Optik - International Journal for Light and Electron Optics 169 (2018) 269–276

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.com/locate/ijleo

Original research article

A novel Bragg fiber waveguide based narrow band inline optical filter

Ritesh Kumar Chourasia, Surendra Prasad, Vivek Singh*

Department of Physics, Institute of Science, Banaras Hindu University, Varanasi, 221005, India

ARTICLE INFO

Keywords:
Bragg fiber waveguide
Defect mode
Transfer matrix method
Narrowband filters

ABSTRACT

Theoretical analysis of Bragg fiber waveguide based inline optical filter having a defect layer is presented. Defect layer is introduced in Bragg fiber waveguide by breaking its cladding layer periodicity. Considering the cylindrical wave equations, the transmittance of proposed waveguide is obtained using transfer matrix method. It is observed that the proposed Bragg waveguide represent photonic band gap and a narrow defect mode (pass band) is present in this band gap region. This defect mode can be obtained in any position between the wavelength ranges *1.241* μm–*1.550* μm with the help of incident angle of light. The narrowness of the defect mode depends on the number of unit cell present in the cladding region. This proposed waveguide may be used to design a narrowband transmission filters.

1. Introduction

The optical fiber waveguides are widely recognized and used for worldwide delivery of the internet and modern communication due to their robustness, immunity to electromagnetic interference, cost effective, compact size, remote delivery, etc. The conventional optical fibers consist of a high refractive index core. This core is surrounded by a comparatively low refractive index cladding and finally both core and cladding is surrounded by a jacket. The basic principle of operation of these waveguides is total internal reflection. The light propagates in such waveguides through high refractive index core and suffers high dispersion and transmission losses. To minimize dispersion and transmission losses in optical waveguides, a new type of waveguide called Bragg fiber waveguide is proposed by some researches [1–4]. The Bragg fiber waveguide consists of a core (hollow or solid) surrounded by some alternate layers of high and low refractive index materials. These alternate layers are known as cladding layers and light guided in the core region due to multiple Bragg reflection occurred by these cladding layers. Similar to photonic crystals, these alternate cladding layers provide photonic band gap in the Bragg fiber waveguide [5], where a range of light is stopped to propagate in the core region. The Bragg fiber waveguide is a cylindrical waveguide that can be used in long distance communication therefore it may provide many inline applications such as Bragg reflectors [6], beam splitters [7], bio and chemical sensors [8–10] etc. By capitalizing the existence of the photonic band gaps in a Bragg fiber waveguide, it is possible to design a narrowband transmission filter, which is the motivation of present work. For fabrication point of view, the low loss design of Bragg fibers can be fabricated through the periodic arrangements of polymers. The Bragg fiber waveguide can be fabricated through a simple thin film rolling approach [11–13].

However, any break in the special periodicity of alternate layers in photonic crystal will provide a pass band in the photonic band gaps region and is called defect mode [14]. Similar to the condition of cavity resonator this defect mode is obtained when the resonant condition is satisfied. With the help of this defect mode, it is also possible to obtain a narrowband transmission in the band gap region of Bragg fiber waveguide. Therefore, in this paper, a defect mode is introduced in the Bragg fiber waveguide for the first

* Corresponding author at: Department of Physics Faculty of Science, Banaras Hindu University, Varanasi, 221005, U.P, India.
E-mail address: viveks@bhu.ac.in (V. Singh).

https://doi.org/10.1016/j.ijleo.2018.05.087
Received 10 June 2017; Accepted 20 May 2018

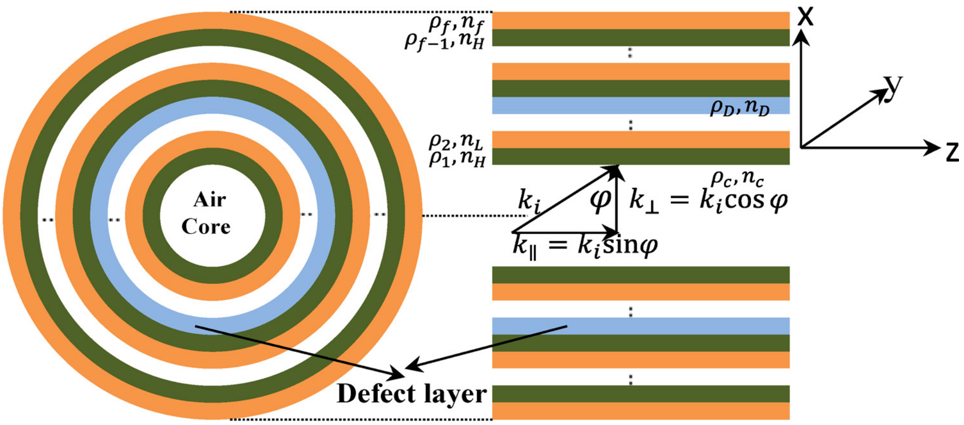

Fig. 1. Schematic diagram of proposed Bragg fiber waveguide.

time in our knowledge and the characteristic of defect mode in a Bragg fiber waveguide is studied for optical filter application. The defect mode in the proposed waveguide is introduced by breaking the special periodicity of its alternate cladding layers. Since our considered structure is cylindrical periodic structure, therefore in present formulation cylindrical wave equations and transfer matrix method is employed to obtain the transmittance of proposed structure. There are many methods to analyze the periodic structure, but it is found that the transfer matrix method approach is better among them [15]. These transfer matrix method can also be applied on concentric cylindrical multilayer structure under certain assumptions [16]. The paper is organized of as follows. In Section 2, basic equations, and theoretical formulation of proposed Bragg based temperature sensor is given. The obtained results are discussed and illustrated in Section 3. A conclusion is drawn in Section 4.

2. Theoretical model

2.1. Matrix formalism in cylindrical system

The schematic view of proposed Bragg waveguide is shown in the Fig. 1. The central region of waveguide consists of an air core surrounded by high refractive index (ZnO) and low refractive index (SiO_2) periodic dielectric layers. The respective refractive indices and thickness of high and low cladding layers are denoted by n_H, d_H, and n_L d_L.

The refractive index for fused silica glass SiO_2 is considered as [17]

$$n^2 = 2.81418 + \frac{0.87968\lambda^2}{\lambda^2 - 0.3042^2} - 0.00711\lambda^2 \tag{1a}$$

The refractive index of the ZnO is considered as [18]

$$n^2 = 1 + \frac{0.6961663\lambda^2}{\lambda^2 - 0.0684043^2} + \frac{0.4079426\lambda^2}{\lambda^2 - 0.1162414^2} + \frac{0.8974794\lambda^2}{\lambda^2 - 9.896161^2} \tag{1b}$$

The optical path of light in these layers are assumed as quarter wavelength, i.e., $n_H d_H = n_L d_L = \lambda_0/4$. In order to introduce a defect layer, the periodicity of cladding layer is broken after eight unit cell of proposed structure. The reflection and transmission response of cylindrical Bragg fiber can be analyzed by cylindrical wave transfer matrix method [16]. The Maxwell's equations for any layer having permeability μ and permittivity ε can be written as

$$\nabla \times E = -j\omega\mu H \tag{2a}$$

$$\nabla \times H = j\omega\varepsilon E \tag{2b}$$

By considering the temporal part of all the fields is *exp(jωt)*, the relation between longitudinal and transverse component of electric and magnetic field is developed in cylindrical coordinate (ρ, ϕ, z) system [19]. The propagation of cylindrical wave is either diverging or converging to the axis of symmetry $\rho = 0$ (z-axis). In this case, the derivatives of the fields with respect z can be omitted. Hence, by considering two fundamental propagation of modes, one is *H*-polarized wave which has three non-zero components, H_z, E_ϕ *and* E_ρ and other is *E*-polarized wave which has another three non-zero components E_z, H_ϕ *and* H_ρ, the wave propagation in proposed waveguide can be analyzed. The Helmholtz wave equation for cylindrical coordinate system is written as:

For magnetic field:

$$\rho\frac{\partial}{\partial\rho}\left(\rho\frac{\partial H_z}{\partial\rho}\right) - \rho^2\frac{1}{\varepsilon}\frac{\partial\varepsilon}{\partial\rho}\frac{\partial H_z}{\partial\rho} + \frac{\partial}{\partial\varphi}\left(\frac{\partial H_z}{\partial\varphi}\right) + \omega^2\mu\varepsilon\rho^2 H_z = 0 \tag{3}$$

For electric field: