Abstract:

We experimentally realize ultrafast all-optical switching in the 1.5 µm spectral region using cross-phase modulation inside a 5 mm long silicon waveguide. Modulation depths of up to 90% and switching window durations ~ 1 ps are achieved using 500 fs pump pulses with energies below 10 pJ.

Summary of Research:

Silicon has attracted increasing attention for nonlinear applications owing to its strong third-order nonlinearity. In addition, the high refractive index of silicon enables tight optical mode confinement, promoting a more effective nonlinear interaction. Therefore, nonlinear optical phenomena in silicon have been extensively studied, such as cross-phase modulation (XPM).

In this work, we realize experimentally an ultrafast all-optical switch in a 5 mm long silicon waveguide using XPM-induced nonlinear polarization rotation (NPR), an approach proposed by us recently [1-4]. Such a Kerr shutter has been demonstrated in polarization maintaining optical fibers [5], but until now it has not been realized in silicon waveguides. Our Kerr switch does not require an interferometric configuration, yet we can obtain two modulated signals simultaneously at the output.

Waveguides are fabricated on silicon-on-insulator (SOI) wafers with a 3 µm buried oxide layer (BOX) and a thin silicon layer (thickness 400 nm). The waveguides used in our measurements are designed with a width of 600 nm and a height of 400 nm. The fabricated waveguides are air-clad on top and are aligned along the [110] direction on the (100) silicon surface using electron-beam lithography with negative-tone hydrogen silsesquioxane (HSQ) photoresist. Silicon layer is etched by inductively coupled plasma reactive-ion etching (ICP-RIE) with chlorine gas. Figure 1 shows the cross section of the fabricated silicon waveguide.

In order to reduce coupling losses, we adopt the mode-converter design of Ref. 6. Figure 2 shows the mode converter is formed by inversely tapering both ends of the silicon waveguide to a 30 nm width over a tapering length of 50 µm. Polymer waveguides (width 1.7 µm and height 2.5 µm) are aligned on top of the silicon nano-taper. The polymer waveguides are defined by i-line (365 nm) stepper lithography with misalignment of less than 0.3 µm. The wafers are cleaved along the crystal orientation. Propagation losses of the two fundamental TE and TM modes are below 10 dB/cm. Coupling losses are calculated by subtracting
propagation losses from the measured insertion loss, resulting in a coupling loss of 7 ± 1 dB for the TE mode and 8 ± 1 dB for the TM mode.

We launch pump pulses and CW probe in the waveguide for realizing Kerr switching. Input pulse width is 500 fs at wavelength of 1560 nm. The temporal width of the switching window of the probe is resolved using an autocorrelator. Figure 3 shows the measured switching windows with different pump peak powers. For peak powers below 2 W, the FWHM of the traces is 1.1 ps. Assuming a hyperbolic secant shape for the switched probe signal, we estimate the width of the switching window to be 700 fs. The walk-off effects currently limit the switching window, and the modulation depth is mainly limited by the two-photon absorption.

References: