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Dispersion Tailoring in a High-Index Core Bragg Fiber

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Abstract: In this paper, investigation on the effect of variation in fill factor ratio d/Λ on the dispersion characteristics, particularly on zero dispersion wavelength of a High-index Core Bragg fiber has been done. The dispersion of the Bragg fiber can be tailored to achieve desired zero dispersion wavelength by changing the fill factor ratio d/Λ.

Keywords: Bragg fiber; dispersion; fill factor; pitch; zero dispersion wavelength.

I. INTRODUCTION

The Bragg fibers are based on 1D photonic crystals, formed by a low-index core surrounded by an alternating cladding of high- and low refractive-index layers. The confinement of light within the core is governed by cylindrical Bragg reflection off the alternating layers [1]. In such Bragg fibers, the light guidance is through PBG mechanism. The Bragg fibers can also be formed by high-index core surrounded by an alternating cladding of low- and high refractive-index layers. In such Bragg fibers, the light guidance is through modified total internal reflection mechanism [2, 3].
In this work, the author, systematically studied the effect of variation of width of layer of air with respect to silica layer. In the designed High-Index Core Bragg Fibers (HCFBs), all the geometrical properties are kept same except the ratio of air-layer width and the pitch. It is a cylindrically symmetric microstructured fiber having a high-index core (silica in our case) surrounded by a multilayered cladding made of alternating layers of silica and a lower refractive-index dielectric i.e. air. The author had further simulated these fibers and found dispersion characteristics using finite difference method which is fairly accurate method for modal analysis.

II. FIBER DESIGN

In this work, designed High-Index Core Bragg Fibers had been designed, with all same geometrical properties except the ratio of air-ring thickness and the pitch i.e. d/Λ. It is a cylindrically symmetric microstructured fiber having a high-index core (silica in our case) surrounded by a multilayered cladding made of alternating layers of silica and a lower refractive-index dielectric (air). Silica fibers have become very popular due to low loss due to refined fabrication processes and low cost due to production at mass scale for telecommunication networks [4]. Due to their large transmission range (0.21 μm – 3.7 μm) and most of the optical instruments and equipments designed around this range, it is always very convenient to work with silica based fibers.
Basically, it is very convenient to work with silica fibers because of the following reasons [5]:

- Highly pure silica can be made very economically due to simple and efficient processes to obtain silica from silicon which is available in abundance.
- The transmission range of silica is very broad (practically 300nm to 2500 nm) with its spectral range spanning from visible to near-infrared wavelength.
- It is very easy to draw silica into an optical fiber due to its physical and chemical properties. The softening temperature of silica is very high (~ 1600oC) with a high transition temperature (~1150oC) and it shows very slow variation in viscosity with change in temperature. These properties make it suitable for drawing fibers. Silica also shows good resistance to humidity and thus deteriorates very slowly with changes in climatic conditions [4].

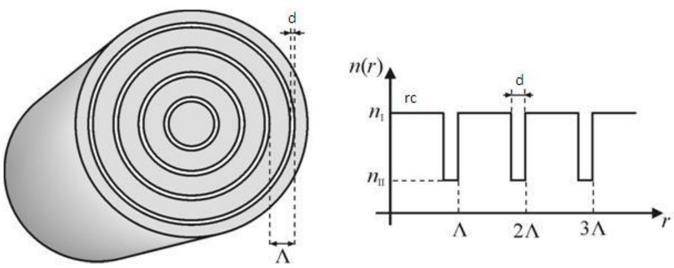

Fig. 1. Schematic of Bragg Fiber Design

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The multilayered structure geometry is characterized by the core radius, r_c, low-index layer thickness, d, and pitch, Λ. The refractive indices are alternately n_2 and n_1, where $n_2 < n_1$. In fact, we have selected the refractive indices of silica and air as n_1 and n_2, respectively.
Values of geometrical parameters for the six fibers analyzed are as following
Radius of the core, r_c = 2.3 um.
Width of the air rings, d
Pitch, Λ = 0.8 um.

III. DISPERSION

The wave propagation constant β is a function of wavelength λ, or angular frequency ω. Since β is a slowly varying function of this angular frequency, it can be approximated by Taylor series expansion about the central frequency.

$$\beta(\omega) = \beta_0 + \beta_1(\omega-\omega_0) + \frac{1}{2}\beta_2(\omega-\omega_0)^2 + \frac{1}{6}\beta_3(\omega-\omega_0)^3 + \ldots\ldots \quad (1)$$

where

$$\beta_n = \left[\frac{d^n\beta}{d\omega^n}\right]_{\omega=\omega_0} \quad (2)$$

The first term of the (1) causes the phase shift and the second teβrm determines the group velocity. The third term shows the dependence of group velocity of a monochromatic wave on the wave frequency. This means that a pulse is subject to broadening as it travels through the fiber due to different group velocities of the frequency components of the pulse. This pulse broadening is called as chromatic dispersion or group velocity dispersion (GVD). The dispersion region can be classified as normal or anomalous, depending on the sign of β_2 . When $\beta_2 > 0$, the dispersion is said to be normal and when $\beta_2 < 0$, the dispersion is said to be anomalous. In the normal-dispersion region, lower frequency components of an optical signal travel faster than the higher frequency components, whereas in the anomalous dispersion region, lower frequency components of an optical signal travel slower than the higher frequency components. β_2 is also called as GVD parameter and the chromatic dispersion D is related to β_2 by the following expression.

$$D = -\frac{2\pi c}{\lambda^2}\beta_2 \quad (3)$$

where D is expressed in (ps/km.nm).

In the fourth term, β_3 is known as third order dispersion. It is significant near zero dispersion wavelength. It is related to dispersion D and dispersion slope $S_0 = \partial D / \partial\lambda$ i.e. the rate of change in dispersion D with wavelength.

$$\beta_3 = \frac{\partial\beta_2}{\partial\omega} = -\frac{\lambda^2}{2\pi c}\frac{\partial\beta_2}{\partial\lambda} = -\frac{\lambda^2}{2\pi c}\frac{\partial}{\partial\lambda}\left[-\frac{\lambda^2}{2\pi c}D\right]$$
$$= \frac{\lambda^2}{(2\pi c)^2}(\lambda^2 S_0 + 2\lambda D) \quad (4)$$

The chromatic dispersion D of a Bragg Fiber [6] can be calculated from the effective index of the fundamental mode, n_{eff} for a wavelength range using

$$D = -\frac{\lambda}{c}\frac{d^2 n_{eff}}{d\lambda^2} \quad (5)$$

where c is the velocity of light in a vacuum.

Chromatic Dispersion D, is also expressed as sum of material dispersion D_m and waveguide dispersion, D_w.

$$D = D_m + D_w \quad (6)$$

Material dispersion of silica can be derived from the spectral refractive index of silica. The refractive index of bulk silica [7, 8] can be represented by Sellmeier equation given by (7) and the table gives the values of fitting coefficients A_i and L_i.

$$n^2 = 1 + \sum_{i=1}^{3}\left[\frac{A_i\lambda^2}{\left(\lambda^2 - L_i^2\right)}\right] \quad (7)$$

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Table .1. Sellmeier coefficients for the silica glass

I	A_i	L_i
1	0.6961663	0.0684043
2	0.4079426	0.1162414
3	0.8974794	9.896161

Fig. 2 shows the dispersion characteristics of silica calculated from (7) and Table I. The wavelength at which the GVD is zero is called zero dispersion wavelength (~1288 nm for bulk silica). At around this wavelength, the group index also changes the way it is varying with wavelength. At shorter wavelengths, the group index decreases with increase in wavelength but for wavelengths longer than ZDW, the group index increases with increase in wavelength. When the dispersion D, is below zero, the dispersion is said to be normal and when the dispersion D is above zero, the dispersion is called anomalous dispersion.

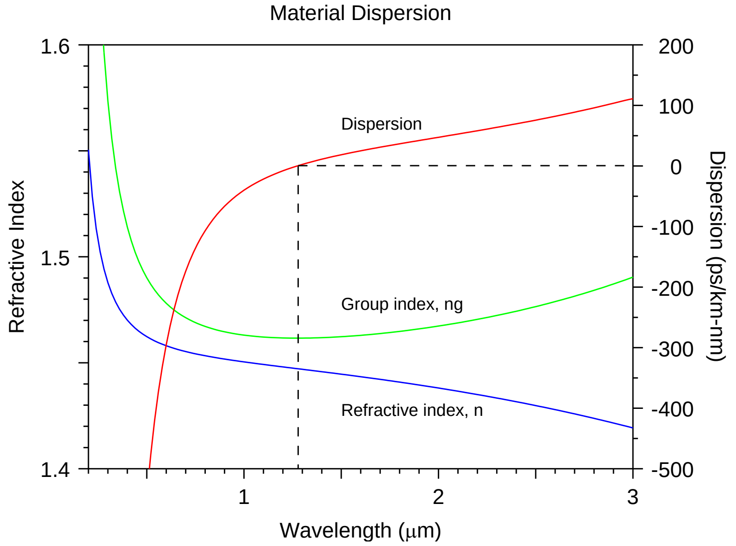

Fig. 2. Refractive index, group index and dispersion curves of silica.

IV. RESULTS

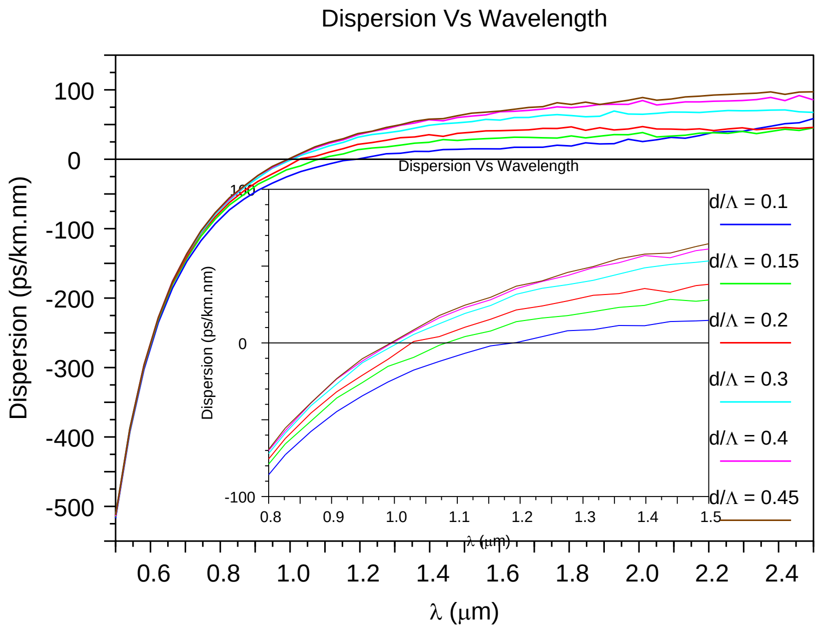

Fig.3. Dispersion Characteristics of Bragg Fiber for fill factor, d/= 0.1 to 0.45

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In this work, the effect of change in fill factor on dispersion characteristics of the fiber has been demonstrated. The fill factor is changed from 0.1 to 0.45. Due to change in the fill factor, the effective index of the cladding region changes and this leads to the variation in the dispersion characteristics of the Bragg fiber. This property is very useful in dispersion tailoring and achieving the desired dispersion characteristics of the fiber.

As shown in Fig. 3, the zero dispersion wavelength (ZDW) of the Bragg fiber can be controlled very well by changing the fill factor. As the fill factor increases, the ZDW of the fiber is shifted towards smaller wavelengths. This property can be exploited to achieved the desired ZDW for a Bragg fiber design.

V. CONCLUSION

It conclude that the zero dispersion wavelength of a Bragg fiber can be tailored by changing the fill factor. As the fill factor increases, the zero dispersion wavelength decreases. This property gives us the flexibility to obtain desired dispersion characteristics in a Bragg fiber and make then a potential candidate for a variety of telecom and nontelecom applications.

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