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Slow light in Silicon Nano-waveguide

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Abstract *We propose a widely tunable slow-light delay element based on nano-scale silicon microring resonator assisted by parametric amplification. This scheme provides flexible adjustment of the delay time and bandwidth to adapt to different data rates.*

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Introduction

Slow lights can be achieved based on linear and nonlinear optical signal processing techniques [1]-[5]. Nonlinear effects in resonators including self phase modulation (SPM) and Raman effect have attracted much interest recently due to the enhanced intra-resonator intensity and the effective path length [5][6]. Here, for the first time to the best of our knowledge, we propose a microring resonator assisted by parametric amplification in nano-silicon waveguide to realize widely tunable slow-light delay and variable bandwidth for different data rates. We find that a weak parametric gain per round trip in the ring is sufficient to compensate the loss so that the transmission spectrum of the resonator can be continuously changed from the deep notch to a unit gain, thus the effective bandwidth and the delay of the slow-light resonator can be adjusted according to the data rate of the signal. Furthermore, we use a figure of merit (FOM) to quantify the signal quality of return-to-zero (RZ) signal under different data rates and delay requirements.

Parametric amplification in microring resonator

In this study, we consider a single coupled nano-Silicon microring resonator with a circumference of 60 μm (see the inset in Fig. 1). The nano-SOI waveguide used in the simulation is designed to be 250-nm height and 500-nm width, with an effective refractive index of 2.68 and a mode area of 0.12 μm^2. These lead to dispersion parameters of β_2 = -0.4 ps^2/m and β_4 = 5.2×10^{-7} ps^4/m at a pump wavelength λ_p in the vicinity of the resonance wavelength at 1576.47 nm. The signal wavelength is λ_s = 1531.42 nm, three times of the free spectral range (FSR) away from the pump wavelength. We assume that free carrier absorption effect is negligible by employing certain techniques such as applying an external electric field or introducing non-radiative centers [7]. The nonlinear refractive index n_2 and the two photon absorption (TPA) coefficient β_T are 7×10^{-14} cm^2/W and 0.45 cm/GW [7]. In order to achieve large tuning range in delay, the resonator is operated near the critical coupling point with a coupling coefficient r = 0.22 and an attenuation of 3.5 cm^{-1}. The linear transfer function of a ring resonator can be written as [6]:

$$T(\omega) = \frac{t - a\exp(i\phi)}{1 - t\exp(i\phi)} \qquad (1)$$

where $t = \sqrt{1-r^2}$ is the transmission coefficient; *a* contains the per-turn loss, parametric gain and TPA induced loss, *Φ* contains both the linear and the amplification-induced nonlinear phase shifts.

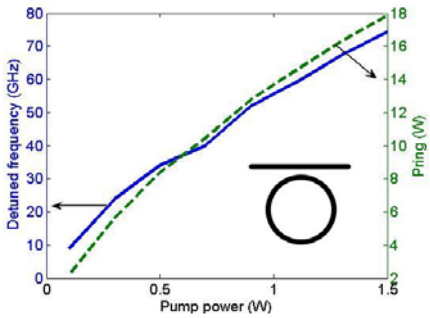

Fig. 1: Detuned frequency of the pump from the resonance (solid curve) and peak power coupled in the resonator, i.e. Pring (dashed curve) vs. λ_p. Inset: single coupled microring resonator.

As the nonlinear phase shift of the pump induced by SPM would red-shift the pump off the resonance, the pump should be detuned from the resonance so that the generation of parametric gain is maximized. Fig. 1 shows that both the detuned frequency and the power coupled in the resonator increase with the pump power. When the peak pump power is 0.1 W, the parametric gain is negligible and there exist deep notch in the transmission and sharp transition in the phase. We then utilize parametric amplification in microring resonator to achieve an optically tunable slow-light element. Simulations show that large delay ranging from ~18 ps to ~150 ps for data rates from 20 Gb/s to 1 Gb/s with low signal distortion [8] can be achieved.

References

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