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Microcavity filters based on hexagonal lattice 2-D photonic crystal structures embedded in ridge waveguides

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Abstract

Two-dimensionally periodic photonic crystal microcavity filters in a ridge waveguide format have been designed and fabricated. Transition mode-matching features were added to increase the optical throughput by more than a factor of two. An increase of Q-factor (more than 100%) was achieved by the addition of two further rows of photonic crystal holes to the microcavity filters. Attempts have also been made to tailor the filter response by applying design concepts used in other Bragg-grating optical filter technologies.

Keywords: Photonic crystals; Photonic integrated circuits; Optical filters

1. Introduction

Compact photonic crystal (PhC) microcavity filters in a ridge waveguide format could play a useful role for wavelength division multiplexing (WDM) and demultiplexing functionality in dense integrated photonic circuits. A stepping-stone towards this engineering task is the design and fabrication of 2-D hexagonal lattice PhC microcavity filters with mode-matching features, to increase optical throughput. Furthermore, an increase in Q-factor was achieved by the addition of two further rows of PhC holes on either side of the microcavity. Moreover, we have applied Bragg-grating concepts in several other filter designs using the same hexagonal PhC lattice configuration, in an attempt to control the filter response.

2. Design and simulation results

The microcavity filters were embedded in ridge waveguides with high lateral refractive-index contrast because good lateral confinement and efficient coupling of light into the device can be achieved using this established waveguide format. Similar waveguide-based 2-D PhC mirrors have been studied as Fabry-Perot resonators to determine the reflectivity,

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transmission, losses as well as the penetration lengths of these mirrors [1]. However, this configuration leads to significant modal mismatch [2] at the interfaces between the PhC and waveguide sections, contributing to reflection losses and reduced transmission over much of the useful spectrum. Two rows of PhC holes with a different filling factor and displaced to mirror-image positions with respect to the outer two rows of the main PhC mirrors (Fig. 1) have been implemented to enhance the optical transmission, in a similar manner to the previous use of transition mode-matching features to increase the optical throughput and Q-factor in 1-D PhC cavity filter structures [3,4].

A 2-D finite difference time domain (FDTD) method has been used to simulate the devices. Three rows of PhC holes (shown in the inset of Fig. 1) were used as mirrors in order to ensure that light arriving at the cavity penetrated readily into it. The PhC hole diameter and period were chosen to be 134 nm and 215 nm respectively to give a band-gap wavelength range, for TE-polarisation, from 680 to 1150 nm in the AlGaAs/GaAs epitaxial waveguide system used. The cavity length (620 nm) was chosen to position the resonance spectrally at approximately 800 nm (Fig. 1). The mode-matching holes (shown in the inset of Fig. 1 and located in mirror-image positions with respect to the two outer rows of the cavity PhC mirrors) have been adjusted numerically to 120 nm diameter, in order to enhance the light throughput at resonance by 47%. The Q-factors obtained from simulation without and with the mode-matching features were 195 and 219, respectively.

We have also applied Bragg-grating filter concepts to hexagonal lattice PhC filters embedded in a 3 μm ridge waveguide. The device parameters were chosen to be: a hole diameter of 245 nm, lattice period of 393 nm and cavity length of 680 nm, giving a band-gap wavelength range, for TE polarisation, from 1100 to 2200 nm. Fig. 2 shows the computed wavelength spectrum, together with a schematic of the device in the inset. This device was the result of a rapid design exercise for in-principle demonstration purposes and therefore the filter response has not been appropriately optimized for a quasi-rectangular filter response ideal for many applications. Similar work has been carried out [5] successfully to engineer the response of 1-D PhC microcavity filters. The computed spectrum of the 2-D hexagonal lattice filters (Fig. 2) showed two resonance peaks (occurring at 1503 and 1599 nm), corresponding to the two cavities that make up the device. The optical throughput of the device is very low, since no optimization has been carried out to enhance the transmission. The computationally estimated Q-factors were 185 and 135 respectively for the peaks at 1503 and 1599 nm.

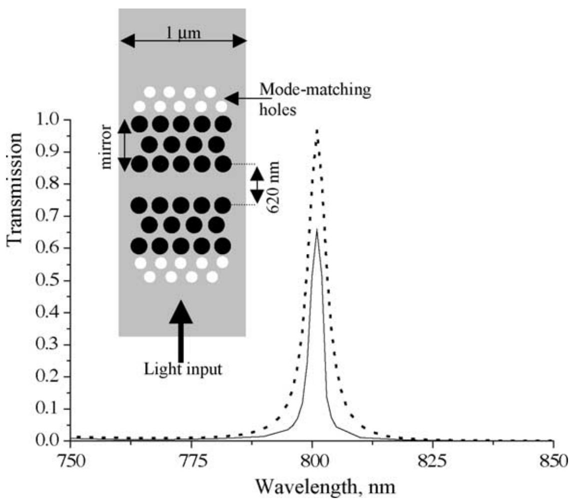

Fig. 1. The computed wavelength spectra of the PhC microcavity filter, without (—) and with (. . ...) mode-matching features. The inset shows a schematic of the device.

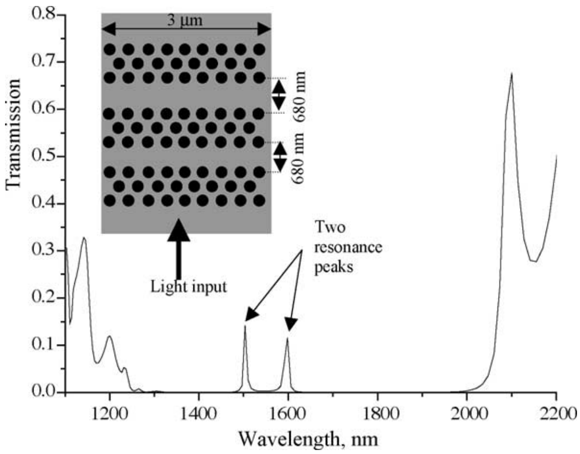

Fig. 2. The computed wavelength spectrum of the doubly-shifted hexagonal-lattice PhC microcavity filter. The inset shows a schematic of the device.