# High Data Rate Signal Integrity in Micron-Scale Silicon Ring Resonators

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**Abstract:** A ring resonator with a FWHM of 0.095 nm (11.6 GHz) is experimentally measured to have a 1.4 dB power penalty for a 10 Gbps NRZ OOK signal, due to spectral distortions. Numerical simulations match these results.

**OCIS codes:** (230.3990) Microstructure devices; (230.5750) Resonators; (120.7000) Transmission

## 1. Introduction

Micron-scale ring resonators have been drawing increased interest as compact photonic components that allow for an unprecedented degree of control over salient optical properties [1], while maintaining a structure which is suitable for high-density integration. Silicon waveguides and resonator structures can be fabricated with low propagation loss [2], and offer the potential for photonic components to be integrated with CMOS circuitry. High performance devices, such as electro-optic and all-optical modulators, can be made from these ring structures [3],[4]. However, because these devices generally require high *Q*, degradation to the propagation of signals with high modulation data rates may be a concern. We show that this degradation is not critical, and use receiver power penalty to quantify the effect.

## 2. Experimental measurements

A passive ring resonator of the same type as those detailed in [3],[4] was fabricated (Fig. 1), and at a center frequency of 1564.62 nm, the *Q* factor was measured to be 16,500 (Fig. 2). With a FWHM of 0.095 nm (11.6 GHz), it is likely that the transmission characteristics of the ring resonator will have an effect on the propagation of a 10 Gbps NRZ OOK signal passing through the drop port (which passes wavelengths at or near resonance). This is because the sidebands of the 10 Gbps NRZ signal (Fig. 2) span 0.102 nm (allowing for a typical 25 % sideband margin [5]), which is on the same order as the resonance width.

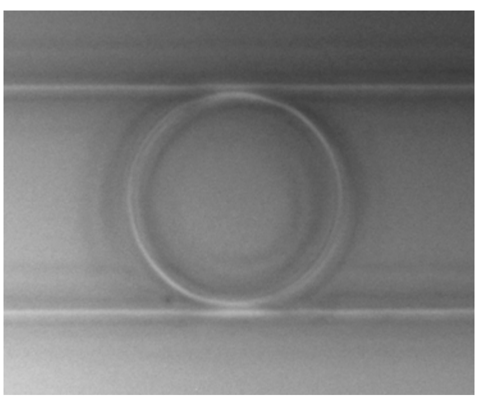

Fig. 1. Micrograph of the ring resonator device, which has a diameter of 10 μm and a waveguide–ring gap of 200 nm.

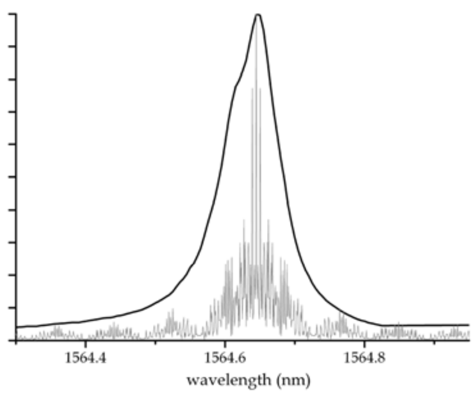


Fig. 2. Plot of the ring resonator wavelength response with the power spectrum of a 10 Gbps PRBS signal superimposed.

In order to investigate the impact of the ring resonator transfer function, an amplitude Bode plot for the ring resonator's response to modulation frequency was generated (Fig. 3). Although the impact of the phase response is not trivial, its effects are minimal compared to the effects of the amplitude response. These data were measured by modulating a continuous wave laser signal at 1564.62 nm (device resonance) with sinusoidal signals (PRBS data for power penalty) using a $LiNbO_3$ modulator. The signals are introduced to the silicon waveguide by a tapered fiber and passed through a series of waveguide turns before entering the ring resonator device. The TE mode output of either the through port or the drop port of the resonator is directed to an EDFA and ASE filter, which compensates for the coupling and waveguide losses. This output signal is detected by a high-speed receiver for analysis. In order to obtain back-to-back measurements, the laser wavelength was changed to 1563.62 nm, resulting in signals exiting at the through port. Because this wavelength is so far from resonance, the signals are affected only by the waveguide, allowing the properties of the ring resonator to be isolated.

The amplitude Bode plot illustrates that the ring resonator has a 3-dB cutoff frequency of 9.0 GHz; this corresponds to 77 % of the ring resonator FWHM. Therefore, for a 10 Gbps NRZ signal, it is expected that the higher order sidebands experience significant attenuation since they are well above this cutoff frequency. Because higher frequency sinusoids result in modulation sidebands that are further displaced from the fundamental frequency, these signals experience more attenuation due to the transfer function of the drop port of the ring resonator. Moreover, this attenuation affects higher frequency components more, resulting in distortion of NRZ data that leads to transition edge lengthening. These waveform distortions result in increased bit error rate (BER), which can be quantified by the receiver power penalty, defined as the additional power margin required to restore received signal quality and overcome the degradation introduced by a given device [5]. For the previously described ring resonator, a power penalty of 1.4 dB was measured at a BER of $10^{-9}$ for a $2^{31}$–1 PRBS (Fig. 4).

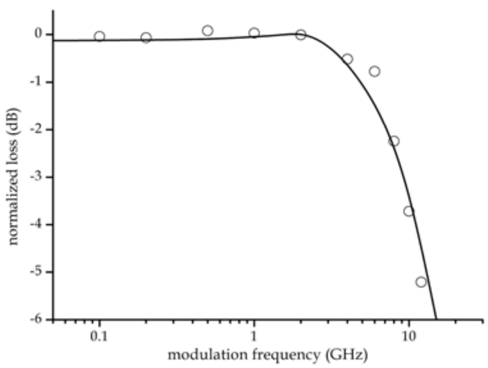


Fig. 3. Amplitude Bode plot for the ring resonator's drop port, including both experimentally measured (○) and numerically simulated (—) data.

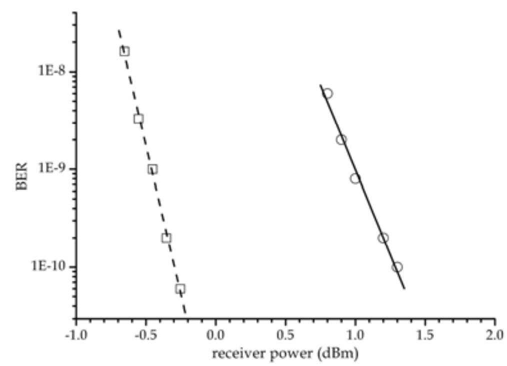


Fig. 4. Plot of BER as it varies with receiver power for the through port (□; back-to-back case) and for the drop port (○). The receiver power penalty is accordingly determined to be 1.4 ± 0.1 dB.

## 3. Numerical simulations

Based upon the empirically measured ring resonator wavelength response, a Fourier transform-based numerical simulator was created. The effect of the ring resonator is considered to be a simple frequency domain transfer function, and time domain characteristics are obtained from the inverse Fourier transform. The resolution of the Fast Fourier Transform (FFT) algorithm used is 0.031 GHz (0.0002 nm).

The simulation of the experimental setup yields an amplitude Bode plot, which agrees very well with the experimentally measured data points, and exhibits 3-dB cutoff frequency of 8.9 GHz (Fig. 3). Numerical calculation of the extinction ratio for the simulated output PRBS waveform indicates a receiver power penalty of 1.1 dB [5]. Both of these metrics deviate from the experimental measurements by less than 7 %.

## 4. Conclusions

We have shown that a ring resonator with a FWHM (in GHz) that is 116 % of the data rate (in Gbps) for an NRZ OOK signal has a power penalty of just 1.4 dB, which supports the prospect of cascading and integrating these components to compose photonic integrated circuit systems. Furthermore, we have related the signal degradation, as measured by the power penalty, to the modulation frequency response illustrated in the amplitude Bode plot. As demonstrated with experimental data and through numerical simulations, ring resonators provide sharp transfer functions which can strongly affect modulation sidebands, and hence, signal integrity. These effects must be taken into consideration when designing devices with high *Q* to be used for switching of high-speed data.

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