Integrated Microring Resonator as a Perfect Absorber

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Abstract

Coherent perfect absorption is demonstrated in an integrated microring resonator laterally coupled to two optical waveguides. Two counterpropagating waves of equal phase and intensity are launched into the microring resonator and eventually they get absorbed.

Integrated microring resonator as a perfect absorber.

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Abstract: Coherent perfect absorption is demonstrated in an integrated microring resonator laterally coupled to two optical waveguides. Two counterpropagating waves of equal phase and intensity are launched into the microring resonator and eventually they get absorbed. As the microring resonator is critically coupled to the optical waveguides

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1. Introduction

In quite an interesting work by Chong et. al., time reversal lasing and interferometric control of absorption was reported [1]. They used a silicon wafer acting as a Fabry Perot cavity, illuminated from both sides with two counterpropagating coherent beams. They demonstrated the total control of absorption by varying the input waves relative phase. This absorbing device was termed as a Coherent Perfect Absorber (CPA) [2]. The CPA idea, as a time-reversed laser, has received great deal of attention and stimulated theoretical and experimental studies into different fields like plasmonics [3], graphene optics [4], acoustic waves [5], terahertz optics [6], photonics crystals [6], and quantum optics [7]. In the latter, for example, the possibility of absorbing single photons was investigated. Among the applications found for the CPA the more prominent are in integrated optical circuits where they may be used as optical modulators, transducers, detectors, and optical switches based on silicon (Si) waveguide or ring resonator technology.

In this work we investigate the design, simulation, fabrication, and characterization of an integrated microring resonator as a perfect absorber. Using the coupled mode theory to analyze the proposed device, we derive a set of conditions to achieve perfect absorption, subsequently we realize simulations to prove the analytic results.

2. Design

A model of the proposed device is presented in Fig. 1. The CPA consists of one lossy microring resonator laterally coupled to two optical waveguides. Each waveguide has an input/output channel labeled as a_l^+ / a_l^-. With this model and using the coupled mode theory we arrive to the device transfer matrix:

$$\begin{pmatrix} a_r^- \\ a_r^+ \end{pmatrix} = \frac{1}{i\sin\theta}\begin{pmatrix} \cos\theta & -1 \\ 1 & -\cos\theta \end{pmatrix}\begin{pmatrix} e^{-iknL/2} & 0 \\ 0 & e^{iknL/2} \end{pmatrix} \times \frac{1}{i\sin\theta}\begin{pmatrix} -\cos\theta & 1 \\ -1 & \cos\theta \end{pmatrix}\begin{pmatrix} a_l^+ \\ a_l^- \end{pmatrix} \tag{1}$$

where L is the ring perimeter, λ is the operating wavelength and k is $2\pi/\lambda$. The refractive index has the form $n = n_i + n_r$ with $n_r > 0$ for a lossy medium. The most striking results are obtained at resonance $(\phi = 2m\pi)$, then we have:

$$\begin{pmatrix} a_r^- \\ a_r^+ \end{pmatrix} = \frac{1}{\sin^2\theta}\begin{pmatrix} e^{\gamma/2}\cos^2\theta - e^{-\gamma/2} & -2\sinh\frac{\gamma}{2}\cos\theta \\ 2\sinh\frac{\gamma}{2}\cos\theta & e^{-\gamma/2}\cos^2\theta - e^{\gamma/2} \end{pmatrix}\begin{pmatrix} a_l^+ \\ a_l^- \end{pmatrix} \tag{2}$$

where $\gamma = kn_i a$ is the distributed loss coefficient. The condition for perfect absorption is that reflections are null for both incident waves,

$$\begin{aligned} a_l^+, a_r^+ &\rightarrow \text{finite} \\ a_l^-, a_r^- &= 0 \end{aligned} \tag{3}$$

therefore the transfer matrix elements must satisfy:

$$T_{11} = 0 \text{ and } a_r^- = T_{21} a_l^+ \tag{4}$$

from the last conditions, we find that for perfect absorption must be satisfied $\cos\theta = \exp(-\gamma/2)$. The last condition says that the coupling losses must be equal to the half trip internal losses, this condition is known as the critical coupling in the literature [8]. The previous condition is exclusively determined by the device and it is independent of the initial conditions. In addition, the previous condition shows that the initial conditions must also satisfy $a_r^+ = a_l^+$ to have perfect absorption.

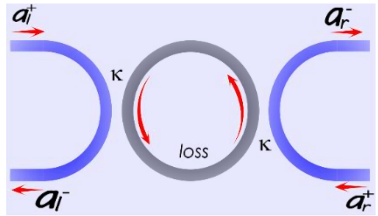

Fig. 2. Schematic model of the proposed CPA with a lossy 50 μm radius micro ring resonator. Input and output wave intensities are marked with arrows. The letter κ represents the coupling strength between the mode in the waveguide and the mode in the microring. The separation between the waveguide and the microring is 150 nm.

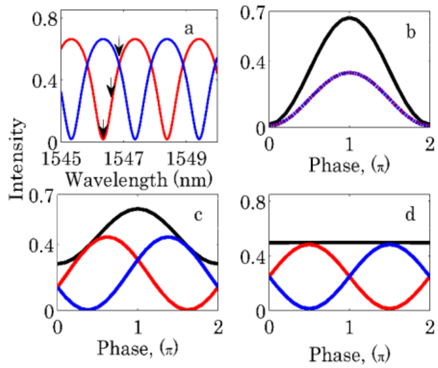

Fig. 1. a) Normalized total output intensity$|a_r^+|^2 + |a_l^-|^2$, as function of the wavelength, when the input waves have a zero (red) and π (blue) phase differences. The arrows point to three interesting wavelengths (1546.35, 1546.6, and 1546.86). The first one is the resonance wavelength, and the third one is a phase insensitive wavelength. Figures b to d show individual output intensities for each channel, $|a_r^-|^2$(blue) right channel and $|a_l^-|^2$(red) left channel, and the total intensity$|a_r^-|^2 + |a_l^-|^2$ (black) for the wavelengths marked with arrows as the phase difference is varied from 0 to π. The point where blue and red lines crosses in a) is a phase insensitive wavelength, as we observe in d), the total output intensity is constant for each phase. In Figure b both lines are superposed.

3. Discussion.

We have demonstrated coherent control of absorption in an integrated microring resonator. Simulations show when the microring is critically coupled to the input waveguides. The absorption is up to nine orders of magnitude. Varying the input phase, the absorption is suppressed and eventually recovered. This characteristic is essential in switching applications for integrated photonics. The operating wavelengths can be tuned in a wide range just by adjusting the coupling constant between the waveguides and the microring. This versatility enables the fabrication of absorbing devices in a wide spectral range.

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