and free carrier index).

Motivation

Due to very high core refractive index (3.48), having lower cost and high compatible with complimentary metal oxide semiconductor (CMOS), the silicon ($\chi^{(3)}$ material) has attracted quite lot of researchers for many photonics applications, including

- Ultrafast all optical switching
- All optical signal processing
- Wavelength conversion[1]

Therefore, to analysing the switching, we have developed a numerical tool, based on split step method[2,3], to analyse the nonlinear effects in silicon waveguides with different nonlinear losses/parameters including:

- Pulse shape and duration
- Two photon absorption (TPA)
- Free carrier absorption (FCA)
- Free carrier index (FCI)

Nonlinear Schrodinger Equation

We have consider the following nonlinear Schrodinger equation to model the system[4].

1. $$\frac{\partial A_c}{\partial z} + \frac{\alpha_{lin}}{2} A_c + i\frac{1}{2}\beta_{2c}\frac{\partial^2 A_c}{\partial t^2} = i\left(\gamma|A_c|^2 + 2\gamma|A_p|^2\right)A_c - \frac{1}{2A_{eff}}\left(\beta_{TPA}|A_c|^2 + 2\beta_{TPA}|A_p|^2\right)A_c - N_g\frac{\sigma_c}{2}A_c - iN_g\frac{2\pi k_c}{\lambda_c}A_c$$

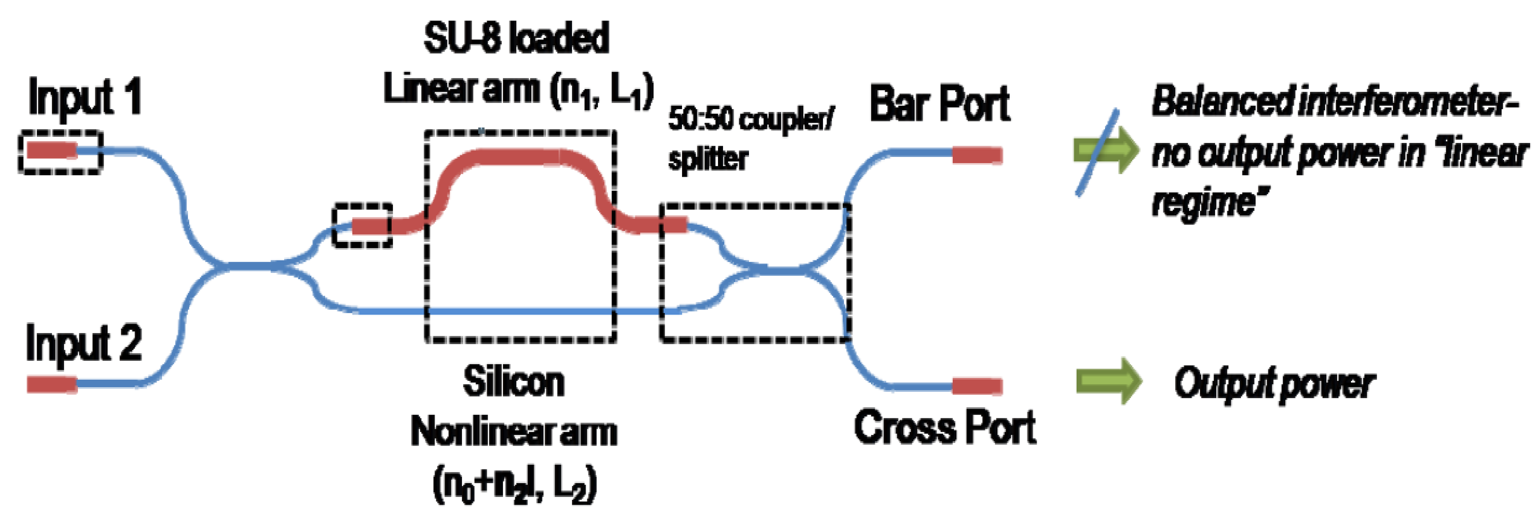
2. $$\frac{\partial A_p}{\partial z} + \frac{\alpha_{lin}}{2} A_p + i\frac{1}{2}\beta_{2p}\frac{\partial^2 A_p}{\partial t^2} = i\left(\gamma|A_p|^2 + 2\gamma|A_c|^2\right)A_p - \frac{1}{2A_{eff}}\left(\beta_{TPA}|A_p|^2 + 2\beta_{TPA}|A_c|^2\right)A_p - N_g\frac{\sigma_p}{2}A_p - iN_g\frac{2\pi k_p}{\lambda_p}A_p$$

Where,

$$\frac{\partial N_g}{\partial t} = \frac{\beta_{TPA}}{2h\nu_c}|A_c|^4 - \frac{N_g}{\tau_g}$$

Experimental setup

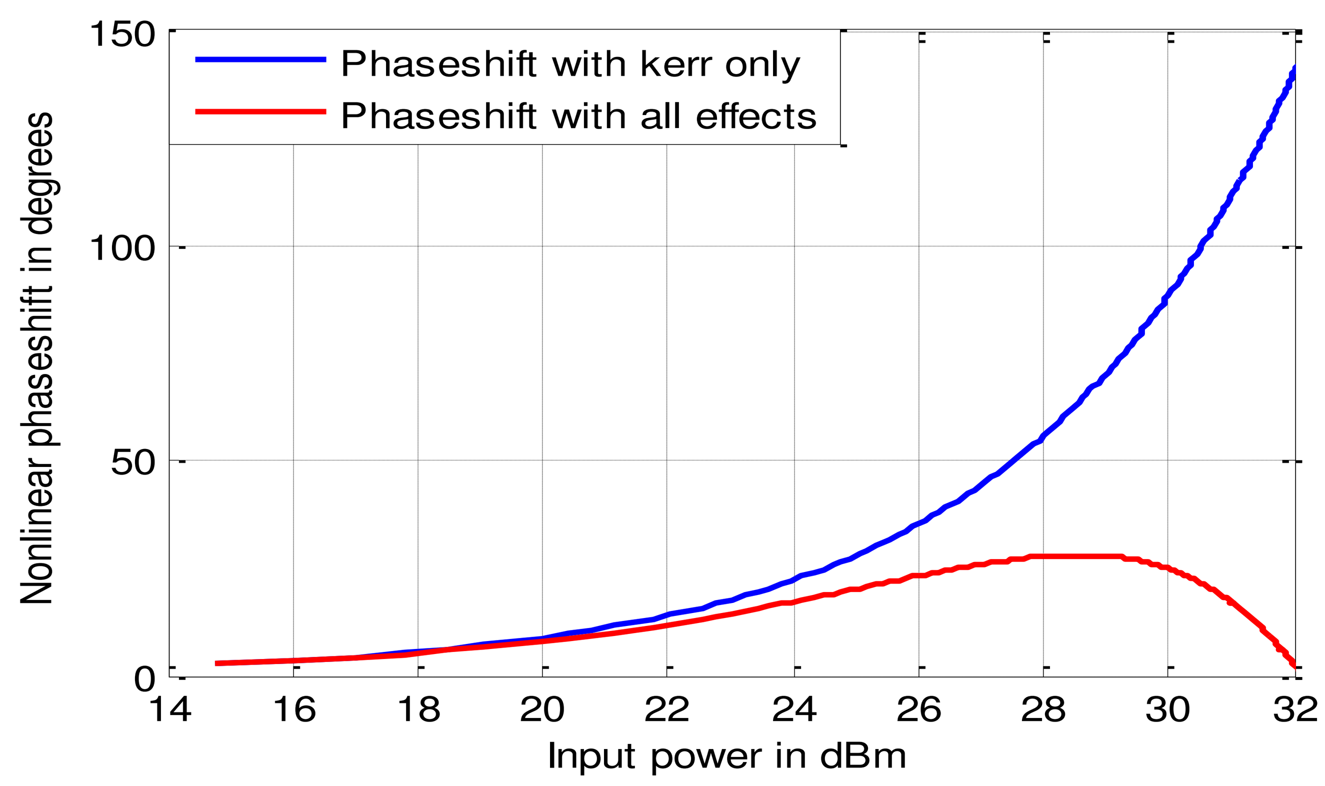
- We are considering a case explained in[3] and considering a high power signal as a pump and a low power input signal.



Simulated results

Using the model based on nonlinear Schrodinger equation, we have calculated the phase shift using Kerr effects and with other nonlinear losses (i.e. TPA, FCA and FCI).

- The effect of TPA and free carriers limits the nonlinear phase shift.
- The saturation occurs at the power of 29 dBm.



Conclusion and Future Work

- Saturation can be observed at the power of 29 dBm.
- Ultra-fast switching of optical pulses.
- Switching of optical pulses with different pulse width.
- Using silicon waveguide for mid-infrared region.

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