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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 high compatible with complimentary metal oxide and semiconductor (CMOS), the silicon ( $\chi^{(3)}$  material) has attracted quite lot of researchers for many photonics applications, including

## **Experimental setup**

• We are considering a case explained in<sup>3</sup> 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).



- Ultrafast all optical switching ullet
- All optical signal processing  $\bullet$
- Wavelength conversion<sup>1</sup> lacksquare

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

- Pulse shape and duration ullet
- Two photon absorption (TPA) lacksquare
- Free carrier absorption (FCA)  $\bullet$
- Free carrier index (FCI)  $\bullet$

### **Nonlinear Schrodinger Equation**

We have consider the following nonlinear Schrodinger equation to model the system<sup>4</sup>.

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

- The effect of TPA and free carriers limits the nonlinear phase ۲ shift.
- The saturation occurs at the power of 29 dBm.



## **Conclusion and Future Work**

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

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,

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

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