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A Comparative Study of Dispersion Characteristiscs of CS_2 Filled PCF based on BK10 material

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Abstract— This paper investigate the effect of background material on dispersion characteristics of a liquid filled fibre. To get best result in terms of flat and low dispersion along with high nonlinearity, CS_2 is selected in the form of highly nonlinear liquid. Here two structures are made with Silica and BK10 as background material. Same kind of infiltration is done with both materials and compared. These design structure finds various applications which also support nonlinear optics

Index Terms— Photonic crystal fibre, Holey fibre, Liquid filled holey fibre, dispersion characteristics, carbon disulphide

1 Introduction

PPhotonic Crystal Fibre or Holey fibre is very popular in optical world due to their dynamic properties and flexibility. They offer a control in the characteristic properties by creating a required change in the structural parameters of cladding airholes [1]. This makes them suitable to be used in a variety of applications [2] like optical amplifier, sensitive chemical and biochemical sensors [3][4], fibre lasers [5], dispersion compensating units, nonlinear devices and SCG [6].

PCF's provide efficient dispersion control by making a proper adjustment in structural parameters of PCF. But once a particular design of holey fibre is fabricated, it becomes difficult to change its optical properties. This problem can be overcome by using liquid filled holey fibres, which provides more flexibility in the optical properties [7]. For such fibres, the manner of filling liquid in selective air holes of cladding can create a high degree of tunability in dispersion properties [8]. Not only liquid some metals [9], polymers [10] liquid crystals [11] can also be used to fill air holes of core or cladding of fibre. But liquids are easy to fill in the fibre core or cladding due to their compressibility. There is a lot of research work in liquid core holey fibre, where core of HCPCF is filled with suitable nonlinear liquid [12]. In this paper we look a highly nonlinear liquid carbon disulphide to fill in PCF. This is uncommon practice to fill core as well as cladding air holes of first layer with silica nonlinear liquid. It enhances the possibility of its application for low dispersion fibre, nonlinear devices, optical switching [13] and a variety of sensors [14-16].

Nowadays PCF are being investigated in the field of nonlinear applications. This nonlinearity in holey fibre or PCF can be achieved with the help of infiltration process. When holey fibres air holes are filled with some liquid then its nonlinearity increases [17]. These liquids may be including ethanol, propanol [18], benzene, carbon tetrachloride, toluene, nitrobenzene, chloroform CS_2 etc. Among all the known liquids, refractive index of CS_2 is highest at telecommunication ($n=320 \times 10^{-20} m^2/w$) so CS_2 filled PCF fibre can provide highest nonlinearity. In nonlinear processes we may need to achieve phase matching of pulses [19]. In optical fibres the phase mismatch arises due to group velocity dispersion (GVD), hence it will influence the efficiency of nonlinear process [20]. Therefore magnitudes as well as slope of GVD curve are very important for nonlinear PCFs. These nonlinear fibres can also be achieved with PCF made with chalcogenide glasses and other background materials at the place of silica. Chow et al obtained a nonlinear PCF with nonlinear coefficient of $580 w^{-1} km^{-1}$ in telecommunication range with Bismuth oxide substrate [21]. This valve of nonlinear coefficient is 100 times greater than that for silica based fibre.

J. Pniewski et al [22] presented a PCF based on PBG-08 soft glass. This design structure of PCF was infiltrated with seventeen different organic liquids. Dispersion characteristic modification of this fibre structure was proposed. A Ahmadian el al [23] proposed a PCF with tellwrite cladding and As_2S_3 present in fibre core. With such design better birefringence and high value of nonlinear coefficient ($28 w^{-1} m^{-1}$) was achieved, it was 3 orders of magnitudes higher than that of regular silica PCF.

To enhance this sequence of investigation with liquid filled holey fibre based on silica and other backgrounds materials, we proposed a comparative study of two designs with different material infiltrated with some analysis. These two background material are silica and BK10. Circular geometry of cladding is selected to be filled with carbon disulphide, which is highly nonlinear liquid. Dispersion characteristics are analysed for such geometries and comparative results are discussed in this paper.

Proposed design structure

In this paper, we consider two hollow cores photonic crystal fibres having five ring circular lattice structures. In order to get desired characteristics we optimized the design with diameter of core as 1.4 μm (D=1.4 μm) and air holes of cladding are taken with diameter of 0.7 μm (d=0.7 μm). Here distance between two adjacent air holes in cladding, considered as patch length ∧ is selected to the 1.4 μm. The air filling fraction, ratio of air hole diameter to pitch length is (d/ ∧ = 0.7142), which is less than 0.8

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as good for fabrication. These values of design parameters are taken same for both the design structure with different background materials, BK10 and pure silica. Figure 1 represents the cross section view of both structures of PCF made on different background materials. These are fabricated in such a way that core and only inner ring of air holes in cladding is filled with carbon disulphide.

Linear refractive index of different materials is very important factor because it can provide values of different PCF characteristics like chromatic dispersion, confinement loss, nonlinearity etc. It can be find out for any material by considering the sellmeier equation of that particular material. In case of pure silica sellmeire equation is given by [24]-

$$n_{silica} = \sqrt{1+\frac{0.6961663\lambda^2}{\lambda^2-0.0684043^2}+\frac{0.4079426\lambda^2}{\lambda^2-0.1162414^2}+\frac{0.8974794\lambda^2}{\lambda^2-9.896161^2}} \quad (1)$$

For BK10 soft glass the sellmiere equation can be calculated by following formula [25]-

$$n_{BK10} = \sqrt{1+\frac{0.888308131\lambda^2}{\lambda^2-0.00516900822}+\frac{0.328964475\lambda^2}{\lambda^2-0.0161190045}+\frac{0.984610769\lambda^2}{\lambda^2-99.7575331}} \quad (2)$$

Carbon disulphide is being used here as an analyte for filling in core and cladding air holes of PCF so it is mandatory to consider its sellmiere equation for finding out effective refractive index of fibre at different values of excitation wavelengths. The sellmiere equation of carbon sulphide is given by [24]-

$$n_{CS_2} = \sqrt{1+\frac{1.50387\lambda^2}{\lambda^2-0.03049}} \quad (3)$$

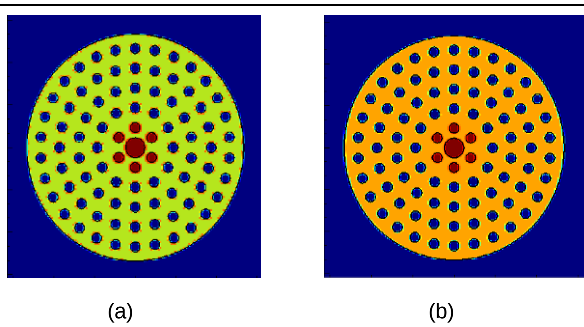

Fig.1. Cross sectional view of CS_2 infiltrated withdifferent background materials (a) BK10 (b) Silica

The linear refractive index such two fibre structures are recorded and drawn as a graph to make a comparative analysis. It is clear from Fig.2 that for the wavelength range from 1µm to 2 µm silica based PCF structure gives lower value of effective refractive index in comparison to BK10 based PCF structure.

Dispersion Characterstictics

The chromatic dispersion provided by any PCF design is very important for evaluating its performance in various applications. The value of dispersion for any fibre can be calculated by following formula [26]-

$$D(\lambda) = -\frac{\lambda}{c}\frac{d^2 n_{eff}}{d\lambda^2} \quad (4)$$

Dispersion characteristics of two PCF designed structures are represented in Fig.3 simultaneously. From this figure we can make a comparative analysis which represents an anomalous relation between dispersion characteristics of two fibres. The nature of dispersion profile changes from a particular point called turning point T for the two structures. If we observe carefully we come to know that up to 1.18 µm, turning point the PCF based on BK10 material gives lower of dispersion than that provided by PCF based on silica in the range from 1 µm to 1.8 µm. On the other hand for greater value of wavelengths (1.18 to 2 µm), the nature of two dispersion curves reverses. Now silica based PCF design provided lesser dispersion in comparison to BK10 based PCF. But slope of dispersion curve is not changing but static for whole wavelength range of interest. The slope of dispersion curve is greater for BK10 based PCF design structure.

Zero dispersion wavelengths

We are able to achieve zero dispersion for both the fibre structures at different values of wavelengths and both are greater than 2 µm. It is clear from Fig.3 that BK10 based PCF structure gives zero dispersion at 2.08 µm and silica based PCF structure could achieve zero dispersion value at 2.4 µm wavelength.

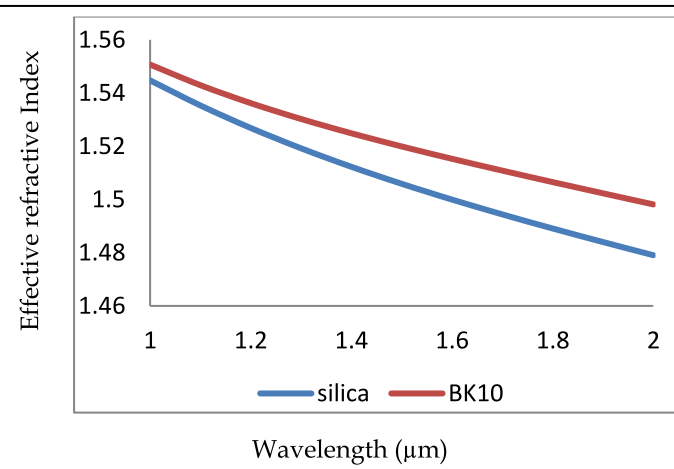

Fig.2. Variation plot of Effective Refractive Index v/s wavelength for different background materials silica and BK10.

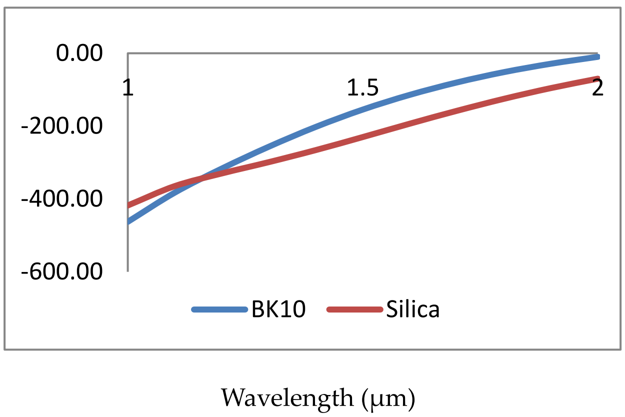

Fig.3. Dispersion curve of the Liquid Infiltrated PCF for two structures with different kinds of background material, silica and BK10.

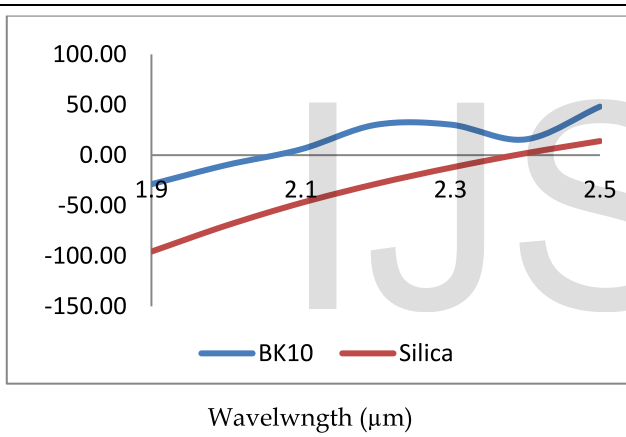

Fig.4. Zero dispersion wavelength of the Liquid Infiltrated PCF for two structures with different kinds of background material, silica and BK10.

Result and Conclusion

In this paper we analyzed the effective refractive index graph and dispersion characteristics of two fibres having different background materials but realises with same geometrical parameters. For two similar designs of carbon disulphide infiltrated PCF structures we could compare the respective values of effective refractive index and dispersion characteristics in the wavelength range 1 μm to 2 μm. A turning point can be observed in dispersion characteristics of both the PCF structures. Hence if we want to apply such designs for a particular application then according to wavelength range of interest a choice of background material can be made for this type of carbon disulphide filled PCF structure. Along with this dispersion flattened fibre or dispersion compensating units can be achieved as high degree of flatness is favoured by the silica based PCF structure in comparison to BK10 based PCF structure.

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