Polarized modes Dispersion in Anisotropic Optical Fiber Communication lines

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Abstract:- Equations are derived for calculation of the propagation constants and of the dispersion of the fundamental modes in anisotropic waveguides .This work shows how to obtain approximate analytic expressions which can be used to calculate with sufficient accuracy for practical applications the waveguide and polarization dispersion of the dominant orthogonally polarized modes in anisotropic optical fiber waveguides and distributions of electric and magnetic fields of these modes are obtained in a transverse cross section of the waveguide. It is shown that the anisotropy of a dielectric in the transverse cross section and the elliptical of the shape of this cross section alter the waveguide dispersion of modes in such waveguides compared with an isotropic waveguide. In the case of waveguides which conserve the state of polarization of the transmitted signal the changes in the waveguide dispersion due to the transverse anisotropy of the refractive index are considerably greater than the changes due to the elliptical of the shape of the transverse cross section of the waveguide. In a waveguide with a transverse anisotropy of the refractive index the maximum waveguide dispersion of two mutually orthogonal modes occurs at different frequencies.

Key-Words: - Dispession, Anisotropy, isotropic dielectric, polarization, Transverse cross section, Perturbation.

1 Introduction

Fiber optics transmission and communication are technologies that are constantly growing and becoming more modernized and increasingly being used in the modern day industries.however, dispersion is one of the properties of optical fibers that cause attenuation or a marked decrease in transmitted power. Dispersion occurs when the light traveling down a fiber optic cable becomes longer in wavelength and eventually dissipates.The broadening of light pulses, called dispersion is a critical factor limiting the quality of signal transmission over optical links. Dispersion is a consequence of the physical properties of the transmission medium. for example the single mode fobers, used in high-speed optical networks are subjected to chromatic dispersion that causes pulse broadening depending on wavelength, and to polarization mode dispersion that causes pulse broadening depending on polarization. Excessive spreading will cause bits to overflow their intended time slots and overlap adjacent bits and then the receiver may then have difficultly discerning and properly interpreting adjacent bits, increasing the bit error rate(BER) [1].

The polarization-mode dispersion in optical fibers has attracted considerable attention over the past few years. Different techniques for polarized – mode dispersion (PMD) measurements and characterization have been reported in many references. Two main factors contribute to PMD in circular fibers: the deformation of the circular Geometry of the fiber and the internal stresses which leads to stress anisotropy, both of which could happen during manufacturing. Other factors that could contribute to PMD in fibers are bends, twists, and cabling process. A circular fiber with small core elliptical deformation causes a difference between the group velocities in the two orthogonal polarizations of the fundamental mode.This difference contributes to the overall dispersion and the effect is referred to as polarization-mode dispersion. The magnitude of PMD in fibers depends on this difference in propagation constants. In ordinary step-index single-mode fibers, PMD vanishes outside the single-mode wavelength region. To improve fiber performance in long-haul high bit rate systems, a zero PMD must be within the single-mode wavelength region.

Anisotropic waveguides are proposed for the use in long-range communication optical communication systems and for integrated optical devices where conservation of a given state of polarization of the transmitted radiation is an essential requirement. Calculations of the parameters of modes in such waveguides are usually carried out by approximate methods based on perturbation theory; the underlying assumption in these methods is that the mode fields in anisotropic waveguides differ little from the fields in an isotropic waveguide. Approximate methods make it possible to calculate, with a precision sufficient for practical purposes, the characteristics of modes in dielectric waveguides with a relatively weak shape or permittivity anisotropy. However, these methods are unsuitable for determination of the characteristics of modes and fields in waveguides with an arbitrary anisotropy [2]. Anisotropic optical fiber waveguides capable of conserving the polarization of the transmitted signal are currently the subject of intensive investigations. This property is very important for various fiber-optic devices and for long distance optical communication systems [3, 15,17,18]. Anisotropic waveguides are understood to be those with a departure of the transverse cross section from the circular symmetry (which is known as the shape anisotropy) and with an anisotropy of the permittivity (refractive index) induced by mechanical stresses. In practice, the parameters of anisotropic waveguides can be calculated conveniently by approximate methods which are sufficiently accurate for the purpose [2-4]. One of these methods, which belong to the class of perturbation theory techniques, is the method of shift formulas [2].

This method was described in [5-8] to calculate the propagation constants and critical wavelengths of all the modes in anisotropic dielectric waveguides. We shall use this method to calculate the dispersion of modes in such waveguides.

Chromatic dispersion is an important characteristic of a medium and can significantly degrade the integrity of wave packets. In practice, chromatic dispersion is not uniformly distributed and often exhibits random variations in space and time. On the other hand, wave propagation through the medium is much faster than temporal variations of the chromatic dispersion.therefore; these random variations can be treated as multiplicative noise that does not change in time. the overall chromatic dispersion in an optical fiber comes from two sourses.The first source is the medium itself. The second source is the specific geometry of the waveguide profile. Material dispersion in the optical fiber is a relatively stable parameter uniformly distributed along the fiber. However waveguide dispersion is not nearly as stable. Existing technology does not yet provide accurate control of the waveguide geometry of modern fibers where dependence of dispersion on wavelength is complex. As a result, the magnitudes of random variations of fiber chromatic dispersion are typically the same as, or in some cases even greater than, that of the mean dispersion [4].The chromatic dispersion is the most important factor that determines the width of a pass band of single-mode waveguides. It can be separated into the material dispersion and the waveguide (mode) dispersion [9].

2 Procedures

According to general waveguide theory, guided modes, and also radiation modes, in a circularly symmetric waveguide can be labeled according to their azimuthally or angular symmetry order . We have taken advantage of this fact to solve the different angular orders, v, separately. In practical terms, the use of rotational symmetry reduces the original 2D problem (fields depending on the two transverse coordinates) into a ID one (fields depending on the radial coordinate only). This provides not only a higher accuracy for a given number of auxiliary modes, but also the different band structures for every angular order. Figure 1 shows the two different band-gap structures and the modal dispersion curves for the guided modes in fiber for v = 1 and v = 0, , including in the latter case the spectrum of TE modes and omitting TM modes as they are very similar. guided modes appear in the forbidden band gaps at their corresponding angular order v. In particular, the single guided mode shown in the upper forbidden band for v = 1 is the fundamental mode of the fiber, which, due to the rotational symmetry of the index profile, corresponds to a polarization doublet $\boldsymbol{HE_{11}}$, as denoted in standard waveguide theory. No other higher-order modes of any angular sector appear in this band for the selection of the geometric parameters fixed in Fig.2 . The transverse intensity distribution for any of the two polarizations of the fundamental mode, $\boldsymbol{HE_{11}}$, and the first intraband guided mode, $\boldsymbol{TE_{01}}$, in Fig.2 are visualized in Figs. 2(a) and 2(b), respectively, for $\lambda = \mathbf{0.8}\mu m$.

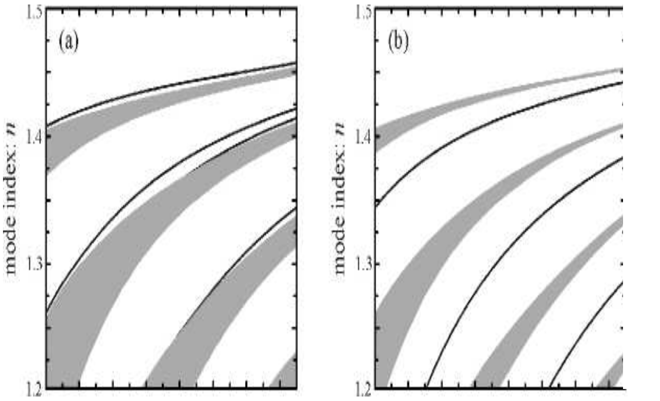
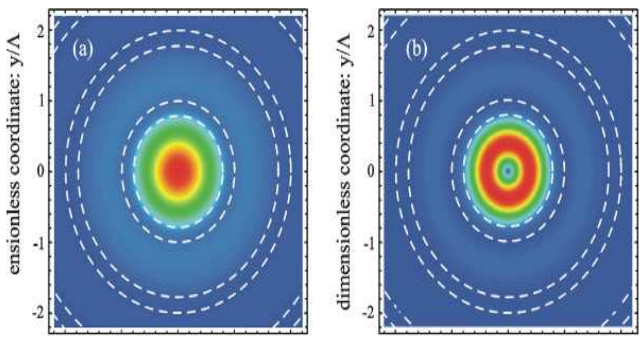


Fig. 1. Band-gap structure and modal dispersion relation curves for two angular sectors: (a) V = 1 (HE modes), and (b) V = 0 (only TE modes). In both cases, $\Lambda = \mathbf{1.190}\mu m$ and $a = \mathbf{0.248}\mu m$.



dimensionless coordinate: x / Λ .

Fig. 2. Transverse intensity distribution for: (a) the fundamental guided mode $\boldsymbol{HE_{11}}$ in Fig. 1, and (b) the first intraband guided mode $\boldsymbol{TE_{01}}$ in Fig. 1. In both cases, $\lambda = \mathbf{0.8}\mu m$.

We have extensively studied the dispersion properties of different high-index-core Bragg-fiber designs We expect to tailor the chromatic dispersion of such fibers by manipulating the geometry of the multilayered cladding. The total dispersion, D, can be given, as a first approximation, in terms of the material dispersion, D_m, and the geometric waveguide dispersion, D_g, using the approximate expression

$(D= D_m + D_q)$. The material dispersion is an input of the problem. The geometric dispersion of the fiber is given in terms of the geometric modal effective refractive index, n_q, as $D_q(A) = -(A/c)d^2n/dA^2$. and, then, starting from the approximate values for Λ and $\boldsymbol{a}$, we can fine tune these parameters to obtain the expected dispersion behaviour. Using this procedure, we have studied the dispersion properties of different fiber designs in two different wavelength windows, the first one located around 0.8 μm and the second one in the vicinity of the optical communication window (around 1.55 μm),we would like to emphasize that all results refer to the fundamental mode of a single-mode structure in the upper forbidden band that corresponds to a polarization doublet $\boldsymbol{HE_{11}}$. It should be stressed as well that the high accuracy required to calculate D is fully provided by our modal method. In Fig. 3 we present some examples of positive, nearly-zero, and negative flattened dispersion designs at 0.8 μm All of them show a zero third-ordered dispersion point. Note that the geometric parameters of the blue curve in Fig. 3 just correspond to that of the plots in Figs. 1 and 2. It is pretty clear the tunability of the structure, even in the region well below the critical silica zero-dispersion wavelength (1.3 μm). It is specially remarkable the possibility of obtaining a flattened positive dispersion profile centered around 0.8 μm (red curve) that can facilitate the stabilization of ultrashort soliton pulses generated at this wavelength by a more effective suppression of higher-order dispersion terms.

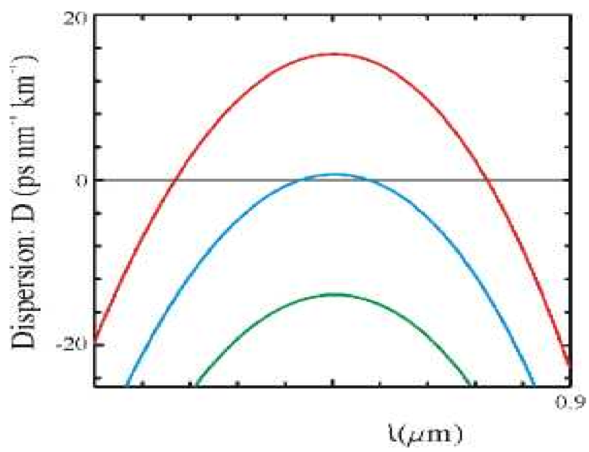


Fig. 3. Positive (Λ = 1.170 μm and a = 0.266 μm), nearly-zero (Λ = 1.190 μm and a = 0.248 μm), and negative (Λ = 1.210 μm and a = 0.232 μm) flattened dispersion curves near 0.8 μm .

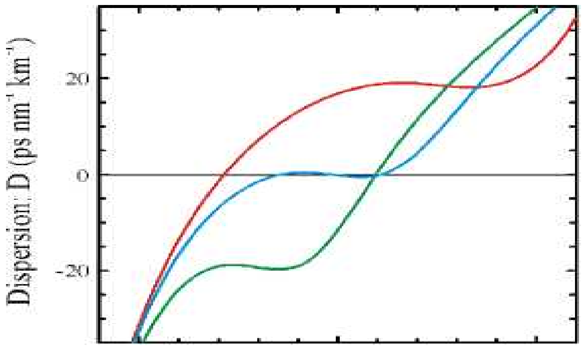


Fig. 4. Positive (Λ = 4.900 μm and a = 0.115 μm, nearly-zero (Λ = 4.210 μm and a = 0.094 μm), and negative (Λ = 3.600 μm and a = 0.082 μm) ultraflattened dispersion curves near 1.55 μm.

High-index-core fibers can also be designed to achieve ultra flattened dispersion behaviour around 1.55 μm Figure 4 shows the curves for the dispersion coefficient *D* corresponding to three different Bragg configurations. Note that this ultra flattened behaviour is preserved in a large wavelength window that extends over several hundreds of nanometres and, unlike flattened dispersion, permits to obtain a point with zero fourth-order dispersion. The tunability of the structure is also clearly demonstrated by the fact that these designs own positive, negative, and zero *D*.

If we go one step further, we can also recognize diverse intermediate situations in which *D* has a low value and at the same time the four-ordered dispersion coefficient is null at 1.55 μm. Some solutions for such a challenging task are plotted in Fig. 5. In particular, we would like to point out that the examination of the blue curves in Fig. 6 reveals a fiber design with an ultra flattened dispersion regime and a low dispersion value around 1.55 μm presenting a point of zero third- and fourth-ordered dispersion at this wavelength simultaneously. This is a fascinating result. However, one has to take into account that in our approach light is guided in silica, not in air, and consequently, in principle, it suffers from residual absorption loss and nonlinear effects as four-wave mixing. The performances of our optical proposal finally depend on the particular application[16].

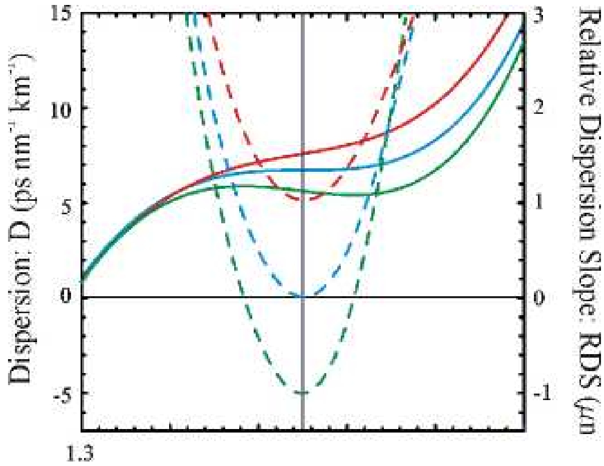


Fig.5. Dispersion (solid curves) and relative dispersion slope (broken curves), defined as *RDS* = *(dD/dA)/D*, corresponding to three different selections of the structural parameters to achieve zero four-ordered dispersion at 1.55 μm: red curve (Λ = 4.710 μm and a = 0.090 μm, blue curve (Λ = 4.570 μm and a = 0.094 μm, and green curve (Λ =4.465 μm and a = 0.096 μm.

Anisotropic waveguides are proposed for the use in long-range communication optical communication systems and for integrated optical devices where conservation of a given state of polarization of the transmitted radiation is an essential requirement. Calculations of the parameters of modes in such waveguides are usually carried out by approximate methods based on perturbation theory. The underlying assumption in these methods is that the mode fields in anisotropic waveguides differ little from the fields in an isotropic waveguide. Approximate methods make it possible to calculate, with a precision sufficient for practical purposes, the characteristics of modes in dielectric waveguides with a relatively weak shape or permittivity anisotropy. However, these methods are unsuitable for determination of the characteristics of modes and fields in waveguides with an arbitrary anisotropy. A relatively simple but quite effective method for calculation of the parameters of modes (propagation constants, critical frequencies, etc.) in complex dielectric waveguides is the method of shift formula. we will use this method to calculate the parameters of guided waves in anisotropic dielectric waveguides and to determine the distributions of the fields of such waves.

We shall consider the waveguide dispersion associated with the guiding properties of waveguides. Wave-guide dispersion, another type, is very similar to material dispersion in that they both cause signals of different wavelengths and frequencies to separate from the light pulse. however, wave-guide dispersion depends on the shape,design,and chemical composition of the fiber core. Only 80% of the power from a light source is confined to the core in a standard single-mode fiber, while the other 20% actually propagates through the inner layer of the cladding. This 20% travels at a faster velocity because the refractive index of the cladding is lower than that of the core.Consequently,signals of differing frequencies and wavelengths are dispersed and the pulse becomes indistinguishable. An increase in the waveguide dispersion in an optical fiber can be used in order to counterbalance material dispersion [2].The parameters of modes in anisotropic dielectric waveguides can be determined by the *a* method of shift formulas which is used to find the normalized field frequency $k(\bar{a}) = \bar{\omega} / c$ where $\bar{\omega}$ is the angular frequency, C is the velocity of light in free space, and the starting point in the calculations is the transverse wave number *a* for the field of a guided mode outside the waveguide, which is the same for waves in the investigated waveguide and in a comparison or reference waveguide *($\bar{a}$ = a).* Here and later the quantities identified by a tilde refer to an investigated anisotropic dielectric waveguide, whereas those without a tilde represent a comparison waveguide[3].The waveguide dispersion of any mode in a dielectric waveguide is defined as the produce the propagation constant of this mode and its frequency. The propagation constant of a mode in an anisotropic waveguide obtained by the method of shift formulas can be written as follows[2,7,8]:

$$\tilde{h} = h + \Delta h_t + \Delta h_l + \Delta h_s \,, \qquad (1)$$

where $\tilde{h}$ and h are the propagation constants of a mode in the investigated anisotropic waveguide and of the corresponding mode in a circular isotropic comparison waveguide; Δh_t ,and Δh_l , are the correction describing the influence of the transverse and longitudinal (axial) anisotropies of the refractive index, respectively; Δh_s is the influence of the shape anisotropy on the propagation constants of modes in a dielectric waveguide. Anisotropic waveguides are used mainly in the single-mode regime. We shall therefore consider only the dominant modes in such waveguides. Bearing in mind that the difference between the refractive indices of the core and cladding in fiber waveguides is small, we can describe as follows the corrections to the propagation constant of the dominant HE_{11}, mode in a fiber waveguide, due to the influence of the transverse and longitudinal anisotropies of the refractive index and due to the ellipticity of the shape of the transverse cross section:

$$\Delta h_t^x = 0 \qquad (2)$$

$$\Delta h_t^y / h = \delta_t B[1 + J_0^2(u) / J_1^2(u)] \qquad (3)$$

$$\Delta h_l / h = \delta_l \Delta(1 - B)B[1 - 2J_0(u)/uJ_1(u) + J_0^2(u)/J_1^2(u)] \qquad (4)$$

$$\Delta h_s^{o,e} / h = \pm\delta_s \Delta^2 (1 - B)B[1 + \left(1 - \upsilon^2/u^2\right) J_0^2(u)/J_1^2(u) + \upsilon^2 J_0^3(u)/uJ_1^3(u)]$$
(5)

where $\Delta = (n_1 - n_2)/n_2$; $\delta_t = (n_y - n_x)/n_2$ $\delta_l = (n_z - n_x)n_2$; $\delta_s = (a - b)/(a + b)$; n_x, n_y and n_z are the components of the refractive index tensor of the core of the investigated anisotropic fiber waveguide; $n_1 = n_x$ is the refractive index of the core of the comparison waveguide; n_2 is the refractive index of the cladding which is the same for both waveguides; *a* and *b* are the major and minor semi axes of the ellipse representing the transverse cross section of the core of the investigated waveguide; $B = \upsilon^2 / V^2; V^2 = u^2 + \upsilon^2$; u and υ are the internal and external normalized transverse wave numbers of the modes. Equation (2) describes the dominant mode in a waveguide with a transverse anisotropy of the dielectric in which the electric field vector is polarized along the *X* axis, whereas Eq. (3) applies to a mode polarized along the *Y* axis. In Eq. (5) the upper sign applies to the odd (o) and the lower sign to the even (e) dominant modes in an elliptic fiber waveguide.

In dielectric waveguides the longitudinal (axial) anisotropy created in the process of their drawing from a blank is fairly weak: $\delta_l \le 10^{-5}$ [10]. Moreover, the longitudinal component of the mode field in fiber waveguides is very small compared with the transverse components. Therefore, the influence of the longitudinal anisotropy of the refractive index on the propagation constants of modes is less than the influence of the transverse anisotropy of the refractive index or of the shape anisotropy, so that we shall ignore the effects of the longitudinal anisotropy. This also follows from a comparison of Eqs. (2)- (5) bearing in mind that we typically have $\Delta \sim 10^{-3}$.

By definition the waveguide dispersion in anisotropic fiber waveguides, subject to Eq. (1), can be written in the form:

$$\frac{d\tilde{h}}{dk} = (1+\frac{\Delta h}{h})\frac{dh}{dk} + h\frac{d}{dk}(\frac{\Delta h}{h}) \ , \qquad (6)$$

where $\Delta h = \Delta h_t + \Delta h_s$ applies to an elliptic waveguide with a transverse anisotropy of the dielectric; in particular, we have $\Delta h = \Delta h_t$ for a circular waveguide with a transverse anisotropy of the dielectric and $\Delta h = \Delta h_s$ for an elliptic waveguide with an isotropic dielectric.

The propagation constant of the dominant mode in a circular isotropic comparison waveguide can be represented by:

$$h = k[n_2^2 + (n_1^2 - n_2^2)B]^{1/2}$$

or, within terms of the order of Δ^2, by

$$h = kn_2[1 + \Delta B + \Delta^2 B(1-B)/2] \qquad (7)$$

Then, the waveguide dispersion of this waveguide can be written as follows:

$$\frac{dh}{dk} = n_2[1 + \Delta B + 2\Delta x_0(1-B) + \Delta^2(1-B)\left(\frac{5}{2}B + x_0 - 2x_0 B - 2x_0^2 B\right)] \qquad (8)$$

where $x_0 = [K_0(\upsilon)/K_1(\upsilon)]^2$

Substituting in Eq. (6) the expressions (2), (3), and (5) we obtain a formula for the calculation of the waveguide dispersion of an anisotropic fiber waveguide:

$$\frac{d\tilde{h}}{dk} = \frac{dh}{dk} + D_t + D_s \qquad (9)$$

where *dh /dk* is defined by Eq. (8), whereas

$$D_t^x = 0 \qquad (10)$$

and

$$D_t^y = n_2\delta_t B\{1 - 2\frac{u^2}{\upsilon}x_0^{1/2} + 5\frac{u^2}{\upsilon^2}x_0 - 2\frac{u^2}{\upsilon}(\frac{u^2}{\upsilon^2}-1)x_0^{3/2} + 2\frac{u^2}{\upsilon^2}(\frac{u^2}{\upsilon^2}-1)x_0^2 + 2\frac{u^4}{\upsilon^3}x_0^{5/2}$$
$$+ \Delta(1-B)[1 - \frac{V^2}{\upsilon}x_0^{1/2} + 3x_0 + \upsilon(1 - \frac{u^2}{\upsilon^2} - 3\frac{u^4}{\upsilon^4})x_0^{3/2} - (2 + 3\frac{u^2}{\upsilon^2} + 6\frac{u^4}{\upsilon^4})x_0^2 + 2\frac{u^2}{\upsilon^3}(1 + 2\frac{u^2}{\upsilon^2})x_0^{5/2} + \frac{u^2}{\upsilon^2}(1 + 2\frac{u^2}{\upsilon^2})x_0^3 - \frac{u^4}{\upsilon^3}x_0^{7/2}]\} \qquad (11)$$

describe the influence of the transverse anisotropy of the dielectric on the mode dispersion of the dominant modes polarized along the *X* and *Y* axes, respectively, and

$$D_s^{o,e} = \pm n_2\delta_s\Delta^2 B(1-B)[1 - 2(\frac{u^2}{\upsilon} - \upsilon)x_0^{1/2} + (5\frac{u^2}{\upsilon^2} - 5 - 3u^2)x_0 + (9\frac{u^2}{\upsilon} - 2\frac{u^4}{\upsilon^3} - 2\upsilon)x_0^{3/2} + (3u^2 - 8\frac{u^2}{\upsilon^2} - 3\frac{u^4}{\upsilon^2} + 2 + 2\frac{u^4}{\upsilon^4})x_0^2 + 6\frac{u^2}{\upsilon}(\frac{u^2}{\upsilon^2} - 1)x_0^{5/2} + 3\frac{u^4}{\upsilon^2}x_0^3] \qquad (12)$$

describes the influence of the shape anisotropy of the transverse cross section on the waveguide dispersion of the dominant odd (upper sign) and even (lower sign) modes.

These expressions can also be used to calculate the polarization dispersion in an anisotropic fiber waveguide:

$$\frac{d\beta_t}{dk} = \frac{d\tilde{h}_x}{dk} - \frac{d\tilde{h}_y}{dk} = -D_t^y \qquad (13)$$

in the case of waveguides with a transverse anisotropy of the dielectric,

$$\frac{d\beta_s}{dk} = \frac{d\tilde{h}^e}{dk} - \frac{d\tilde{h}^o}{dk} = 2D_s \qquad (14)$$

In the case of waveguides with an elliptic transverse cross section, and

$$\frac{d\beta}{dk} = -D_t^y + 2D_s \qquad (15)$$

In the case of elliptic waveguides with a transverse anisotropy of the dielectric. Here, $\beta = \beta_t + \beta_s, \beta_t = \tilde{h}_x - \tilde{h}_y, \beta_s = \tilde{h}^e - \tilde{h}^o$; $\tilde{h}_x$ and $\tilde{h}_y$, $\tilde{h}^e$ and $\tilde{h}^o$ are the propagation constants of, respectively, the dominant mode polarized along the X and Y axes, and of the even and odd dominant modes in an elliptic waveguide.

The expression for the polarization dispersion in an isotropic waveguide with an elliptic transverse cross section, similar to Eq. (14), had been obtained earlier by other authors (see, for example, Ref. 11). Moreover, experimental values of the polarization dispersion in an optical waveguide with a transverse anisotropy of the refractive index and an elliptic waveguide were obtained in Ref. 12. Therefore, it is possible to compare the values of the polarization dispersion calculated using Eqs. (13)-(15) with these experimental values.

The anisotropy of the refractive index in the transverse cross section of a waveguide δ_t, can be calculated fromEq. (7) of Ref. 1 if we know the external pressure p on the waveguide core. The continuous lines in Fig. 6 represent the polarization dispersion $d\beta_t / d\lambda$ for a circular anisotropic fiber waveguide with $\Delta = 2.10^{-3}$ calculated from (13).

For various values of λ^{-2} (λ is the wavelength). The dashed lines are drawn through the experimental points taken from Ref. 12. The experimental values themselves are represented by circles in Fig. 6.

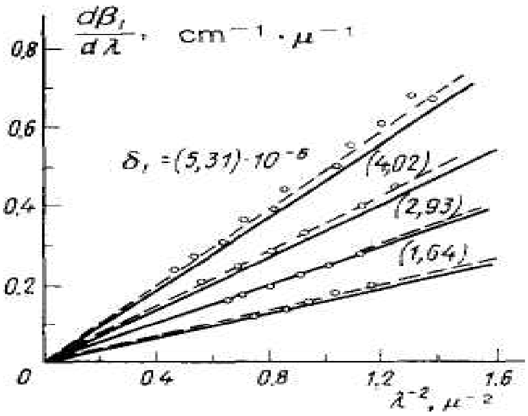


Fig.6: calculated and experimental values.

We can see from Fig. 6 that the difference between the calculated and experimental values of the polarization dispersion does not exceed 7% of waveguide parameters indicated in Fig. 6.

In an investigation [12] of an elliptic waveguide with δ_s=0.21 and Δ= $2.9.10^{-3}$ at λ= 1.1 μ it was found that $\frac{d\beta_s}{dk} = 1.541.10^{-6}$ whereas $\frac{d\beta_s}{dk} = 1.702.10^{-6}$ is the value obtained from Eq. (14) for a waveguide with the same parameters. It therefore follows that if $\delta_s \leq 0.21$, then calculations based on Eq. (14) are subject to an error not exceeding 9.4%.

It is thus clear that the expressions derived above are sufficiently accurate for practical calculations of the waveguide and polarization dispersions of the dominant orthogonally polarized modes in an anisotropic fiber waveguide.

A waveguide can conserve stably a given polarization state of the transmitted signal if a transverse anisotropy of the permittivity and $\delta_t \geq 10^{-4}$ is established in the waveguide[13].

Figure 7 shows the values of the waveguide dispersion for anisotropic fiber waveguides with $\Delta = 3.10^{-3}$. Curves 2-5 denote the waveguide dispersion of modes polarized along the *Y* axis traveling in waveguides with anisotropy $\delta_t of\ -5.10^{-4}, -10^{-4}, 10^{-4}$, and 5. 10^{-4} Curve 1 represents.

3 Results and Discussions

The waveguide dispersion of modes polarized along the *X* axis in the same waveguides. Moreover, this curve represents also the waveguide dispersion of the dominant mode in an isotropic waveguide. The abscissa in Fig. 7 gives the values of the normalized frequency $V = 2\pi R n_2 \sqrt{2\Delta} / \lambda$, where *R* is the waveguide radius. It is clear from Fig. 7 that the anisotropy of the dielectric increases strongly (or reduces, depending on the sign of δ_t) the waveguide dispersion of optical fiber waveguides. The maximum waveguide dispersion for waveguides with different values of the transverse anisotropy of the insulator δ_t, is attained at different frequencies.

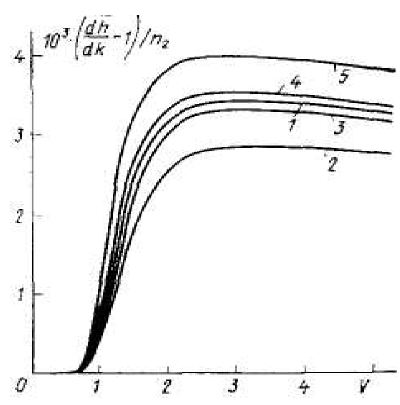


Fig.7:Values of normalized frequencies.

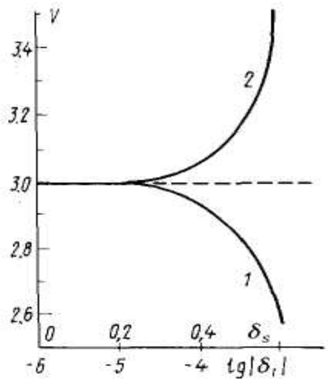


Fig.8:- maximum values of dispersion.

Moreover, the maximum waveguide dispersion of orthogonally polarized modes traveling in anisotropic fiber waveguides also occurs at different frequencies. Continuous curves in Fig. 8 are the normalized frequencies *V* at which the waveguide dispersion has its maximum value, plotted for waveguides with $\delta_t \geq 0$ (curve 1) and $\delta_t \leq 0$ (curve 2).

The deviation from the circular transverse cross section of a waveguide (shape anisotropy) also alters the waveguide dispersion. In this case the waveguide dispersion of even orthogonally polarized modes of elliptic waveguides with different degrees of ellipticity δ_s has its maximum value at the same frequency $V = 2\pi \tilde{R} n_2 \sqrt{2\Delta} / \lambda$ where $\tilde{R} = (a+b)/2$ is the radius of a comparison waveguide (dashed line in Fig.8). At this frequency the waveguide dispersion of the dominant mode of the circular comparison waveguide also has its maximum value. The waveguide dispersions of an elliptic waveguide agree, with the accuracy of the scatter in the graphs, with the value of the waveguide dispersion for a circular waveguide (curve 1 in Fig. 7). Figure 9 makes it possible to determine the order of the waveguide dispersion of an elliptic waveguide. The continuous and dashed curves in Fig. 9(a) represent the values of the waveguide dispersion for even and odd modes of an elliptic waveguide with $\Delta = 3.10^{-3}$ and with different values of the ratio of the minor and major semi axes of the transverse-cross section ellipse *b /a* calculated for *V*= 2.010, whereas the corresponding curves in Fig. 9(b) give the results of calculations for *V*= 3.072.

In this paper we have discussed the dispersion properties of fibers. We have numerically demonstrated the ability of these structures to show, for some specific designs, a flattened dispersion behavior (one point of zero third-order dispersion) around 0.8 μm and even an ultraflattened behavior (one point of zero fourth-order dispersion) around 1.55 μm Moreover, we have recognized some configurations exhibiting positive, negative, or nearly-zero constant dispersion in both wavelength windows. Finally, a noteworthy fiber design that combines low and nearly-constant chromatic dispersion about 1.55 μm with zero third- and fourth-order dispersion at 1.55 μm has been identified.

Also the single-mode fibers provide a solution to the problems of polarization and dispersion. we thus derived expressions for the calculation of the waveguide and polarization dispersions of dominant orthogonally polarized modes in anisotropic fiber waveguides. The anisotropy of the dielectric in the transverse cross section as well as the shape anisotropy alters the waveguide dispersion of these modes compared with that in an isotropic waveguide. In the case of waveguides capable of conserving the Polarization of the transmitted signal ($\delta_t \geq 10^{-4}$).also in this work, the polarization and polarization-mode dispersion in fibers have been discussed. Analysis of optical fibers that maintain polarization over long lengths, provide zero polarization-mode dispersion. the zero polarization-mode dispersion single-mode design is a dispersion-shifted fiber that provides large effective area and hence reduces signal distortions due to nonlinearity in fibers.a comprehensive analysis of polarization-mode dispersion in multiple-clad fibers due to ellipticity of fiber cross-section was carried out using a perturbation technique. The design of large effective area single-mode dispersion-shifted fiber that provides zero polarization-mode dispersion at the wavelength 1.55 μm was accomplished using the analysis developed.

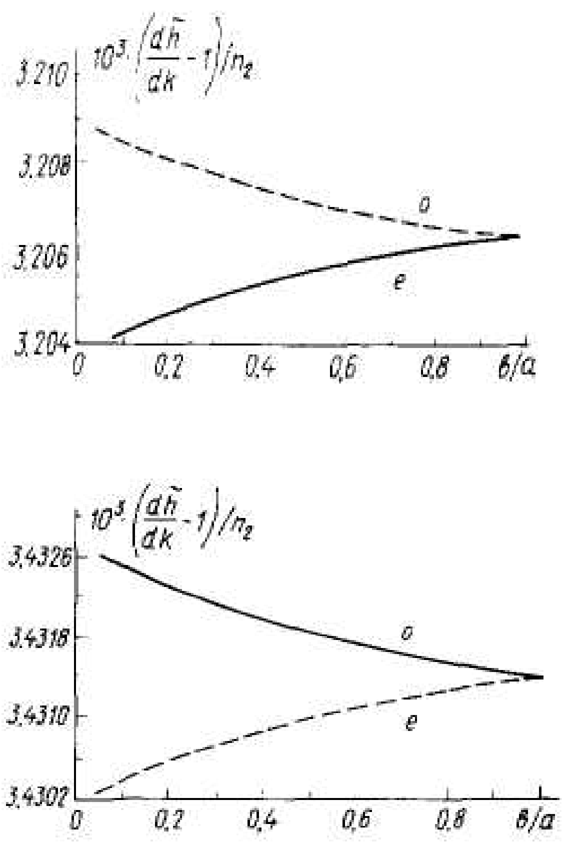


Fig.9 :-(a) values of the waveguide dispersion for even and odd modes.
(b) Results of calculations for V= 3.072.

4 Conclusion

The changes due to the anisotropy of the dielectric are much greater than the changes in the waveguide dispersion due to the shape anisotropy. The transverse anisotropy of the refractive index is the reason why the waveguide dispersions of the modes polarized along mutually perpendicular directions have maxima at different frequencies. The proposed method can be used to calculate the main parameters of guided waves in anisotropic (in a wide sense) dielectric waveguide which can conserve a given state of polarization of the transmitted signal. This method has been used to calculate the propagation constants and the waveguide dispersion of the fundamental modes in an anisotropic dielectric waveguide and the distributions of the fields of these modes. . The results show that under the influence of the anisotropy of the dielectric an energy spot describing the distribution of the fields of the fundamental modes in dielectric waveguides loses its circular symmetry and becomes an ellipse elongated along the coordinate axes which coincide with the principal axes of the permittivity tensor. The influence of changes in the anisotropy on the waveguide dispersion of the fundamental modes in an anisotropic dielectric-waveguide is different from the effects of the permittivity anisotropy. The proposed method can be used to calculate the main parameters of guided waves in anisotropic (in a wide sense) dielectric waveguide which can conserve a given state of polarization of the transmitted signal. This method has been used to calculate the propagation constants and the wave-guide dispersion of the fundamental modes in an anisotropic dielectric waveguide and the distributions of the fields of these modes. The results show that under the influence of the anisotropy of the dielectric an energy spot describing the distribution of the fields of the fundamental modes in dielectric waveguides loses its circular symmetry and becomes an ellipse elongated along the coordinate axes which coincide with the principal axes of the permittivity tensor. the influence of changes in the anisotropy on the waveguide dispersion of the fundamental modes in an anisotropic dielectric-waveguide is different from the effects of the permittivity anisotropy.

5 Suggestions For Further Investigations

The analysis of polarization-mode dispersion presented here accounts for fiber cross-section elliptical deformations. However, in addition to core ellipticity, random residual stress also contributes to polarization-mode dispersion. Thus, the analysis of polarization-mode dispersion should be extended to random anisotropy in the fiber.

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