Radiation of photonic crystals with multiple cavities

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Abstract: Two-dimension hexagonal PhCs with ordered and partially disordered cavities arrays, such as missing holes, are studied using numerical modeling by a 3D FDTD method. A PhC with an ordered array of 19 coupled cavities produces highly directive and 19 times enhanced emission, while the single peak radiation and the peak wavelength width remain about the same as those for the PhC with a single cavity. A modified PhCs with partially disordered cavities arrays are found to emit a 3 times broader and a 7 times more intense peak than those of single-cavity PhCs along with highly directive emission. The use of cavities arrays in PhCs may lead to the development of efficient Si-based light emitters.

Introduction

Effective Si-based light emitters remain the only missing component that prevents optoelectronic devices to be fabricated entirely by means of the Si technology [1-3]. The embedding of dislocations surrounded by point defects provides the formation of deep levels in the Si bandgap and produces a broad emission band around 1.5 μm [1-6]. To reduce the linewidth drastically and to enhance its intensity, microresonators as microcavities constructed as missing holes in air hole-based photonic crystals (PhCs) are typically introduced [7-17]. The main attention has been paid to designing the PhC with the cavities which provides the highest Q-factor, while the task of enhancing the radiation directivity and broaden the radiation spectrum have not yet been the subject of a targeted research. Here, for this purpose, we use the effect of interference in withdraw photonic crystal with multiple missing holes (see Fig. 1) which involves the radiation of coupled cavities arranged either in ordered or partially disordered way with respect to the PhC lattice.

The withdraw photonic crystal

The withdraw PhCs with multiple cavities arrays [Fig. 1] are constructed on the basis of the hexagonal PhC with a cavity such as missing holes. The ratio between the radius r of the air hole and PhCs lattice constant a is set to $r/a = 0.35$ for all the examined structures.

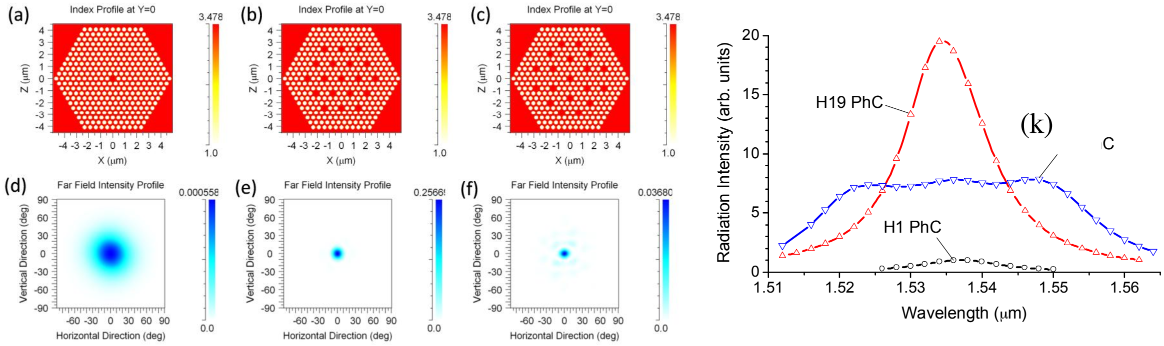

Fig. 1. PhCs with different cavities and total power radiated (to the upper hemisphere) by hexagonal PhCs with different cavities arrays. (a), (b), and (c) - refractive index distribution of withdraw PhCs with cavities named H1, H19, and H19d, respectively; (d), (e), and (f) - far field intensity of PhCs cavities H1, H19, and H19d, respectively; (k) - a radiation intensity from different withdraw PhCs.

To generate a spontaneous luminescence signal, the TE polarized pulsed or continuous wave (cw) at different optical wavelengths is launched in every PhC cavity. The signal is Gaussian-shaped and it has an asymmetrical position with respect to the missing holes centers in hexagonal PhC in the SOI structure with a 250 nm silicon slab on a 2 μm SiO_2 buffer layer. Thus, it is possible to excite and to study all the possible modes of the structure. The power and the field distribution at different cross-sections, along with the total power normally radiated to the structure plane, are calculated by 3D FDTD (see Fig. 1). The simulation area is restricted to the PhC structures nearest vicinity, and a back reflection from the bottom Si-substrate/air interface is not taken into account. This approach makes the calculation 2 times faster, but it introduces an error of about 2-5% in the evaluation of the radiation efficiency which can be neglected in this study.

A PhC with an ordered array (see Fig.1(b)) of 19 coupled cavities (H19) produces highly directive and 19 times enhanced emission, while the single peak radiation and the wavelength width remain about the same as those for the PhC with a single cavity (H1). This results in almost the same coupling efficiency of the fundamental optical mode of every cavity with the modes of the neighboring cavities thus a coupling-induced wavelength shift of the resonant mode is the same for all cavities. A modified PhC (see Fig.1(c)) with partially disordered cavities arrays (H19d) has a variation in coupling-induced wavelength shift of the resonant mode and this structure is found to emit a 3 times broader and 7 times more intense peak than those of a single-cavity PhC along with highly directive emission. The possibility of a strong enhancement of the emission intensity in certain directions may lead to the efficient Si-based light emitters fabrication. Such structures are interesting as the broadband light sources for numerous censoring applications, including fiber Bragg grating interrogation.

Conclusion

The hexagonal PhCs with coupled cavities arrays, such as missing holes, are studied using numerical modeling by a 3D FDTD method. The found array of 19 partially disordered cavities produces a box-like emission spectrum which is 3 times broader and 7 times more intense than a single-cavity emission peak. The author acknowledges RSoft Design Group, Inc., for providing the user license for FDTD simulations [18]. *Work is executed by a support of the grant No 14-19-00848 by the Russian Scientific Fund.*

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