Coherent Perfect Absorption in a Silicon Photonic Ring Resonator

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Abstract: We present the first experimental demonstration of coherent perfect absorption (CPA) in an integrated device. By leveraging the effects of CPA, phase-controlled modulation is achieved in a silicon photonic ring-resonator with an extinction of 8.12dB.

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1. Introduction

As the need for high-speed and energy efficient data communication continues to grow, on-chip photonic interconnection networks are an increasingly integral platform for delivering the required high capacities of data. Over the past decade, silicon photonic (SiPh) integrated devices have been shown to support dense optical communications bandwidths through multiplexing aggregate wavelengths via wavelength-division multiplexing (WDM). The optical modulator, a key component of these chip-scale optical communication systems, has typically been comprised of microring resonator or Mach-Zehnder interferometer (MZI) elements.

Integrated optical modulators using microring resonators are well suited for dense integration due to their low power usage, small area, and high extinction ratio [1]. These modulators typically use free carrier effects to shift the resonance of the microring. However, a relatively new type of optical modulator has been designed to utilize a combination of super position and critical coupling, known as coherent perfect absorption (CPA), whereby the absorption in a resonant cavity is controlled interferometrically [2]. While integrated CPA-based modulators and switches have been proposed for microring resonators [3,4] and plasmonic structures [5], an experimental demonstration of such a device has yet to be achieved. Here, a CPA ring resonator is characterized for the first time, demonstrating a 7.85 dB switch value when switched by π degrees in phase, corresponding to 8.12 dB in resonant extinction.

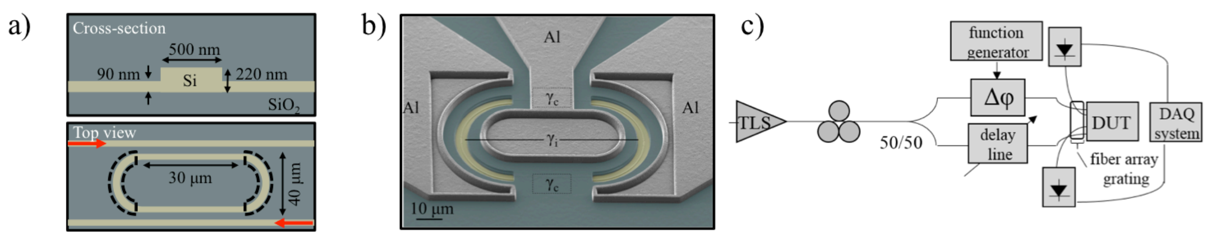

Fig. 1: a) Top: Illustration of waveguide cross-section. Bottom: Visual representation of two input and two output device operation. b) false color SEM image of ring-resonator structure. γ_i is the internal loss and γ_c is the coupling loss c) Experimental setup for the two measurements performed on the device under test (DUT). OSA: Optical Spectrum Analyzer, TLS: Tunable Laser Source, DAQ: Data Acquisition unit. Lines to TLS and DAQ are electrical cables. The rest are optical fibers.

2. Device Characteristics and Operation

The device was fabricated at Singapore Institute of Microelectronics (IME) on a silicon-on insulator (SOI) platform with a 220 nm silicon device layer and a 2 μm buried SiO_2 layer with dimensions shown in Fig. 1a and Fig. 1b. The length of the straight segment of the racetrack was 30 μm and the coupling length was set to 10 μm, and a center-to-center coupling distance of 820 nm. To enable CPA, absorption was induced in the resonator *via* ion-implantation through windows in the top cladding of the curved region of the ring (Fig. 1b) to create divacancy lattice defects. The absorption in the ring can be controllably reduced through annealing steps to achieve critical coupling in the ring [6].

3. Results and Discussion

There were two main characterizations performed on this device. The experimental setup for these characterizations is shown in Fig. 1c. The device coupling is achieved with holographic grating couplers and a fiber array. Phase modulation is performed off-chip using a $LiNbO_3$ electro-optic phase modulator. First, by syncing the continuous wavelength (CW) laser source with the optical spectrum analyzer (OSA), fast wavelength sweeps were performed. This measurement, shown in Fig. 2a, exhibited the extinction ratio of the device and corresponded with the profile theoretically derived. Several trials were taken and averaged due to the fiber-induced phase fluctuations limiting the accuracy of each trial. The average of each V=0 and $V=V_\pi$ was then fit to the theoretical profile, which was derived by temporal coupled-mode theory (TCMT) in [4]. Next, in order to verify the full phase amplitude modulation range of the device, a linear ramp voltage generated by the function generator was applied to the phase modulator inline to one arm to impart a $\Delta\varphi$ phase difference between the two inputs of the CPA modulator. The two output arms of the device are collected with photodetectors and transferred to the DAQ in the computer, sampling at a rate corresponding to the generated signal. Fig. 2b shows the resulting phase controlled amplitude modulation as a function of the applied voltage.

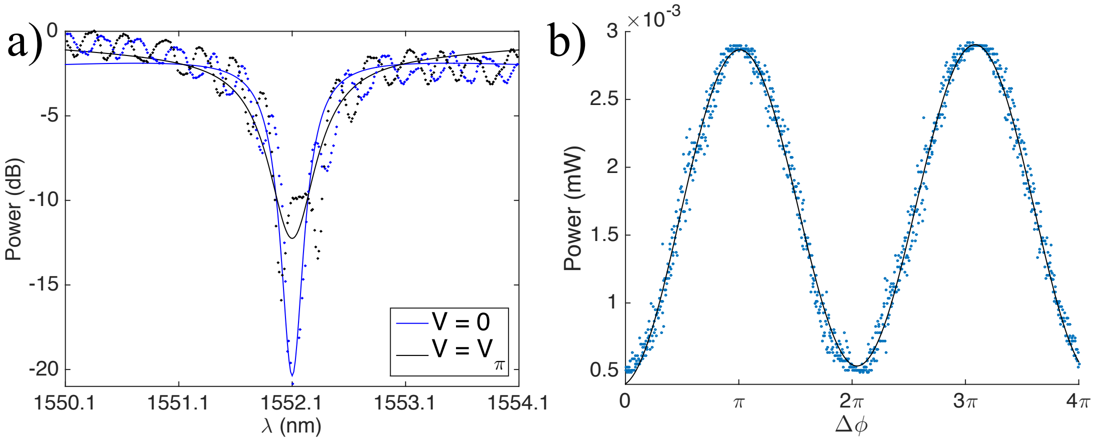

Fig. 2: a) Normalized power (dB) vs. wavelength (nm) over 1552.1 nm resonance across 4 nm span b) Amplitude modulation vs. phase difference at resonance (1552.1 nm). Blue dots represent data and black line represents best fit.

By inspecting a specific lineshape of the ring resonance, we can compare the difference in the extinction ratio of Fig. 2a with the modulation depth shown in Fig. 2b. As mentioned, this modulation depth was acquired by the shifting of extinction when the phase difference between interfering beams is varied by V_π.

The difference in extinction between bias voltage V=0 and $V=V_\pi$ is seen to be 8.12 dB, while a modulation depth of 7.85 dB shown in Fig. 2b. This 3.3% discrepancy is accounted to off-chip random phase fluctuations in the optical fiber. The relative phase cannot be precisely known because of the possible phase drift between successive wavelength scans. Note that this uncertainty does not apply to Fig. 2b since data acquisition was performed on an order greater than the rate of random phase fluctuations. From the lineshape of Fig. 2a, we also find that the Q factor is 1724 for $V=V_\pi$ and 2874 for V=0.

3. Conclusion

This is the first demonstration of on-chip, phase-controlled modulation through CPA. The resonator is characterized to have a 7.85 dB switch value when switched by π degrees in phase, corresponding to 8.12 dB in resonant extinction.

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