Optical Crosstalk in a Silicon Nanowaveguide

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Abstract: We characterize optical crosstalk and the associated bit-error rate degradation in silicon nanowaveguides. Results indicate that crosstalk decreases with increasing modulation frequency, which we attribute to free-carrier lifetime in the nanowaveguides.

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Wavelength-division-multiplexed (WDM) communication systems have attracted significant interest in recent years, due to the large bandwidth that can be utilized for data transmission. However, data transmission in these multiplexed wavelength channels is accompanied by optical crosstalk. In fiber-based WDM systems, the primary source of crosstalk comes from individual components and from nonlinear effects, including cross-phase modulation (XPM), stimulated Raman scattering (SRS), and optical Kerr effect-polarization dependent loss (OKE-PDL) [1-4]. Recent demonstrations have shown that silicon has potential as a platform for integrated WDM networks [5-7]. In silicon, sub-micron-size waveguides are required for single-mode operation [8]. These dimensions allow for high confinement of the optical mode, which enhances the nonlinearity [9]. While this is desirable for parametric processes such as four-wave mixing, this could also be a coupling mechanism for inter-channel crosstalk. Since crosstalk will hinder the performance of silicon-based on-chip WDM systems, it is essential to understand its causes and impact on optical networks. In this paper we characterize crosstalk in a silicon nanowaveguide by measuring the amount of crosstalk and the signal bit-error rate (BER) for various data rates. Our results indicate that an important contribution to crosstalk in silicon nanowaveguides arises from a combination of two-photon absorption (TPA) and free-carrier absorption (FCA).

We define crosstalk to be [4],

$$\text{Crosstalk}\,(dB) = 10\log\left(\frac{\text{RF power at } \lambda_{signal}}{\text{RF power at } \lambda_{pump}}\right). \tag{1}$$

In our experiment, the signal and pump are combined, amplified, and sent into a nanowaveguide. A preamplifier is inserted in the pump arm to adjust the relative power between the signal and pump waves. For crosstalk measurements, both the signal and pump are generated using a clock source that drives a Mach-Zehnder modulator. The signal modulation frequency is fixed at 9.953 GHz while the pump modulation frequency is varied from 50 MHz to 9.95 GHz. The output from the nanowaveguide is amplified, filtered and sent into a photodiode and an electrical spectrum analyzer (ESA). We measure the RF power at the pump modulation frequency for both the signal and pump input wavelengths by tuning the tunable bandpass filter (TBPF). For bit-error rate (BER) measurements, both the signal and pump are generated using a pattern generator with a 2^{31}-1 pseudo-random bit sequence (PRBS). The data rate is fixed at 9.953 Gb/s for both the signal and the pump. The output from the nanowaveguide is amplified, filtered, and sent through a variable optical attenuator (VOA) into a 10-Gb/s lightwave receiver and a bit-error-rate tester (BERT). For both measurements, the output spectrum from the nanowaveguide is monitored using a tap coupler.

Figure 1(a) shows crosstalk on the signal as a function of the pump modulation frequency. The signal and pump power inside the nanowaveguide are 3 dBm and 13 dBm, respectively. We observe that the crosstalk is dependent on the modulation frequency, which we attribute to free-carrier absorption induced by two-photon absorption in the nanowaveguide. Figure 1(b) shows crosstalk as a function of pump power. We observe lower crosstalk and smaller variations with respect to pump power at higher pump modulation frequencies.

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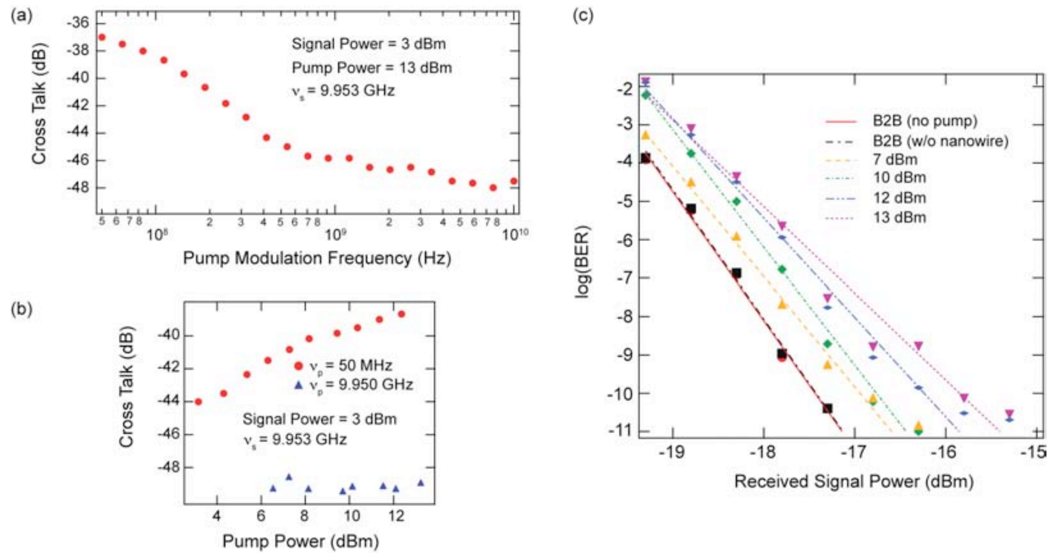

Fig. 1. Experimental results. (a) Crosstalk as a function of pump modulation frequency. (b) Crosstalk as a function of pump power. (c) BER measurement for various signal powers. The numbers represent the power inside the nanowaveguide. Two back-to-back measurements are performed, one with no pump and the other with the nanowaveguide removed from the setup.

Figure 1(c) shows the BER measurement for various power levels for multi-wavelength operation in the nanowaveguide. The signal (1554 nm) and the pump (1550 nm) are generated using a pattern generator with a pseudo-random bit sequence (PRBS) at 2^{31}-1 with a data rate of 9.953 Gb/s. In order to prevent correlated patterns in both inputs, a timing offset of approximately 20 μs is introduced between the signal and the pump. The power levels of both modes are equalized and sent into the waveguide. The signal and pump powers inside the nanowaveguide are varied from 7 dBm to 13 dBm. Two separate B2B measurements are performed, the first with the pump off and the second without the nanowaveguide. This indicates that the crosstalk is due to the interaction of the signal and the pump.

In conclusion, we have characterized crosstalk in a silicon nanowaveguide. Our results indicate that the crosstalk on the signal is dependent on the pump modulation frequency, which can be attributed to free-carrier lifetime in the nanowaveguide. BER measurements indicate that the signal degradation is dependent on both the pump modulation frequency and the signal power. For multi-wavelength operation, the signal power levels must be optimized to minimize crosstalk between channels, and the utilization of amplitude invariant modulation formats such as phase-shift keying should be considered.

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