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High-rate data buffering in silicon nanophotonic devices

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A silicon microring resonator based on shifts induced by the thermal nonlinear effect shows promise for managing delays in data transmission with minimal distortion.

Buffers represent one of the most important components in a communications router. The device must be able to store data packets for a substantial period of time and release the data within an acceptable delay when the switch is clear. Optical buffers—devices that store optically transmitted data—are considered key elements to achieve synchronized and contention-free traffic in the design of all-light-based communication networks. Conventional buffers use optical fiber delay lines, but since the delay is for a fixed amount of time, they are unable to guarantee contention-free connections in the switch or through a network. Hence, research on tunable optical delay lines is generating significant interest, especially with optical communications now gearing up for large-scale integration.

Advances in silicon technology are making this material a choice candidate for future integrated photonics. On-chip delay lines based on silicon-on-insulator (SOI) photonic wire waveguides were recently demonstrated, consisting of up to 100 microring resonators cascaded in either coupled-resonator or all-pass filter (APF) configurations with error-free operation up to 5Gbps.[1] This demonstration was a major milestone in the development of all-optical buffers for interconnects. Tunable delays in an SOI planar waveguide based on slow light induced by stimulated Raman scattering (SRS) have also been reported,[2] as well as intensity-tunable group delays in silicon microresonators enhanced by SRS.[3]

The functional mechanism of a ring resonator-based optical delay line can be described as follows: When a probe beam is injected into a ring with a frequency matching the resonance of the ring, light is forced to circle multiple times, lengthening the delay. If beam frequency deviates from resonance, it will bypass the ring and no delay will occur. When a pump light, whose frequency is of a different resonance, is injected into the microring resonator, the absorbed energy is eventually converted to thermal energy, altering the refractive index and resonance conditions. In silicon, the thermo-optic coefficient is very large, and the thermal nonlinear effect has a low power threshold. Therefore, the group delay of the signal can be changed by modulating the pump light power.[4]

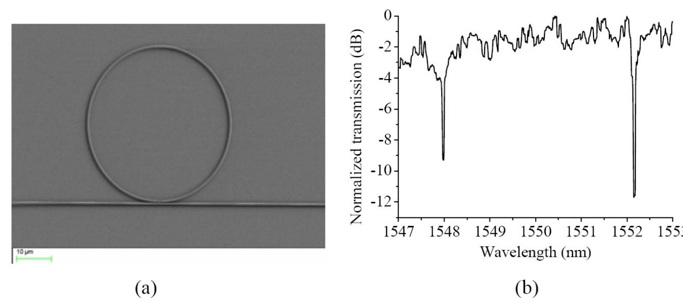

Figure 1. *(a) Scanning electron microscope image of a microring resonator and (b) its resonance spectrum.*

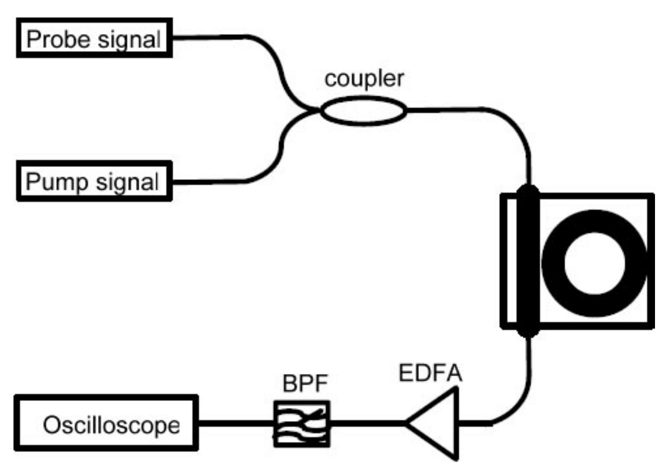

Figure 2. *Experimental setup for a tunable microring delay line. BPF: Bandpass filter. EDFA: Erbium-doped fiber amplifier.*

We have fabricated a silicon microring resonator on an SOI wafer consisting of a 250nm-thick silicon slab on top of a 3μm

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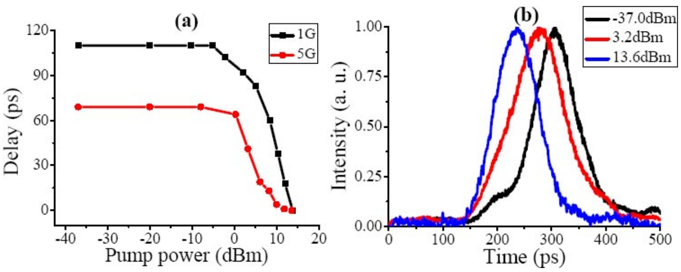

Figure 3. *(a) Delay of the 1 and 5Gbps RZ signals vs. pump power from the input fiber. (b) Waveforms of the delayed RZ signals at a data rate of 5Gbps. dBm: Decibels below 1mW.*

silica buffer layer. The cross-section of the silicon waveguide is 450×250nm with a mode area of ∼0.1μm^2 for the transverse-electric optical mode. A microring with a radius of 20μm is side-coupled to the straight waveguide with an air gap of 120nm between the two structures. A scanning electron microscope image of the silicon microring resonator is shown in Figure 1(a), and the experimental setup is depicted in Figure 2.

The pump and the probe signal sit at two adjacent resonances in the vicinity of 1550nm, as illustrated in Figure 1(b). The probe signal is a 2^7-1 return-to-zero (RZ) pseudo-random binary sequence signal. The pump signal is a continuous wave. Figure 3(a) shows the delay of the 1 and 5Gbps RZ signals as a function of pump power when the RZ signals are initially at the center of the resonance. Figure 3(b) shows the corresponding waveforms of the 5Gbps RZ signals at typical pump powers. The maximum delay is ∼110ps for the 1Gbps signal and 70ps for 5Gbps. The threshold of the pump power is ∼0dBm (∼–10dBm into the microring resonator).

Single microring resonators represent the building blocks of more complex nanowaveguide-based structures such as periodically distributed microresonators. These include single-channel side-coupled integrated spaced sequence of resonators (SCISSOR) devices and coupled-resonator optical waveguide (CROW) structures, respectively referring to parallel and serial cascaded ring architectures. Our proposed optical tuning method may be used in these slow-light structures to tune the microring resonators over a wide range. Future steps include designing and optimizing new microring structures that would enable significantly greater delays for higher-rate signals and less distortion.

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