Optical Materials 66 (2017) 542–546

Contents lists available at ScienceDirect

Optical Materials

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

High-extinction ratio and short-length polarization splitter based on microstructured optical fiber with tellurite glass

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ARTICLE INFO

Article history:
Received 13 December 2016
Received in revised form
8 February 2017
Accepted 11 February 2017

Keywords:
Tellurite glass
Microstructured optical fiber
Polarization splitter

ABSTRACT

A new type of tellurite glass based on dual-core microstructured optical fiber with an Au wire has been numerically evaluated. This novel substance is a suitable optical fiber material for nonlinear applications due to its high nonlinear coefficient. A full-vector finite element method is employed to analyze the characteristics of the polarization splitter. A splitter with an ultrashort length of 1.079 mm and a high extinction ratio of 174.92 dB at the wavelength of 1.55 μm has been obtained. Moreover, the splitter exhibits a bandwidth with an extinction ratio as high as 20 dB of about 70 nm. An effective mode area A_{eff} of the optical fiber of 21.53 μm^2 for one of the supermodes of the x even mode has been calculated.

1. Introduction

Polarization splitters are crucial components of fiber-optic sensor and optical communication systems. The most interesting application is the polarization-division multiplexing communication in which independent signals are simultaneously transmitted on two orthogonal polarization states [1], in other words, the input light can be split into two cores. Polarization splitting can be obtained by employing highly birefringent microstructured optical fibers with two or three cores [2]. Microstructured optical fibers (MOFs), which are constituted by a single bulk material containing a lattice of air holes running parallel to the axis, have attracted great attention in recent years. Compared with conventional fibers, MOFs exhibit interesting properties such as endless single mode propagation [3,4], high birefringence [5], anomalous dispersion from the visible to the near-infrared (IR) [6], and large mode area with high nonlinearity [7,8].

Polarization beam splitters (PBS) based on MOFs have been extensively studied recently. Zhang et al. proposed a single-polarization wavelength splitter whose fiber length is 10.7 mm when light is guided in each core at the wavelengths of 1.3 μm and 1.55 μm [9]. A D-shaped plasmonic polarization splitter with an ultra-short length of 84 μm was designed by Aliaa F. Rageh et al., although its extinction ratio can only reach −21.5 dB and −41 dB for the x and y polarizations at the wavelength of 1.55 μm [10]. In addition, Zi et al. designed a 249 μm-length PBS whose extinction ratio can reach −50.7 dB at the communication wavelength of 1.55 μm [11].

Most reports of MOFs have described fibers made of silica, although fibers drawn from other glasses have also been reported. Non-silica glasses such as tellurite, chalcogenide and fluoride glasses have excellent optical transparency in the wavelength ranges of 0.5–5 μm, 0.4–6 μm and 1–16 μm, respectively. Nevertheless, the transmission window of silica is limited to wavelengths below 3 μm [12]. Furthermore, high-index non-silica glasses exhibit nonlinear refractive indices n_2 at least an order of magnitude higher than that of silica. And with respect to chalcogenide and fluoride glasses, tellurite ones are much less poisonous, more thermally stable, and are highly suitable for infrared nonlinear applications [13,14]. Fan et al. numerically investigated a 52.29 mm-long dual-core splitter, employing a high refractive index As_2S_3 core, which exhibited extinction ratios of −85.57 dB and −56.81 dB for the two polarizations at the wavelength of 1.31 μm [15]. Zhao et al. introduced a modulation core and two fluorine-doped cores to achieve an ultrabroadband splitter with a bandwidth of 320 nm by using a 52.8 mm-long three-core PCF [16]. A circular lattice MOF with tellurite glass was designed by Luke. S et al., which exhibited a very high nonlinearity with a maximum of 12,100 W^{-1} km at 0.45 μm, and an ultra high negative dispersion for a wide range of wavelengths was also obtained [17].

In this study, we design and simulate a novel kind of tellurite

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http://dx.doi.org/10.1016/j.optmat.2017.02.024
0925-3467/

glass (75% TeO_2, 25% ZnO) based on hexagonal lattice dual-core MOF (DC-MOF) with an Au wire in the middle. The finite element method (FEM) with the Comsol Multiphysics [18] software is employed to analyze the characteristics of the PBS. The MOF based tellurite glass reported here can be fabricated from an extruded preform [12]. Simulations demonstrate that a length as short as 1.079 mm and an extinction ratio as high as 174.92 dB for a polarization beam splitter based on tellurite glass can be obtained simultaneously.

2. Model and theory

Fig. 1 illustrates the cross section of the proposed hexagonal MOF-based tellurite glass with Au wires. The background material is the tellurite glass which has a composition of 75 TeO_2-25 ZnO (mol %). The diameters of the white, green, yellow and blue air holes are denoted by d, d_1, d_2 and d_3, respectively. In particular, the sizes of the long axis and the short axis of the elliptical one are defined as d_{2x} and d_{2y}. The lattice pitch Λ is set to 2.4 μm. Among the air holes, an Au wire is included in the yellow elliptical air hole to achieve high birefringence.

Perfectly matched layers (PML) and scattering boundary condition (SBC) are applied for the simulation of the MOF. The fundamental equation for the FEM can be expressed as [19]:

$$\nabla \times \left(\mu_r^{-1} \nabla \times E\right) - k_0^2 [\varepsilon_r] E = 0 \tag{1}$$

where E is the electric field vector, $k_0 = 2\pi/\lambda$ is the vacuum wavenumber, and λ is the operating wavelength.

The waveguide dispersion $D_w(\lambda)$ of the MOF can be evaluated from Ref. [20]:

$$D_w(\lambda) = -\frac{\lambda}{c} \frac{\partial^2 \left| R_e\left(n_{eff}\right) \right|}{\partial \lambda^2} \tag{2}$$

here, the effective refractive index n_{eff} can be solved by the FEM, c is the speed of light in vacuum and Re stands for the real part.

The material dispersion for the tellurite glass is given by the Sellmeier equation [21]:

$$n^2(\lambda) = A + \frac{B\lambda^2}{\lambda^2 - C} + \frac{D\lambda^2}{\lambda^2 - E} \tag{3}$$

where λ is the wavelength in micrometers, and the Sellmeier coefficients are shown in Table 1.

For an accurate calculation, the material dispersion of Au is determined by the Drude-Lorentz model [22]:

$$\varepsilon_m = \varepsilon_\infty - \frac{\omega_D^2}{\omega(\omega + j\gamma_D)} - \frac{\Delta\varepsilon \cdot \Omega_L^2}{\left(\omega^2 - \Omega_L^2\right) + j\Gamma_L \omega} \tag{4}$$

and the corresponding parameters in Eq. (4) are shown in Table 2.

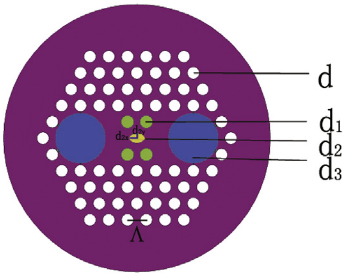

Fig. 1. Schematic diagram of the dual-core microstructured optical fiber based on tellurite glass with an Au wire.

Table 1
Sellmeier coefficients of the tellurite glass.

A	B	C	D	E
2.4843245	1.6174321	5.3715551×10^{-2}	2.4765135	225

Furthermore, the confinement losses are also a crucial parameter to balance the performance of the DC-MOF with Au wire, which are deduced from the value of n_{eff} as [23]:

$$L = 8.686 \times \frac{2\pi}{\lambda} I_m\left(n_{eff}\right) \times 10^4 \tag{5}$$

in dB/cm, where the operating wavelength is expressed in micrometers and Im(n_{eff}) stands for the imaginary part of the effective refractive index, respectively.

The effective mode area A_{eff} can be obtained by Ref. [17]:

$$A_{eff} = \frac{\left(\int\int |E|^2 dxdy\right)^2}{\int\int |E|^4 dxdy} \tag{6}$$

where E represents the electric field amplitude of the optical fiber core.

In DC-MOFs, there are four nearly degenerate supermodes, including the symmetric (even) and anti-symmetric (odd) modes of x and y polarizations, respectively. So the coupling length can be explicitly defined by using the following relation [24]:

$$L_i = \frac{\lambda}{2(n_e^i - n_o^i)}, i = x, y \tag{7}$$

where n_e^i and n_o^i indicate the effective refractive indices of the even and odd supermodes in the i-polarized direction.

In addition, the power at the output of the cores and the extinction ratio (ER) are two important technical parameters for the polarization beam splitter. If $P_{in}^{x,y}$ denotes the input power coupled into one of the fiber cores, the power at the output of the other core $P_{out}^{x,y}$ can be calculated by Ref. [25]:

$$P_{out}^{x,y} = P_{in}^{x,y} \cdot \cos^2\left(\frac{\pi z}{2L}\right) \tag{8}$$

where z is the transmission distance and L denotes the coupling length of the fiber. As a consequence, the extinction ratio is defined as the power of a particular polarization mode in the expected output core versus the power of the other polarization mode in the same core, as described by the following equation [26]:

Table 2
The Drude - Lorentz parameters of the Au wire.

ε_∞	$\omega_D/2\pi$ (THz)	$\gamma_D/2\pi$ (THz)	$\Omega_L/2\pi$ (THz)	$\Gamma_L/2\pi$ (THz)	$\Delta\varepsilon$
5.9673	2113.6	15.92	650.07	104.86	1.09