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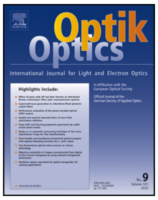

Photonic crystal power combiner based on hexagonal waveguides

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ABSTRACT

A new 2 × 1 power combiner scheme based on two-dimensional photonic crystal has been designed using hexangular waveguides. These waveguides are created by reducing the radius of inner rods in alternate manner which subsequently leads to coupled resonator optical waveguide structure. In this design, the outer hexagon has two input ports and the output port is embedded in the inner hexagonal. Due to geometrical and metallurgical engineering, the photonic bandgap locates in the THz region. Three different radii of coupled resonator optical waveguide rods have been studied. It has been shown that the structure with largest inner rods provides better power output.

1. Introduction

A power combiner is a passive device which accepts multiple incoming signals, combines them and transfers an output signal. When it is used in reverse, it may function as a power splitter [1]. There are many designs for power combiners with operating frequency ranges in radio frequency (RF) or microwave [2–6]. Electronic RF power combiners are divided into two main categories: Resistive [7] and hybrid [8] power combiners that use resistors and transformers, respectively.

Resistive approach is simple and has low cost although its loss rate is high. On the other hand, the hybrid approach has low loss but suffers from complexity and high cost. In microwave frequency range, the common power combiner is Wilkinson combiner [9]. Another type of power combiner that has recently attracted much attention is photonic crystal (PhC) based power combiner. This type commonly encompasses two configurations of T- and Y- junctions [10–14].

Photonic Crystal is a material with periodicity in refractive index and it is a unique medium for wave optical engineering due to its photonic bandgap [15]. By designing the waveguides propagating light with a frequency within the photonic bandgap, various optoelectronic devices can be designed [16–20]. Employing PhCs in optoelectronic devices results in size reduction and low cost because PhC circuit has a small number of commercial components. The most important characteristic which makes photonic crystals unique medium for optoelectronic devices and in this case for power combiners is the possibility of designing lossless bends. This facility is provided by coupled resonator optical waveguide (CROW) which is an array of cavity defects that traps electromagnetic wave for the frequency within the photonic bandgap an provides the outstanding feature of making lossless bend [21]. In this paper, we design a new structure for power combining which has two hexagonal waveguides that guide the light with THz frequency. We study three CROW structures with different radii

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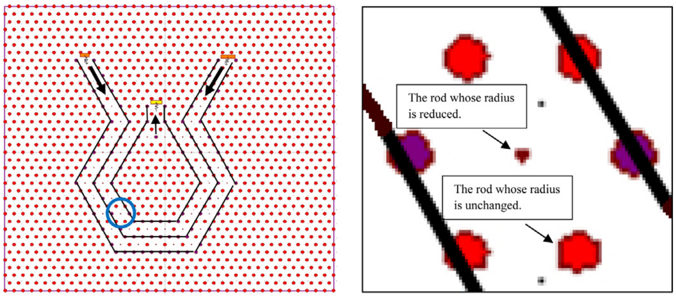

Fig. 1. (a) Schematic of a photonic crystal power combiner based on hexagonal waveguides. The main directions of input and output powers has been shown schematically by the arrows (b). The CROW rod is pointed at the magnified region of the structure which is circled in part (a).

of microcavity rods. We have simulated the propagation of light wave using *FullWAVE* module in RSoft CAD which is based on finite difference time domain (FDTD) method. Also, the perfectly matched layers have been considered as boundary condition.

2. CROW based power combiner

Our proposed two-dimensional (2D) photonic crystal comprises an array of circular shape, infinitely long silicon rods in air that has hexagonal arrangement. The refractive index and radius of silicon rods are set to 3.42 and 112 nm, respectively. The lattice constant or center to center distance is 620 nm. These characteristics introduce a compact power combiner with dimensions in micro range. By supposing the electric field parallel to the rods (i.e. TM polarization), the mentioned structure has the wavelength range from $\lambda = 1.22\ \mu\text{m}$ to $\lambda = 1.90\ \mu\text{m}$ corresponding to 157–245 THz in frequency. The schematic of proposed structure which is created by reducing of the inner rods of hexagonal waveguides in alternate manner (i.e. CROW-based structure) is shown in Fig. 1. Precisely speaking, this crow structure comprises two hexangular rings with 120° bends. The outer ring has two branches from which the wave is launched into the structure. The inner one has an output port for monitoring the intensity of interfered waves. Due to one-rod distance between waveguides and consequent tunneling phenomena, the light can be coupled from the outer waveguide into the inner one. The interference of these twin waveguides besides the inner CROWs leads to a strong interference. The combination of resulted clockwise and counterclockwise interferences is seen at the output.

The governing wave equation for the propagation of electromagnetic waves in this PhC-based structure is [22]:

$$\boldsymbol{\Theta}\boldsymbol{H}(\boldsymbol{r}) = \left(\frac{\omega}{\mathrm{C}}\right)^2 \boldsymbol{H}(\boldsymbol{r}),\ \boldsymbol{\Theta} = \nabla \times \frac{1}{\varepsilon_{\mathrm{r}}(\mathbf{r})}\nabla\times \tag{1}$$

where **H** is magnetic field intensity, ω is the frequency and C is the light speed in free space. $\varepsilon_r(\mathbf{r})$ is the dielectric property of the structure that includes M number of microcavities and can be obtained by [23]:

$$\frac{1}{\varepsilon_r(\mathbf{r})} = \frac{1}{\varepsilon_p(\mathbf{r})} + \sum_{n=0}^{M-1} d(\mathbf{r};\mathbf{r}_n),\ d(\mathbf{r};\mathbf{r}_n) = \frac{1}{\varepsilon_d(\mathbf{r}-\mathbf{r}_n)} - \frac{1}{\varepsilon_p(\mathbf{r})} \tag{2}$$

where $\varepsilon_p(\mathbf{r})$ is the dielectric property of a perfect structure and $\varepsilon_d(\mathbf{r}-\mathbf{r}_n)$ is the dielectric property of a microcavity which centered at r_n. In Ref. [23], this equation is derived for defect array which is created by removing the desired rods. However, in this study, we have created the defects by reducing the radius of rods. We took three CROW-based structures into consideration which differed in their inner rod radii. In the first structure, the inner rod radii were reduced by factor of 6. This is the smallest radius that we have considered. By benefiting from MOST module, the wavelength for which the output would become maximum was found (i.e. $\lambda = 1.48\ \mu\text{m}$, 202 THz). The output power with respect to CT (T is the time) has been shown in Fig. 2. For better display, the simulation results have been fitted by multi-peak Gaussian curves.

The maximum output power obtained for this structure was 99.2%, however, the average power output was 34.4%. The light propagation along the rods with reduced radius was weak and defect modes were not symmetric. The average output power is not very high due to destructive interferences. Therefore, the power output for other sizes of inner rod radius has been calculated. In the second simulation, the radius of CROW rods has been reduced by a factor of 5. In other words, the radius was larger than the previous simulation. By repeating the same steps as the first simulation, the wavelength for which the output power became maximum has been chosen using MOST module. The wavelength of $\lambda = 1.47\ \mu\text{m}$ (frequency of 204 THz) satisfied the above-mentioned requirement. The related simulation results have been shown in Fig. 3.

According to these results, the highest power obtained by this structure was 78.71% and the average output power was 31.14%. In comparison with the first design, the guided mode in this structure had better localization in CROW but output power had lower intensity both in highest peak and average power. This was due to alternate constructive and destructive interferences which periodically reduced and increased the power amplitude in bouncing manner as shown in Fig. 3(b).