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The Effect of Dielectric Permeability in Anisotropic Bending Spiral Optical Fiber on Transmission Parameters

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Introduction

Spiral shaped fibers have a number of potentially attractive features, and it can help to confine the electromagnetic fields. And can be used also as a very effective means for suppressing high order modes in large core fiber.

Anisotropic optical fiber waveguides capable of conserving the polarization of the transmitted signal, this property is very important for various optical fiber devices and for long distance optical communication systems. and as it is known that the various anisotropic components were used widely in optical fiber systems of transfer and used mainly in the single-mode regime[1, 2, 3, 4].

The simplest way of reception an anisotropic optical properties of environment in optical fiber is the voltage creation in fibers which caused by mechanical stresses. Such this anisotropy of optical properties called: photo elasticity and it can appear at bended fibers in the cooled condition. So it is very interesting to study the spiral typical form of optical fiber, since this spiral bend is widely used in the designing of optical cables.

Material and Methods

The vector of electrical induction $\vec{D}$, and vector of electrical field $\vec{E}$, are connected by the following ratio:

$$D_i = \sum_{j=1}^{3} \varepsilon_0 \varepsilon_{ij} E_j \,, \tag{1}$$

where ε_{ij} – Elements tensor of dielectric permeability, which Characterize the anisotropy of dielectric properties of bent optical fiber; ε_0 – an electrical constant.

In work [5], the equation for tensor elements of dielectric permeability which depend on the parameters χ and υ, which describe the curvature and torsion form of spiral has been obtained according to the coordinates *x, y, z* and *r*, φ, *z*. this equation studies the bending spiral fiber optics and gives the analysis for tensor elements of anisotropic optical fiber dependence in the system of coordinate *x, y, z.*

$$\hat{\varepsilon} = \begin{Vmatrix} \varepsilon_{rr} & \varepsilon_{r\varphi} & \varepsilon_{rz} \\ \varepsilon_{\varphi r} & \varepsilon_{\varphi\varphi} & \varepsilon_{\varphi z} \\ \varepsilon_{zr} & \varepsilon_{z\varphi} & \varepsilon_{zz} \end{Vmatrix} , \tag{2}$$

Let's analyze the dependence of tensor elements of ε_{ij} according to the parameters χ and υ in the system of coordinates *r*,φ, *z*. Thus the dielectric permeability tensor $\hat{\varepsilon}$ will take the next form [5,6], where the diagonal elements ε_{rr} , $\varepsilon_{\varphi\varphi}$ and ε_{zz} are determined by the ratios:

$$\varepsilon_{rr} = \varepsilon_{\varphi\varphi} = \varepsilon(r); \tag{3}$$

$$\varepsilon_{zz} = \varepsilon(r) - 2\chi r \cos\varphi + \chi^2 r^2 \cos^2\varphi + \upsilon^2 r^2 . \tag{4}$$

The non-diagonal elements $\varepsilon_{r\varphi} = \varepsilon_{\varphi r} = \varepsilon_{rz} = \varepsilon_{zr} = 0$,

$$\varepsilon_{\varphi z} = \varepsilon_{z\varphi} = -\upsilon r \; . \tag{5}$$

In (3–5) parameters χ and υ are defined as follows [5]:

$$\chi = \frac{R}{R^2 + (\rho/2\pi)^2} , \quad \upsilon = \frac{\rho}{2\pi} \frac{1}{R^2 + (\rho/2\pi)^2} . \tag{6}$$

In ratio (4), the second and the third parts take in consideration the dependence of ε_{zz} on coordinates *r* and φ, because the second and third parts happened due to curvature and the fourth part because of the torsion of the spiral.

The physical sense of tensor elements of dielectric permeability ε_{ij} for the bending spiral optical fiber is conducted according to the connection of these elements with the functions of the metric elements of the deformation, which caused by the curvature and torsion of the spiral.

The physical sense of tensor elements of dielectric permeability ε_{ij} for the bending spiral optical fiber is conducted according to the connection of these elements with the functions of the metric elements of the deformation, which caused by the curvature and torsion of spiral [7,8,9]. Thus the elements of ε_{ij} which locate on the main diagonal tensor (2), represent the distribution of dielectric permeability along *i* axis, which caused by mechanical deformations in this direction (compression or stretching). The positive values of deformation tensor components correspond to compression [5], that results in increasing of ε_{ij} in a direction of the given coordinate. The stretching leads to reduction of the elements of ε_{ij} along the given coordinate.

To study the dependence of tensor components ε_{ij} on the bend parameters *R* and ρ, we make a calculation for ε_{ij} elements at ρ = 50 ; 100 mm ,and *R* = 5; 7,5; 10 mm depending on *r* and φ coordinates, this calculation is given in Table 1.

Fig. 1 show the dependence of ε_{zz} on φ and other values of ε_{ij} components of pure quartz optical fiber at λ =1.55 μm, *R* =5 mm, ρ =50 mm. Thus curve 1 corresponds to coordinate *r* = 1 μm, the curve 2 corresponds to coordinate *r* = 2.5 μm. And the component $\varepsilon_{\varphi z}$ = 9.009·10^{-5} at *r* = 1 μm. and when r = 2.5 μm, the component $\varepsilon_{\varphi z}$ = 2.2523·10^{-4}.

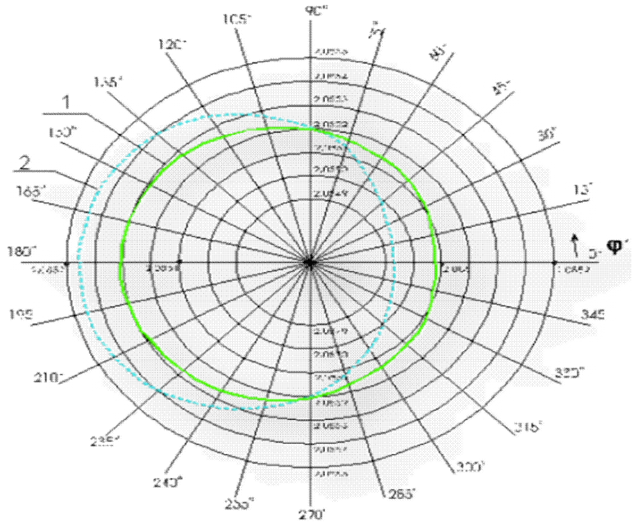

Fig. 1. The dependence ε_{zz} on φ

Table. 1. Dependence $\Delta\varepsilon_{zz}(R,\rho,r,\varphi)\cdot 10^{-4}$

φ, degree.	5				7.5				10				*R* mm
	50		100		50		100		50		100		ρ mm
	1	2.5	1	2.5	1	2.5	1	2.5	1	2.5	1	2.5	*r* μm
0	-1.12	-2.84	-0.36	-0.9	-1.26	-3.14	-0.49	-1,21	-1.23	-3.06	-0.57	-1.42	
15	-1.1	-2.73	-0.34	-0.87	-1.21	-3.03	-0.47	-1.17	-1.19	-2.96	-0.55	-1.37	
30	-0.98	-2.45	-0.31	-0.78	-1.09	-2.72	-0.42	-1.05	-1.06	-2.65	-0.49	-1.23	
45	-0.8	-2.0	-0.26	-0.64	-0.89	-2.22	-0.35	-0.86	-0.87	-2.17	-0.4	-1.0	
60	-0.57	-1.42	-0.18	-0.45	-0.63	-1.57	-0.24	-0.61	-0.61	-1.53	-0.29	-0.71	
75	-0.3	-0.73	-0.1	-0.23	-0.33	-0.81	-0.13	-0.32	-0.32	-0.79	-0.15	-0.37	
90	0	0	0	0	0	0	0	0	0	0	0	0	
105	+0.3	+0.73	+0.1	+0.23	+0.33	+0.81	+0.13	+0.32	+0.32	+0.79	+0.15	+0.37	
120	+0.57	+1.42	+0.18	+0.45	+0.63	+1.57	+0.24	+0.61	+0.61	+1.53	+0.29	+0.71	
135	+.,8	+2.0	+0.26	+0.64	+0.89	+2.22	+0.35	+0.86	+0.87	+2.17	+0.4	+1.0	
150	+0.98	+2.45	+0.31	+0.78	+1.09	+2.72	+0.42	+1.05	+1.06	+2.65	+0.49	+1.23	
165	+1.1	+2.73	+0.34	+0.87	+1.21	+3.03	+0.47	+1.17	+1.19	+2.96	+0.55	+1.37	
180	+1.12	+2.84	+0.36	+0.9	+1.26	+3.14	+0.49	+1.21	+1.23	+3.06	+0.57	+1.42	

From Fig. 1 we can notice that when the dependence of ε_{zz} on φ is more expressed, then the coordinate *r* will be bigger.

The second and third parts in ratio (4), which represent ($2\chi.r.\cos\varphi$) and ($\chi^2.r^2.\cos^2\varphi$) form the basic contribution to change ε_{zz} of anisotropic optical fiber in comparison with $\varepsilon(r)$ of isotropic optical fiber. But the rank of the fourth part ($\upsilon^2.r^2$) in ratio (4) differs on (10^{-6} and 10^{-3}) from ranks of the second and the third part. Therefore the fourth part was practically not taken into account at the values of parameters *R* = 5; 7,5; 10 mm, and ρ = 50; 100 mm.

For this reason and at any values of coordinate *r* ,the value ε_{zz} of anisotropic optical fiber which bent on spiral will be coincide with ε isotropic optical fiber if φ =90° and 270°.

Generally the dependence of ε_{zz} on coordinates (*R*, ρ, *r* , φ) can possibly be presented as following :

$$\varepsilon_{zz} = \varepsilon(r) \pm \Delta\varepsilon \ , \qquad (7)$$

$$\Delta\varepsilon = -2\chi^2\cos\varphi + \chi^2 r^2\cos^2\varphi + \upsilon^2 r^2 \ , \qquad (8)$$

where $\Delta\varepsilon_{zz}$ depends only on the four parameters (*R*, ρ, *r* , φ) and does not depend on the length of a wave λ .

Results

The calculation of $\Delta\varepsilon$ for various values *R*, ρ, *r* depending on φ is made, these results are given in the Table 1.

From Table1 we notice, that $\Delta\varepsilon_{zz}$ is symmetric but with opposite sign concerning coordinate φ =90°. Except that in bottom section of φ axis (from180° to 360°) the $\Delta\varepsilon_{zz}$ will be mirror display (similar for φ axis from 0° to 180°). So in this table the values $\Delta\varepsilon$ are given only in the specified interval of changes φ. This expression is right and corresponds with ratio (8) when $\upsilon^2 r^2 \approx 0$.
By taking into consideration the third part of ratio (8), and the values of $\Delta\varepsilon_{zz}$ from the table.1 which their degree of precision is 10^{-9} according to the vertical axis (+90° … 270°) and the horizontal axis (0° … 180°) the symmetric curves of $\varepsilon_{zz}(\varphi, r)$ in Fig.1 will vanish.

Thus $\Delta\varepsilon_{zz}$ depends on coordinate's *r* more than on parameters χ and υ, which describe curvature and torsion. Also the big values of ρ corresponds with the small values of $\Delta\varepsilon_{zz}$. With the changing of *R* (from 5 to 10 mm) and with the constancy of *r* and ρ, the value of $\Delta\varepsilon_{zz}$ will increase no more than 30%.

Conclusions

The values of $\Delta\varepsilon_{zz}$ which are given in Table 1 allow to settle ε_{zz} for anisotropic bent on spiral optical fiber depending on parameters of a spiral irrespective of optical fiber structure and for any wave length of optical radiation, and base on the analysis of expression (4) and the calculations, which are carried out, it's possible to conclude that the dielectric permeability of anisotropic bent on spiral optical fiber changes in cross section under a certain law. And this leads to a change in the fiber transmission parameters, such attenuation and dispersion.
Therefore the ideal choice of optimum form of a bend within certain limits leads to the possibility of changing the transfer parameters (attenuation and dispersion) into a better form.

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This study shows that the assumption of geometric parameters of the spiral shaped of optical fiber leads to an exact solution for the fiber modes. Also it shows the possibility of changing the transfer parameters (attenuation and dispersion) into a better form. Spiral fibers are proven to be particularly efficient as they produce excellent confinement of the electromagnetic fields. The components of dielectric permeability tensor ε_{ij} according to the parameters χ and υ in the system of coordinates *r*, φ is analyzed. The tensor components ε_{ij} dependences on the bend parameters *R* and ρ are calculated. Ill. 1, bibl. 9 (in English; summaries in English, Russian and Lithuanian).

М. И. Ал-Гавагзех. Влияние диэлектрической проницаемости спирали оптического волокна на параметры передачи данных // Электроника и электротехника. – Каунас: Технология, 2009. – № 1(89). – С. 45–48.

Предположено, что геометрические параметры сформированной спирали оптического волокна влияют на параметры мод электромагнитного сигнала. Также показана возможность изменения параметров передачи сигнала (ослабления и дисперсии) таким образом, чтобы можно было получить нужные величины его параметров. Спиральные волокна особенно эффективные, поскольку они превосходно экранируют излучаемые электромагнитные поля. Анализируются зависимость компонентов тензора диэлектрической проницаемости ε_{ij} от параметров χ и υ в системе координат *r*, φ. Рассчитаны зависимости компонентов тензора ε_{ij} от параметров изгиба R и ρ. Ил. 1, библ. 9 (на английском языке; рефераты на английском, русском и литовском яз.).

M. Y. Al-Gawagzeh. Dielektrinės skvarbos poveikis anizotropinės spirale susuktos optinės skaidulos signalų perdavimo parametrams // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 1(89). – P. 45–48.

Tyrime pateikta prielaida apie spiralinės formos optinės skaidulos geometrinių parametrų sąryšį su optinių modų parametrais. Taip pat parodyta, jog, keičiant geometrinius parametrus, galima modifikuoti signalo perdavimą lemiančius parametrus (slopinimą ir dispersiją). Taip šiuos parametrus galima keisti norima linkme tam tikrose ribose. Spiralinės formos optinės skaidulos naudojamos dėl jų išskirtinio efektyvumo slopinant skleidžiamą elektromagnetinį lauką. Analizuotos dielektrinės skvarbos tenzoriaus ε_{ij} komponenčių priklausomybės nuo parametrų χ ir υ kai skaidula yra *r*, φ koordinačių sistemoje. Apskaičiuotos ε_{ij} tenzoriaus komponenčių priklausomybės nuo sulenkimo parametrų *R* ir ρ. Il. 1, bibl. 9 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).