Optik 126 (2015) 3093–3098

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

A new circular chalcogenide/silica hybrid microstructured optical fiber with high negative dispersion for the purpose of dispersion compensation

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ARTICLE INFO

Article history:
Received 10 June 2014
Accepted 14 July 2015

Keywords:
Chalcogenide glass
Circular microstructured optical fiber
Negative dispersion
Dispersion compensation
Confinement loss

ABSTRACT

In this paper, a new circular microstructured optical fiber (C-MOF) based upon photonic band gap (PBG) light guiding mechanism is proposed which can be used for dispersion compensation in optical transmission systems. The C-MOF core is made up of silica glass and the holes in the cladding network are filled with As_2Se_3 chalcogenide glass. By selecting an appropriate geometrical parameters for the structure, the dispersion and confinement losses of the proposed C-MOF at 1.55 μm are respectively calculated to be −2450 ps/nm/km and 0.013 dB/m. Relative dispersion slope (RDS) of the C-MOF at 1.55 μm is about 0.00332 nm^{-1}. The proposed C-MOF is suitable for use in wavelength division multiplexing and dispersion compensating systems in optical fiber transmission networks.

1. Introduction

In fiber-optic communication systems, dispersion in transmission fibers limits both the data bit rate and the data transmission distance [1–4]. Dispersion causes the widening of the optical signals when propagating through an optical fiber. With widening of optical signals, volume of data transmission is reduced and also data retrieval becomes difficult [5]. Subsequently, in long-haul optical transmission systems, in order to minimize the widening of optical pulses, dispersion needs to be compensated.

There are several techniques for dispersion compensation [1]. The technique using dispersion compensating fibers (DCFs) is cheap and relatively easy to employ [6]. DCFs should have negative dispersion coefficients which in turn enable them to overcome the positive dispersion coefficients of the transmission fibers [7]. In order to reduce the length of DCFs and hence reduce costs, they should have relatively large values for negative dispersion coefficients [1–4,6,7]. The dispersion and dispersion slope of transmission fibers should be compensated simultaneously [8].

The conventional DCFs which are designed to have a high negative dispersion in a narrow band of wavelengths are not suitable for dispersion compensation in broadband communication systems. Recently, the microstructured optical fibers (MOFs) or photonic crystal fibers (PCFs) are used in the design of DCFs [9]. Within the structure of such fibers, there is an array of holes around the fiber core acting as the cladding which is filled by air or other materials such as fluoride. These holes are stretched along the fiber length and they can have different sizes and shapes [10].

Such structures due to their high flexibility in the design have high potentials to harness optical properties such as dispersion and nonlinearity in a wide range of wavelengths.

The distance between the holes (Λ), the hole diameter (d), the shape and the number of holes can strongly affect the optical characteristics of microstructured optical fibers [11].

The silica microstructured optical fibers over the years have been of much interest in various optical societies and in order to use them in optical transmission systems, various schemes have therefore been proposed for such fibers. In silica glass at infrared optical spectrum, the phonon energy and losses are high and transparency is low. Hence such a glass cannot be used as the key material in the manufacture of optical fibers for applications, such as nonlinear applications in the infrared wavelength range [12]. Subsequently, extensive research and development have been carried by various research groups in order to achieve other materials for the production of microstructured optical fibers. Amongst the non silicate minerals, chalcogenide glasses have attracted much attention [13,14]. Chalcogenide glasses are combinations of

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http://dx.doi.org/10.1016/j.ijleo.2015.07.095
0030-4026/

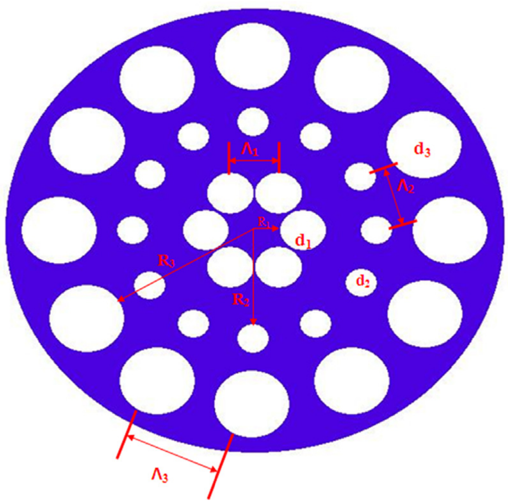

Fig. 1. Schematic of the proposed C-MOF.

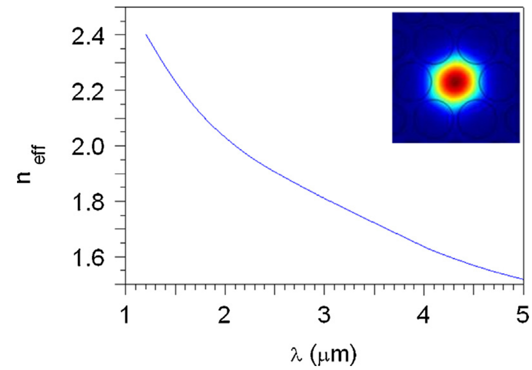

Fig. 2. The effective refractive index versus wavelength for the proposed C-MOF.

chalcogen elements such as sulfur, selenium, tellurium and other elements such as arsenic, germanium or gallium [15].

The chalcogenide glasses compared to silica glasses have unique features such as high nonlinearity and transparency in the infrared wavelength range and also high linear refractive index with values ranging from 2.5 to 3 in different compounds [16,17]. These features make this class of material most suitable for certain applications in optics, such as nonlinear optics, in medicine such as tomography, endoscopy and surgery and in transmission systems such as communication fibers and customized filters [18,19]. The MOFs based on chalcogenide glasses are suitable for power delivery in lasers and the construction biochemical and chemical sensors [20–22].

If chalcogenide compounds with their high refractive indices are used in the construction of MOFs, a high contrast between the refractive index of the core and the cladding is created. Hence, creating MOFs with high negative dispersion can be made possible [16].

Since these compounds have less mechanical stability than silica and their viscosity is strongly dependent on temperature, therefore making high quality MOFs with chalcogenide glasses is hard. One solution to overcome such problems and also be able to take full advantage of the optical characteristics of chalcogenide glasses is to incorporate chalcogenide glasses into silica MOFs. Indeed one can fill the cladding holes in silica MOFs with chalcogenide glasses [23,24]. As a result, using chalcogenide glasses in silica MOFs can create DCFs with high negative dispersion.

The mechanisms of the light guidance in MOFs are either justified with total internal reflection (TIR) or photonic band gap (PBG) theories. In MOFs with the core having higher refractive index than the cladding, the light is guided in the core based upon TIR. On the other hand, in MOFs with the core having refractive index lower than that of the cladding, light guidance inside the core is explained by PBG. In such fibers, the holes in the cladding that have higher refractive index than the fiber core itself, constitute individual waveguides that each supports some of the guided modes in the fiber. If the incoming light resonates with the cladding modes, the light waves move away from the core and is driven into the fiber cladding. If the incoming light does not resonate with the cladding modes, the light is confined inside the fiber core. This guidance mechanism is known as ARROW [24–27].

Up until now many fiber structures have been proposed for the use as DCFs. Some of the DCFs proposed in recent years that are based upon MOFs for compensating dispersion are mentioned below. The MHF proposed in [1] has a dispersion coefficient value of −1455 ps/(nm km) at 1.55 μm, the novel pure silica DC-MOFs proposed in [2] has a dispersion coefficient of about −130 to −360 ps/(nm km) at 1.4–1.6 μm, and the broadband DC-HyPCF proposed in [3] has a dispersion coefficient of about −555.93 ps/(nm km) at 1.55 μm. The dispersion coefficient in the proposed M-OPCF in [4] is about −588 ps/(nm km) at 1.55 μm and the C-PCF proposed in [6] has a negative dispersion of about −248.65 to −1069 ps/(nm km) over E to L wavelengths.

In this paper, we have proposed a new type of circular MOF (C-MOF) with silica core and the cladding consisting of three circular rings of holes which are filled with chalcogenide glasses. The diameter of the holes (d) and the distance between the adjacent holes (Λ) in each ring are different to those in the other two rings. Using these structural characteristics, negative dispersion with value about −2450 ps/nm/km at 1.55 μm can be obtained. The optical properties of such structures are studied by the multipole method [28].

This paper is formed as follows. In Section 2, the proposed MOF structure is described. Section 3 focuses on the theory of optical properties in MOFs. In Section 4, numerical results obtained are presented and discussed. Section 5 summarizes the conclusions.

2. Geometries of the proposed C-MOF

The cross section of the proposed C-MOF is shown in Fig. 1. The structure of the Proposed C-MOF is made up of a silica core and a circular array of holes as the cladding around the core which is filled with As_2Se_3 chalcogenide glass. As it can be observed in Fig. 1, the cladding network is composed of three rings. Each ring is composed of holes with different diameters. d_1, d_2, and d_3 are diameters of the holes in the first, second, and third ring, respectively. Λ_1, Λ_2, and Λ_3 are the distances between the adjacent holes in the first, second, and third ring, respectively. The distance between the adjacent holes in each ring is different from those of the other rings. As shown in Fig. 1, the radius of the first, second, and third ring on the circular network of cladding are specified with R_1, R_2, and R_3 respectively. The radius of the rings affects dispersion coefficient, confinement loss, and nonlinearity coefficient.

The diameter of the proposed C-MOF is 36 μm. The diameter of the holes in the first ring plays an important role in the dispersion characteristics of the structure. Small hole diameter in the first ring creates low dispersion and large hole diameter on the other hand, brings about a large dispersion in the proposed structure.

As the refractive index of As_2Se_3 is higher than that of silica, consequently, it can be effective in controlling the C-MOF optical characteristics such as dispersion. The light guidance in this structure is justified using photonic band gap model. Field intensity distribution and effective refractive index of the guided mode in the proposed C-MOF is shown in Fig. 2.