ECE325 Advanced Photonics

Photonics circuitry applications and optimizations
some examples
lesson 17

Andrea Fratalocchi

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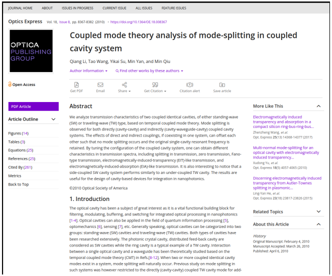
Outline

Optical filters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Optics Express Vol. 18, Issue 8, pp. 8367-8382 (2010) • https://doi.org/10.1364/OE.18.008367

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Coupled mode theory analysis of mode-splitting in coupled cavity system

Qiang Li, Tao Wang, Yikai Su, Min Yan, and Min Qiu

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Abstract

We analyze transmission characteristics of two coupled identical cavities, of either standing-wave (SW) or traveling-wave (TW) type, based on temporal coupled mode theory. Mode splitting is observed for both directly (cavity-cavity) and indirectly (cavity-waveguide-cavity) coupled cavity systems. The effects of direct and indirect couplings, if coexisting in one system, can offset each other such that no mode splitting occurs and the original single-cavity resonant frequency is retained. By tuning the configuration of the coupled cavity system, one can obtain different characteristics in transmission spectra, including splitting in transmission, zero transmission, Fano-type transmission, electromagnetically-induced-transparency (EIT)-like transmission, and electromagnetically-induced-absorption (EIA)-like transmission. It is also interesting to notice that a side-coupled SW cavity system performs similarly to an under-coupled TW cavity. The results are useful for the design of cavity-based devices for integration in nanophotonics.

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1. Introduction

The optical cavity has been a subject of great interest as it is a vital functional building block for filtering, modulating, buffering, and switching for integrated optical processing in nanophotonics [1-4]. Optical cavities can also be applied in the field of quantum information processing [5], optomechanics [6], sensing [7], etc. Generally speaking, optical cavities can be categorized into two groups: standing-wave (SW) cavities and traveling-wave (TW) cavities. Both types of cavities have been researched extensively. The photonic crystal cavity, distributed feed-back cavity are considered as SW cavities while the ring cavity is a typical example of a TW cavity. Interaction between a single optical cavity and a waveguide has been theoretically studied based on the temporal coupled mode theory (CMT) in Refs.[8-12]. When two or more coupled identical cavity modes exist in a system, mode splitting will naturally occur. Previous study on mode splitting in such systems was however restricted to the directly (cavity-cavity) coupled TW cavity mode for add-

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Related Topics

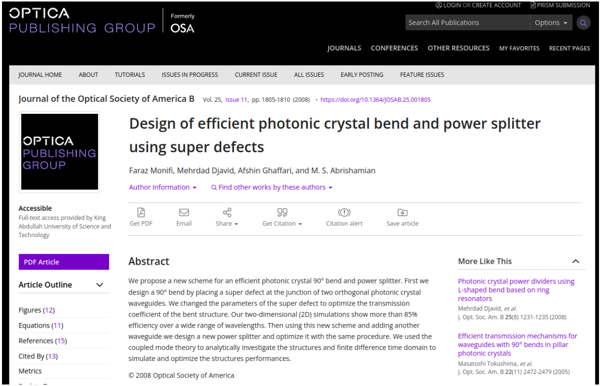
About this Article

History
Original Manuscript: February 4, 2010
Manuscript Accepted: March 26, 2010
Published: April 6, 2010

1. Opt. Express 18, 8367-8382 (2010) https://doi.org/10.1364/OE.18.008367
2. Opt. Express 25, 15868-15889 (2017) https://doi.org/10.1364/OE.25.015868
3. Laser & Photon. Rev., 6: 47-73. https://doi.org/10.1002/lpor.201100017
4. J. Opt. Soc. Am. A 20, 569-572 (2003) https://doi.org/10.1364/JOSAA.20.000569

Outline

Bending and splitting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Journal of the Optical Society of America B Vol. 25, Issue 11, pp. 1805-1810 (2008) • https://doi.org/10.1364/JOSAB.25.001805

Design of efficient photonic crystal bend and power splitter using super defects

Faraz Monifi, Mehrdad Djavid, Afshin Ghaffari, and M. S. Abrishamian

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Abstract

We propose a new scheme for an efficient photonic crystal 90° bend and power splitter. First we design a 90° bend by placing a super defect at the junction of two orthogonal photonic crystal waveguides. We changed the parameters of the super defect to optimize the transmission coefficient of the bent structure. Our two-dimensional (2D) simulations show more than 85% efficiency over a wide range of wavelengths. Then using this new scheme and adding another waveguide we design a new power splitter and optimize it with the same procedure. We used the coupled mode theory to analytically investigate the structures and finite difference time domain to simulate and optimize the structures performances.

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Masatoshi Tokushima, *et al.*
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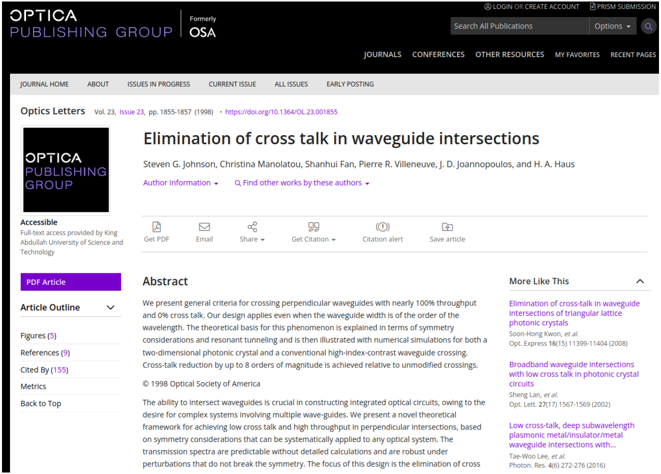
Junctions



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Optics Letters Vol. 23, Issue 23, pp. 1855-1857 (1998) • https://doi.org/10.1364/OL.23.001855

Elimination of cross talk in waveguide intersections

Steven G. Johnson, Christina Manolatou, Shanhui Fan, Pierre R. Villeneuve, J. D. Joannopoulos, and H. A. Haus

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Abstract

We present general criteria for crossing perpendicular waveguides with nearly 100% throughput and 0% cross talk. Our design applies even when the waveguide width is of the order of the wavelength. The theoretical basis for this phenomenon is explained in terms of symmetry considerations and resonant tunneling and is then illustrated with numerical simulations for both a two-dimensional photonic crystal and a conventional high-index-contrast waveguide crossing. Cross-talk reduction by up to 8 orders of magnitude is achieved relative to unmodified crossings.

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The ability to intersect waveguides is crucial in constructing integrated optical circuits, owing to the desire for complex systems involving multiple wave-guides. We present a novel theoretical framework for achieving low cross talk and high throughput in perpendicular intersections, based on symmetry considerations that can be systematically applied to any optical system. The transmission spectra are predictable without detailed calculations and are robust under perturbations that do not break the symmetry. The focus of this design is the elimination of cross

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Opt. Express **16**(15) 11399-11404 (2008)

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Sheng Lan, *et al.*
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Low cross-talk, deep subwavelength plasmonic metal/insulator/metal waveguide intersections with...
Tae-Woo Lee, *et al.*
Photon. Res. **4**(6) 272-276 (2016)

1. Opt. Lett. 23, 1855-1857 (1998) https://doi.org/10.1364/OL.23.001855

Outline

Channel drop filters

Coupling of Modes Analysis of Resonant Channel Add–Drop Filters

C. Manolatou, M. J. Khan, Shanhui Fan, Pierre R. Villeneuve, H. A. Haus, *Life Fellow, IEEE*, and J. D. Joannopoulos

***Abstract*— The operation principle of resonant channel add–drop filters based on degenerate symmetric and antisymmetric standing-wave modes has been described elsewhere using group theoretical arguments. In this paper, the analysis is carried out using coupling of modes in time. A possible implementation of such a filter is a four-port system utilizing a pair of identical single-mode standing wave resonators. The analysis allows a simple derivation of the constraints imposed on the design parameters in order to establish degeneracy. Numerical simulations of wave propagation through such a filter are also shown, as idealized by a two-dimensional geometry.**

***Index Terms*—Coupled-mode analysis, FDTD method, optical filters, optical waveguides, resonators, wavelength division multiplexing.**

I. Introduction

THE WIDE USE of optical wavelength division multiplexing (WDM) calls for compact, convenient channel add–drop filters. The "Dragone" filter [1] provides a means of simultaneously separating all the channels, which can then be dropped and/or added individually. After recombination via an inverse filter, the full WDM distribution is restored. This type of filter is now widely used. Resonators have also been considered for channel dropping devices. If the resonators are small enough so that the spacing of the resonant frequencies accommodates the set of WDM channels within the communications window, the goal of dropping one channel by one filter without affecting the other channels is achieved. One proposed version uses distributed feedback (DFB) resonators side-coupled to the signal bus [2]. In order to remove all of the power in one channel, two such resonators are required. Another version uses ring resonators between two optical waveguides, one guide acting as the signal bus and the other as the receiving waveguide. This structure has the advantage that a single resonator can remove all of the power in one channel [3]. The filter responses of these structures are Lorentzian (single pole). By combining a number of resonators with appropriate coupling, more sophisticated transfer characteristics could be achieved [3], [4]. This concept has already been studied in the context of microwave circuit design.

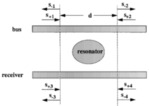

Fig. 1. General four-port system consisting of a resonator between two waveguides.

While a ring resonator between two optical waveguides provides an ideal basic structure for removal of a channel from the signal bus, the performance of ring resonator filters can be affected adversely by the coupling between counterpropagating waves caused by surface roughness [5]. Smooth surfaces are required of a high quality not yet achievable with existing fabrication technology. This fact raises the question as to whether the performance of a ring channel dropping filter could be realized with a resonant structure not as sensitive to surface roughness. The principle of operation of such a structure was explained using group theoretical arguments in [6]–[8]. Here we recast the description and the explanation of its operation into coupled-mode theory (CMT) in time.

Briefly summarized, we show that an optical resonator with degenerate symmetric and antisymmetric modes side-coupled to two waveguides performs the same function as a ring resonator. For a symmetric system consisting of two identical coupled resonators between two waveguides, the expected splitting of the degeneracy can be counteracted by proper coupling to the waveguides. This concept is also demonstrated by finite-difference time-domain (FDTD) simulations of wave propagation through such a filter.

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Outline

Nanoscale light-trapping

Nanophotonic light-trapping theory for solar cells

Zongfu Yu · Aaswath Raman · Shanhui Fan

Received: 1 March 2011 / Accepted: 15 September 2011 / Published online: 28 September 2011
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Abstract Conventional light-trapping theory, based on a ray-optics approach, was developed for standard thick photovoltaic cells. The classical theory established an upper limit for possible absorption enhancement in this context and provided a design strategy for reaching this limit. This theory has become the foundation for light management in bulk silicon PV cells, and has had enormous influence on the optical design of solar cells in general. This theory, however, is not applicable in the nanophotonic regime. Here we develop a statistical temporal coupled-mode theory of light trapping based on a rigorous electromagnetic approach. Our theory reveals that the standard limit can be substantially surpassed when optical modes in the active layer are confined to deep-subwavelength scale, opening new avenues for highly efficient next-generation solar cells.

many wavelengths thick [2–4]. From a ray-optics perspective, conventional light trapping exploits the effect of total internal reflection between the semiconductor material (such as silicon, with a refractive index $n \sim 3.5$) and the surrounding medium (usually assumed to be air). By roughening the semiconductor-air interface (Fig. 1a), one randomizes the light propagation directions inside the material. The effect of total internal reflection then results in a much longer propagation distance inside the material and hence a substantial absorption enhancement. For such light-trapping schemes, the standard theory shows that the absorption enhancement factor has an upper limit of $4n^2/\sin^2\theta$ [2–4], where θ is the angle of the emission cone in the medium surrounding the cell (Fig. 1a). This limit of $4n^2/\sin^2\theta$ will be referred to in this paper as the *conventional limit*. This is in contrast to the

1. Appl. Phys. A 105, 329–339 (2011). https://doi.org/10.1007/s00339-011-6617-4

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Enhanced energy storage in chaotic optical resonators

C. Liu, A. Di Falco, D. Molinari, Y. Khan, B. S. Ooi, T. F. Krauss & A. Fratalocchi

Nature Photonics **7**, 473–478 (2013) | Cite this article

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Abstract

Chaos is a phenomenon that occurs in many aspects of contemporary science. In classical dynamics, chaos is defined as a hypersensitivity to initial conditions. The presence of chaos is often unwanted, as it introduces unpredictability, which makes it difficult to predict or explain experimental results. Conversely, we demonstrate here how chaos can be used to enhance the ability of an optical resonator to store energy. We combine analytic theory with

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High order Anapoles

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PAPER

Fundamental and high-order anapoles in all-dielectric metamaterials via Fano–Feshbach modes competition

Juan Sebastian Totero Gongora[1], Gael Favraud[1] and Andrea Fratalocchi[1]

Published 1 February 2017 • © 2017 IOP Publishing Ltd
Nanotechnology, Volume 28, Number 10
Nanoscale metamaterials
Citation Juan Sebastian Totero Gongora *et al* 2017 *Nanotechnology* **28** 104001

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Abstract

One of the most fascinating possibilities enabled by metamaterials is the strong reduction of the electromagnetic scattering from nanostructures. In dielectric nanoparticles, the formation of a minimal

1. Nanotechnology 28 104001 (2017) https://doi.org/10.1088/1361-6528/aa593d

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Universal approximators

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Broadband vectorial ultrathin optics with experimental efficiency up to 99% in the visible region via universal approximators

F. Getman, M. Makarenko, A. Burguete-Lopez & A. Fratalocchi

Light: Science & Applications **10**, Article number: 47 (2021) | Cite this article

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Abstract

Integrating conventional optics into compact nanostructured surfaces is the goal of flat optics. Despite the enormous progress in this technology, there are still critical challenges for real-world applications due to the limited operational efficiency in the visible region, on average lower than 60%, which originates from absorption losses in wavelength-thick (≈ 500 nm) structures. Another issue is the realization of on-demand optical components for controlling vectorial light at visible frequencies simultaneously in both reflection and transmission and with a predetermined wavefront shape. In this work, we developed an inverse design approach that allows the realization of highly efficient (up to 99%) ultrathin

1. Light Sci Appl 10, 47 (2021). https://doi.org/10.1038/s41377-021-00489-7
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