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Optic Fiber on the Basis of Photonic Crystal

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1. Introduction

1.1 Phylums of optic fibers

The optic fiber represents internal dielectric medium (crystal, glass etc.), which one is contained a main body of a quantity of light transmitted on a fiber, and which one is called as a core. The core can be surrounded by a layer with lower refractive index, which one is called as a shell. For protection against exposures and for increase of a mechanical strength the core with a shell can be coated with a padding layer of plastic.

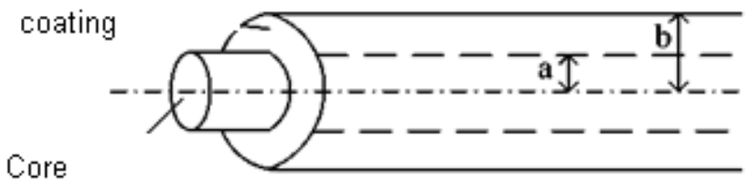


Fig. 1. An optic fiber.

There are different phylums of fibers. The optic fibers without a shell represent simply glass or quartz fiber. They are friable and are ineffective. For them large losses, as on border of two mediums the electrical field is not equal to zero point and the border is rather incomplete. Besides, that such fiber was monomode; his diameter should be less than 1 micron. Such fibers now practically are not applied.

Optic fibers with a shell. The core in such optic fibers is coated with a shell with lower refractive index. The losses in fibers with a shell are much less than losses in fibers without a shell. As we shall see hereinafter, the illumination in such fibers depends on reduced frequency. And essentialist: the manufacturing of such fibers is technologically possible, in which one one mode of propagation will be diffused only. Hereinafter we shall esteem basically only fibers with a shell.

On a structure of refractive index of a fiber it is possible to secure two most often meeting of a type: stepwise and gradient.

In a stepwise fiber the refractive index in a core remains to a constant (see fig. 2a):

In a gradient fiber the refractive index of a core varies depending on r - spacing interval from an axis of a fiber (see fig. 2b).

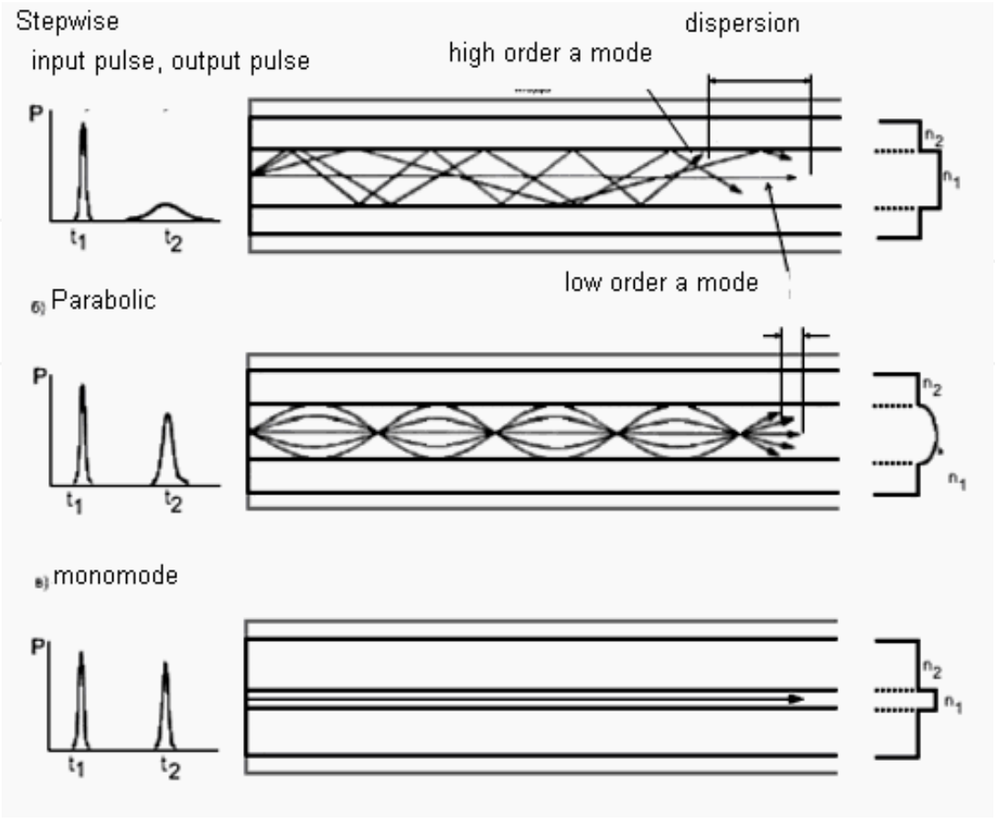


Fig. 2. Phylums of optic fibers, their structures of refractive index and broadering of an optical impulse: and - stepwise; - parabolic; in - monomode.

As we shall see later, in a gradient fiber, in which one the refractive index varies under the parabolic law, the optical pathes of different beams will be practically identical, that essentially reduces a dispersion of a fiber. The gradient fiber as contrasted to stepwise has the best characteristics on dispersion and consequently has large throughput capacity.
The selected law of change of refractive index can be more or less composite. The directional illumination is possible as well in a homogeneous material, if to him to give the definite form. Gears of an illumination in most often used stepwise and gradient fibers.

1.2 Stepwise fiber - A numbered aperture

Let's consider a stepwise optic fiber (fig. 2a). Let and - radius of a core, b - radius of a shell. If diameter of a fiber about several tens micrometers, and difference of refractive indexes about 10-2, it is possible to use concepts of a ray optics and to speak about propagation of light rays.
Let's consider the gear of an illumination in a fiber, neglecting absorption in stuff, it is necessary to allow which one, generally speaking. Let light beam in a core is diffused bevel way θ to an axis Oz, the axis Oz is directed on an axis of a fiber (fig. 3).
Longitudinal wave number or propagation coefficients:

$$\beta = k\cos\theta = \frac{\omega}{c} n_1 \cos\theta = \text{const} .$$

The surge, gated in in a core of a fiber, will be retained in her at the expense of full internal reflection at fulfilment of a condition $\theta < \theta_{kr}$, where θ_{kr} - critical angle. At fulfilment of a condition of full internal reflection the surge in a shell is an only imaginary and fast damp on exponential law at deleting from a demarcation a core a shell. At increase of a angle? The condition of total reflection ceases to be executed, and the surge in a shell becomes real. Pursuant to above mentioned it is possible to secure three kinds of rays:

1. Routed rays (rays distributing in a fiber),
2. Beams distributing with outflow (loss),
3. Refracted beams? If is satisfied condition of full internal reflection,

And alone area, where the beam is real, is the core, the beam is considered as routed (fig. 3).
If the beam appears by real in some part of a shell, he is diffused with outflow ((fig. 4).
If the beam appears by real in all volume of a shell, we deal with a refracted beam.

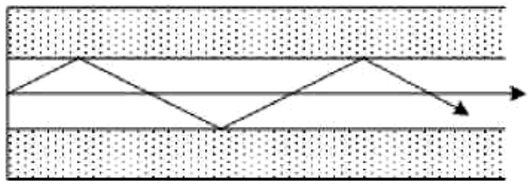


Fig. 3. Routed beam. There is a total reflection from a shell.

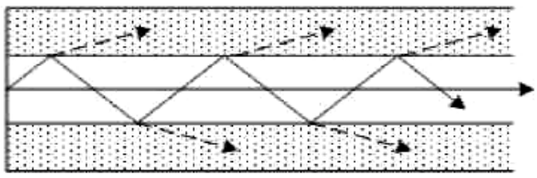


Fig. 4. Beam distributing with outflow. The part of a beam inpours into a shell.

Let's consider in more detail beams distributing in a fiber. Let beam drops from air on butt end of a fiber bevel way Ω. Let's find a maximum angle Ω_m , under which one it is possible to enter this beam into a fiber, that the beam was hereinafter diffused in a fiber. Thus the ray in a core will be diffused bevel way θ_{kr}, conforming to a case of total reflection from a demarcation with a shell (see fig. 5).

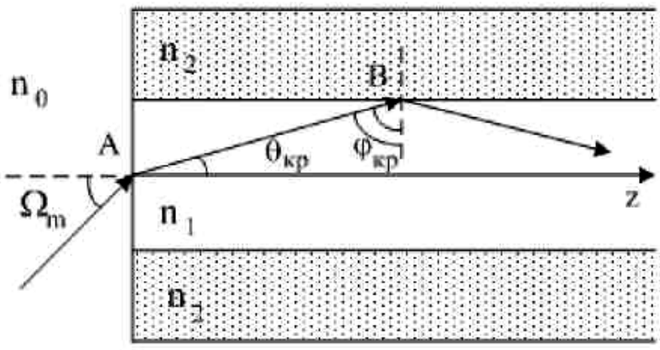


Fig. 5. An illumination in a stepwise fiber.

For a demarcation an air - core of a fiber (point A):

$$\frac{\sin\Omega_m}{\sin\theta_{кр}} = \frac{n_1}{n_0}.$$

Here n0 - refractive index of air. Let's count n_0 =1.
Let's find sin Ω_m

$$\cos\ \theta_{кр} = n_2 / n_1 .$$

Angle $\theta_{кр}$ is discovered:

$$\sin\Omega_m = n_1 \sin\theta_{кр} = n_1\sqrt{1-\cos^2\theta_{кр}} = n_1\sqrt{1-\frac{n_2^2}{n_1^2}} = \sqrt{n_1^2 - n_2^2}.$$

Value sin Ω_m call as a numbered aperture of a fiber. The numbered aperture has notation NA. Thus, the numbered aperture is peer

$$NA = \sin\Omega_m = \sqrt{n_1^2 - n_2^2}.$$

The numbered aperture of a fiber determines a maximum corner(angle) of input in a fiber of a beam, which one will test total reflection and to be diffused in a fiber.
If the condition of total reflection is defaulted, the beams with outflow or refracted beams will be diffused.

1.3 Gradiant fiber - A numbered aperture

Let's consider a gradient optic fiber (see fig. 2б). His(its) refractive index, as against a stepwise fiber, varies at change r:

$$\begin{cases} n = n(r), \text{ если } r < a, \\ n = n_2, \text{ если } r \geq a. \end{cases}$$

To similarly stepwise fiber, it is possible to find a maximum angle of input of radiation in a fiber, only he will depend on spacing interval r:? m =? m (r). Value sin Ω_m (r) we shall call as a local numbered aperture of a fiber:

$$NA(r) = \sin\Omega_m(r) = \sqrt{n^2(r) - n_2^2}.$$

Any beams dropping on butt end of a fiber apart r from an axis and falling inside of an aperture tumulus with an apex angle $\Omega_m(r)$, tests after input total reflection and is diffused in a fiber. The local numbered aperture is max on an axis of a fiber and up to zero point on border a core and shells drops.
As numbered aperture of a gradient fiber we shall call maximum value of the local numeric aperture.
For a gradient fiber with a quadratic structure of refractive index the effective numbered aperture is determined, which one is peer:

$$NA_{eff} = \frac{\sqrt{n^2(0) - n_2^2}}{\sqrt{2}} .$$

1.4 Power entered into a fiber

Let's show, that only part of light which is radiated a small diffuse source, placed on an axis of sighting of a fiber near to his butt end, can be entered into a fiber. Let's consider a small diffuse light source, the brightness which one is identical in all directions figured in figure 6. Let I0- power which is radiated in unit of solid angle on a normal to a source, I (0) = I_0cos0 - power which is radiated bevel way 0. Then power which is radiated in small solid angle δθ, is peer:

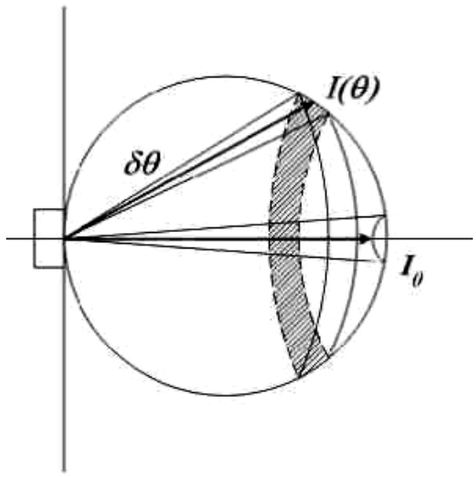


Fig. 6.

$$I_0 \cos\theta \, \delta\theta = I_0 \cos\theta \, 2\pi \sin\theta \, \delta\theta .$$

The total power which is radiated such source, is by integrating of this expression on all directions:

$$\Phi_0 = \int_0^{\pi/2} (I_0 \cos\theta)(2\pi)(\sin\theta) d\theta = 2\pi I_0 \int_0^{\pi/2} \sin\theta \, d(\sin\theta) =$$

$$= 2\pi I_0 \left(\frac{\sin^2\theta}{2} \right) \Bigg|_{\theta=0}^{\pi/2} = \pi I_0 .$$

The power, gated in in a fiber, diameter of a core which one is more than diameter of a source, is determined by a following integral:

$$\Phi = \int_0^{\Omega_m} (I_0 \cos\theta)(2\pi)(\sin\theta)d\theta = 2\pi I_0 \left(\frac{\sin^2\theta}{2} \right)\Bigg|_{\theta=0}^{\Omega_m} =$$

$$= \pi I_0 \sin^2 \Omega_m = \Phi_0 (NA)^2 .$$

$$\frac{\Phi}{\Phi_0} = \sin^2 \Omega_m = (NA)^2 .$$

$$NA = \sqrt{n_1^2 - n_2^2} = \sqrt{\frac{(n_1 - n_2)(n_1 + n_2)n_1}{n_1}} \approx$$

$$\approx \sqrt{\frac{2n_1^2(n_1 - n_2)}{n_1}} = n_1\sqrt{2\Delta} ,$$

$$\text{где } \Delta = \frac{n_1^2 - n_2^2}{2n_1^2} .$$

The power entered into a fiber, depends on a numbered aperture of a fiber NA.
To enter into a fiber maximal light, it is necessary to supply large values of values n_1 and Δ. Apparently, that best, that it can be made to use for manufacturing of a fiber glass with large refractive index and to not cover with his shell. However thus alongside with increase of power entered into a fiber, there are two problems:

1. The part of a surge even at full internal reflection inpours out through an echoing area. And the foregone availability of irregularities and heterogeneities on her will convert a surge, fading in air, in distributing, that results in large losses.
2. At increase Δ the intermodal dispersion is augmented, that results in signal degradation.

1.5 Pathway of light rayss

a. Stepwise fiber.

The refractive index of a core of a stepwise fiber n1 is a constant. A angle θ, under which one the beam is diffused in a fiber, is a constant. The beam is diffused, testing total reflection on a demarcation a core - shell. Between two series total reflections a ray path straight-line.

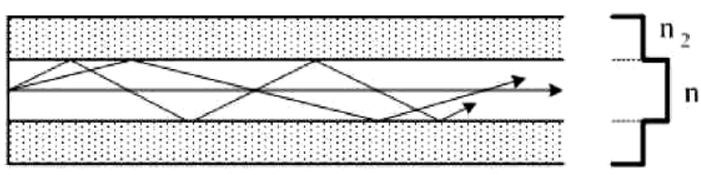


Fig. 7. A pathway of rays in a stepwise multimode fiber.

The pathway consists of equal sections received one of other by a mixing length lengthwise axis Oz on definite spacing interval and turn on a angle. Around of an axis Oz. In a transverse projection they concern the same circumference of radius R.

b. Gradient fiber.

Because of that the refractive index of a core varies, the pathway of beams in a gradient fiber has composite nature and depends on a concrete view of relation n (r). In that specific case fibers with quadratic refractive index

$$n = n_0 (1 - \frac{n_2}{2n_0} r^2)$$

The ray path in a transverse projection represents a closed curve. In a longitudinal section of a pathway are smoothly varying lines (fig. 8).

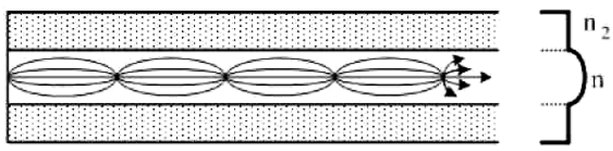


Fig. 8. Feature of such gradient fiber is that the optical lengths of paths are identical to all beams, that corresponds to absence of an intermodal dispersion.

2. Special optic fibers

2.1 Total characteristic of special optic fibers

Overwhelming majority of optic fibers for telecommunications acting on the world market - of a fiber conforming international standards: ITU T Recommendation G.652 - G.656. It, so-called main optic fibers, main problem which one - delivery of a maximum amount of information with maximum speed on maximum spacing intervals with minimum losses.

Main problem of special optic fibers - fulfilment of miscellaneous operations with light signals and flows (strengthening, modulation, filtration etc.), and also activity of fibers in special modes and conditions (for example, at high mechanical loads - impact or static, heat, irradiation, humidity, in YF mean IR and distant IR ranges). Therefore requirements to optical losses in such fibers depart on the second schedule. Representative length of special optic fibers not kilometres, as in case of main fibers, and from units up to several tens meters.

Many sires of special optic fibers dilate the clients in an orb of a biomedicine, aircraft and in military branches. Other sires see more capabilities for special optic fibers in application in sensors and fiber optic gyros. Already it becomes now clear, that in any version of further development the special optic fibers will be used in the equipment of communications networks of following breed.

Now it is possible to call about twenty phylums of special optic fibers distinguished by the design characteristics and the basic properties. Is resulted the basic items of information on some eurysynusic special optic fibers conditionally categorized on the most relevant areas of their application in optical communication below. Further in sections are resulted more in-depth information on four phylums of special optic fibers: activated, photosensing, anisotropic, photonic crystal.

2.1.1 Fiber, as fissile medium, for fiber lasers and amplifiers

The optic fibers, doped by erbium, are designed for erbium of fiber amplifiers (EDFA) with a broad band of the requirements to characteristics, predestined for DWDM, CATV and other applications of a telecommunication. EDFA amplifiers actuates power amplifiers, preamplifiers both linear amplifiers for C- and L-ranges.

In representative erbium the fiber amplifier doped by erbium a fiber 980 nm (or 1480 nm) is pumped by a laser diode with a wavelength to supply amplification in range 1550 nm. Erbium the fiber should be executed by such to supply a peak efficiency of absorption of pumping with a wavelength 980 nm, and also optimum signal amplification in range 1550 nm. It is executed by creation of a fiber with a high numbered aperture with representative value from 0.23 to reach reasonable overlapping of areas of a field of pumping and field of a signal. The wavelength of a cut-off of a fiber has also critical value in his design, as it determines a wavelength, on which one the fiber should work in a single mode. Representative erbium the fiber has such wavelength of a cut-off, which one guarantees, that the pumping will be diffused in a single mode ensuring maximum overlap between area of a field and area erbium of ions in a core of a fiber.

Ytterbium a fiber and ytterbium a fiber with a double shell will be used in high-power stimulus sources and amplifiers. These fibers were designed to meet the requirements to optical high-power amplifiers, industrial and military lasers, and also infrared sources. The fibers were specially designed effectively to aggregate a monomode signal and high power of pumping from the multimode diode in a passive fiber with a double shell. Integrating cheap with large output power multimode diodes of pumping on a wavelength 915 or 976 nm with these fibers is possible easily to reach high-watt power levels with effective attitude of electrical power to optical. Using stepwise fibers in a mode of continuous radiation, the output power reaches kilowatt with an angle of divergence restricted only by diffraction. In a pulse mode the mean power about 100 watt even for femtosecond can be reached fiber laser. Amplifiers with ytterbium by a fiber with a double shell - attractive technology for the phased high-power gratings. They have many advantages, including large strengthening and ease in control of a thermal way.

2.1.2 Fiber for pumping fiber lasers

These fibers have a multimode core conforming on the sizes to diameter of an inner shell ytterbium of a fiber used as a fissile member for fiber lasers and amplifiers. They will be used for power transmission of radiation from an optical source of pumping of a fiber laser (or amplifier) to his fissile member and delivery of an output laser emission for different applications. They can be utilised as connectors - pigtails for laser diodes of pumping and as shoulders for fiber couplers and summators. Summarizes output power from several laser diodes of pumping in one fiber, augmenting thereby power of pumping.

The data of a fiber have following features: they multimode, have a large numbered aperture (~0,45), damping on a wavelength 915 nm about 3 db/kms. Some fibers for power transmission of radiation from an optical source of pumping can reallocate back distributing light, reflected from an active fiber of the laser, which one is the main cause of failures of multimode laser diodes of pumping.

2.1.3 Fiber for optical multiplexers and demultiplexers

The optical multiplexers and demultiplexers of an input / conclusion usually form with usage of photosensing fibers. Capacity of an optic fiber under operating of light to change

refractive index of a core is called as a photosensitivity of a fiber. When the ultraviolet radiation illuminates a core of a fiber doped by germanium, the ultra-violet photons lacerate electron-pair bindings, the refractive index of a core changes and after irradiation remains invariable. The photosensing fibers will be used for creation of fiber Bragg gratings, which one, are a main component of multiplexers and demultiplexers of an input / conclusion of radiation. The fiber Bragg grating represents an optic fiber with an alternation of refractive index along his core. Irradiating a photosensing fiber by the laser through a phase mask, it is possible to create a fiber Bragg grating.

The main property of this grating is the reflection of light, distributing on a fiber, in a narrow bandwidth, which one is centered about a Bragg wavelength. The fiber Bragg grating has a high reflection coefficient on a definite wavelength, small insertion losses, sharp selectivity of a wavelength and small crosstalks. Therefore she is the rather attractive device for the installation in multiplexers and demultiplexers of an input / conclusion. To carve out an input signal from opposite to a distributing radio echo, the optical not mutual circulator will be used. Each multiplexer of an input / conclusion has two circulators: one for input of a definite wavelength, other - for a conclusion. The circulator usually introduces losses from 0,5 up to 1 db. The insertion losses grow the more, than more gratings and circulators in the multiplexer (demultiplexer).

2.1.4 Fiber for optical choppers

There are two types of optical wave-guide modulators: planar and fiber. Both types are be by phase modulators more often. The planar modulator is constructed as an optical waveguide on a substrate (integrally - optical chopper). He provides modulation and coordination with fibers established on an input and an output of the planar chip, which one can be either customary monomode fibers or polarization fibers .

Alternative version of external modulators is completely fiber acousto-optical modulator. Most often completely fiber acousto-optical modulator represents devices executing frequency shift on the basis of surface acoustic waves. In them the phenomenon of communication of polarized modes in polarization fibers or spatial communication of modes in customary monomode fibers will be used.

Thus, in optical fiber modulators will be used both polarization fibers, and customary optic fibers. The monomode fibers with birefringence transmit optical radiation by two disconnected modes, which one are linearly polarized, are orthogonally related and have different phase velocities of propagation. The polarization fibers are constructed so that to transmit input light only to one linear polarization. The desirable direction of a polarization plane receives on the basis of a principle of creation of mechanical pressure, using in a fiber an elliptical shell an ambient round core or round shell an ambient elliptical core, and also other frames of a fiber.

2.1.5 Fibers for optical filters

Now there are many phylums of optical fiber filters: filters on diffraction or Bragg gratings, filters Fabre-Pero, etc. Fabre-Pero the filter represents a resonator consisting from two bound among themselves of optical waveguides with particulateing reflect mirrors on test leadss. The filters of Mach are constructed with usage of two directional couplers and two customary fibers, one of which is a reference shoulder, and in the friend the refractive index is varied pursuant to a control signal. The Bragg fiber filter represents a photosensing fiber,

on a part which one is formed the Bragg grating. The characteristics of such fiber are submitted in section 5.3. If to change (to operate)((control)) the season of a grating of the Bragg filter, he becomes a tunable filter. The season of a grating can be changed at the expense of heating or mechanical pressure.

2.1.6 Fibers for compensation of a dispersion

Indemnification of dispersion can be executed by several methods. For example, the special fibers or devices dispersions, named by compensators, (dispersion compensating modules) can be applied. These fibers have a large negative dispersion (80-100 ps/nm), and also negative slope of a dispersion curve. With the help of fibers compensatory dispersion, it is possible to execute the broad audience of operations.

The second example of indemnification of dispersion can serve fiber Bragg of a grating with the variable season. In these fibers the season changes along a fiber linearly. Thereof, the surges of miscellaneous length are mirrored from gratings arranged on miscellaneous spacing intervals from an input, that results in miscellaneous time of their propagation and accordingly to indemnification of a chromatic dispersion. All compensators with the linear season of a grating are not rebuilt devices. In rebuilt compensators the change of the season of a grating along a fiber should be non-linear. The variation of indemnification of dispersion is reached by stretching of a fiber by a mechanical or thermal way.

Thus, for indemnification of a dispersion the optic fibers with a negative dispersion and photosensing fibers will be used, from which one receive Bragg fiber gratings with the variable season.

2.1.7 Fiber for sources of supercontinuum

The special examples of special optic fibers are Photonic crystal fibers. Due to a development of a series of unique properties they find a use not only in optical communication, but also in transfer of large powers, sensing sensors, nonlinear circuits and other areas. In photonic crystal fibers the area of a shell of a fiber with longitudinal air passages will be used, which one encircles a core, where the radiation is massed. Their internal periodic frame made of filled air capillary tubes represent in cross section hexagonal or square grating. The handling phylum of a grating, its step, form of air passages and refractive index of a glass allows to receive properties, which one do not exist for customary fibers. So, for example, the brightly expressed non-linear properties do photonic crystal fibers capable to generate supercontinuum, i.e. to convert light of a definite wavelength to the public with more by lengthy and more by short waves. Thus, the creation of broadband light sources on new principles is possible.

2.2 Activated fibers for the optical amplifiers and lasers

2.2.1 Stuffs for the Erbium fiber amplifiers

In fact amplifying medium of the amplifier is an Erbium fiber - the optical fiber with impurity of the Erbium ions. Such optical waveguides are produced by the same methods, as optical waveguides for a transmission of information, with attachment of intermediate operation of impregnation not foundered stuff of a core by solution of salts of erbium or operation of doping by ions of erbium from a gas phase directly in a precipitation process of a core. The wave-guide parameters of the erbium optical fiber do similar to the parameters of optical wave-guides used for a transmission of information, with the purposes of

reduction losses on connections. Principled is the selection of addition elements reshaping a core of the fissile optical wave-guide, and also guard ropes of an ion concentration of erbium. The different components in a quartz glass change nature of Stark scission of energy levels of erbium ions (fig. 1.2.4). By-turn it results in change of absorption spectrums and radiation. In a fig.. 1.2.8 the radiation spectrums of ions of erbium are submitted in a quartz glass doped most often used in technology of optical fibers by the used of in technology, phosphorum and aluminium. From the introduced data it is visible, that the most broad luminescent spectrum (so, and spectrum of strengthening), amounting about 40 nm on half-height, is reached at usage as the component of aluminium. Therefore this member became indispensable component of a stuff of a core erbium of optical fibers.

The ion concentration of erbium in a core of an optic fiber actually determines his length used in the amplifier at given signal levels and pumping. The high limit of concentration of fissile ions is determined by originating of effect of cooperative up-conversion. This phenomenon is that is possible at large concentration of fissile ions the formation of clusters consisting of two and more ions of erbium. When these ions appear in an exited state, there is an exchange of energies, as a result of which one of them passes in a condition with higher energy, and second - is nonradioactive relaxation on an index plane. Thus, the part of ions of erbium occludes radiation of a reinforced signal, reducing efficiency of the amplifier.

Other direction of researches in an expansion region of a band of strengthening erbium of amplifiers, and also increase of an ion concentration of erbium is connected to looking for other (not silicate) glass-forming matrixes for a core of a fiber. Recently so has appeared considerable concern to phosphate, telluride and fluoride glasses.

Width of a luminescent spectrum for phosphate glasses is close to by silicate (fig. 1.2.14). Here of scoring for these stuffs as contrasted to by silicate matrixes no. Nevertheless, increase of concentration of erbium in phosphate glasses does not result in noticeable formation of erbium clusters, as it takes place in silicate glasses. Therefore phosphate glasses have lower coefficients of non-linear up-conversion luminescence damping in comparison with silicate glasses. It allows realizing in phosphate glasses much higher erbium ion concentrations without noticeable concentration damping, in comparison with silicate glasses.

High concentration phosphate glasses doped by erbium and ytterbium, have found the application at mining planar wave-guide amplifiers.

In spite of attractiveness telluride and fluoride matrixes, they do not find yet broad usage in optical fiber amplifiers in a kind of composite technology of an extract of a fiber.

2.2.2 Activated fibers with a double shell

In fiber lasers the optical pumping will be used, that is creations of inverse in fissile medium need external radiation of optical range. For example, pumpings Nd of lasers need radiation with a wavelength in region 810 nm, for Yb of lasers in the field of 910-980 nm, though it is possible to use and other lengths of surges falling in a band of absorption.

The pumping of the maiden fiber lasers implemented through a lateral area with the help of radiation of lamps - flashes. Such scheme of pumping allowed to reach efficiency of generating, that is attitude of power of generating to power of sources of pumping, no more than 5 %. It is connected, first of all, that the large part of power of pumping was not occluded. The pumping of a fiber laser through butt end of the optical waveguide utilised directly in a core. Such scheme allowed to occlude all radiated power of pumping, so and it is essential to increase efficiency of generating. However, apparently, that in this case it is

impossible to use a lamp pumping because of its small brightness, and is unique by a possible source of pumping under such scheme there are lasers. Thus, for effective pumping of fiber lasers it is possible to use solid-state or semiconducting lasers, and the brightness last allows till now to enter into a monomode core power more several watt.

To raise output power of fiber lasers and to simplify input of radiation of semiconducting laser diodes in an optical fiber, have offered to use the optical waveguide with a double clad fiber - DCF. The optical waveguide of such design represents (fig. 9) monomode a core - 1 inside the multimode optical waveguide (maiden shell) - 2, surrounded second shell (polymer or from a quartz glass) with lower refractive index - 3. Out of door such design sometimes covers

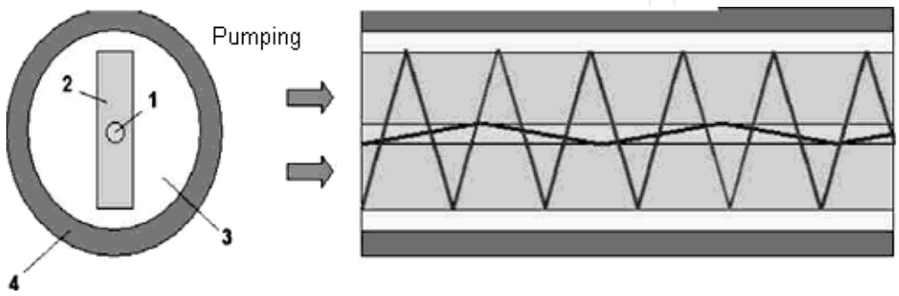


Fig. 9.

By containment shell - 4. In such frame the radiation of pumping at the expense of full internal reflection from the second shell is diffused on the maiden shell, being step-by-step occluded in a core, doped by fissile ions, on which one the radiation of generating is diffused. The area of the maiden shell can be much more area of a core, that allows to enter into such frame much more powers of pumping, than in a core. Despite of such advancing usage a lamp pumping for such fiber lasers practically is eliminated, as the maximum sectional area of the maiden shell does not exceed 1 mm ^{2}, and as a rule lies within the limits of 0,01-0,1 мм^2. The increase of the area of the maiden shell is limited first of all to necessity to have sufficient absorption of radiation of pumping from the maiden shell. The section(cross-section) of the maiden shell can be made rectangular, and thus it is possible by a maximum mode to agree the aperture and frame of fields of the channel of pumping laser diode used for pumping and, accordingly to increase efficiency of pumping.

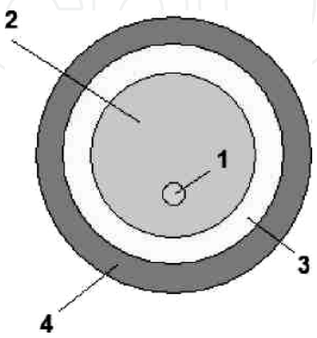


Fig. 10. An active fiber with a double shell (DCF): 1 - core, activated ytterbium, with refractive index n1, 2 - maiden shell for distribution of pumping with n2 (n2 < n1), 3 - second shell with n3 (n3 < n2), 4 protective coatings.

The absorption on a core is limited to maximum technologically accessible concentration of fissile ions, and the area of a core is limited to conditions her one mode or monomode and other parameters. Depending on a cross-section profile of the optical waveguide the lobe of modes which are not blocked with a core varies. Apparently, that best absorption of radiation of pumping needs such form of the optical waveguide, which one minimized or would eliminate existence of such modes. Besides for increase of absorption in optical waveguides accepting distribution of such modes is possible to place a core of the optical waveguide not in center (fig. 10), or to use a bending of the optical waveguide, that enriches exchange between modes intersecting a core and modes, having in centre a minimum.

2.2.3 Photonic crystal activated fibers

Recently rough development was received by lasers on the basis of photonic crystal fibers. Photonic crystal fiber have following distinctive features as contrasted to by customary fibers:

- High numbered aperture 0.6 (limiting idealized values 0.9);
- Large diameter of a core (up to 40 microns), which one can support a single mode. As a result of it in photonic crystal fibers it is possible to realize high powers of pumping and generating without noticeable heating;
- Absence of non-linear effects;
- A high anisotropy of frame of a fiber permitting to skip radiation with a high scale of polarization.

2.2.4 Photonic crystal (microstructured) fibers

Photonic crystal the fiber, in has a solid core and also has the expressed non-linear - optical behaviour. As opposed to him, for a hollow-by-a-core fiber, the non-linear - optical behaviour show is gentle. Last two types of fibers are applied as spectral selectors and to indemnification of a dispersion in fiber communication circuits.

Some advantages and lacks photonic crystal of fibers, as contrasted to customary, are adduced in tab. 1

The characteristics	a customary fiber	FC-fiber
The numbered aperture, NA	0.06	> 0.6 is reached 0.9 - limit
Diameter of a fiber for a single mode, micron	7 λ= 1540 nm	> 40 λ= 300 – 2000 nm
The area of a core, mkm^2	50	from 3 to 1000
The non-linear effects	a full set	miss or are brightly expressed
The losses, db/km	0.2 are close to an idealized limit	10- reached idealized limit 0.0005

Table 1. The comparative characteristics customary and photonic crystal of fibers.

From the table it is visible, that photonic crystal of a fiber can have a large numbered aperture, that easies input of radiation in them. The non-linear - optical effects in a photonic crystal fiber can be overwhelmed or, to the contrary, are increased. The losses in photonic

crystal fibers, now considerably exceed losses in fibers regular style. In a fig. 11 is given frame photonic crystal of a fiber and channelling inside it the beams.

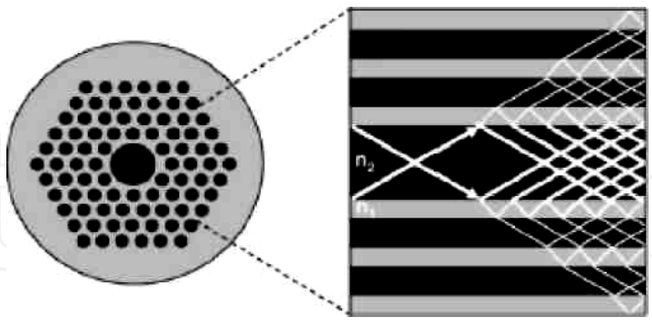


Fig. 11.

As a result of it in a core of photonic crystal are reshaped wave modes, similar to modes of common fibers (fig. 12)

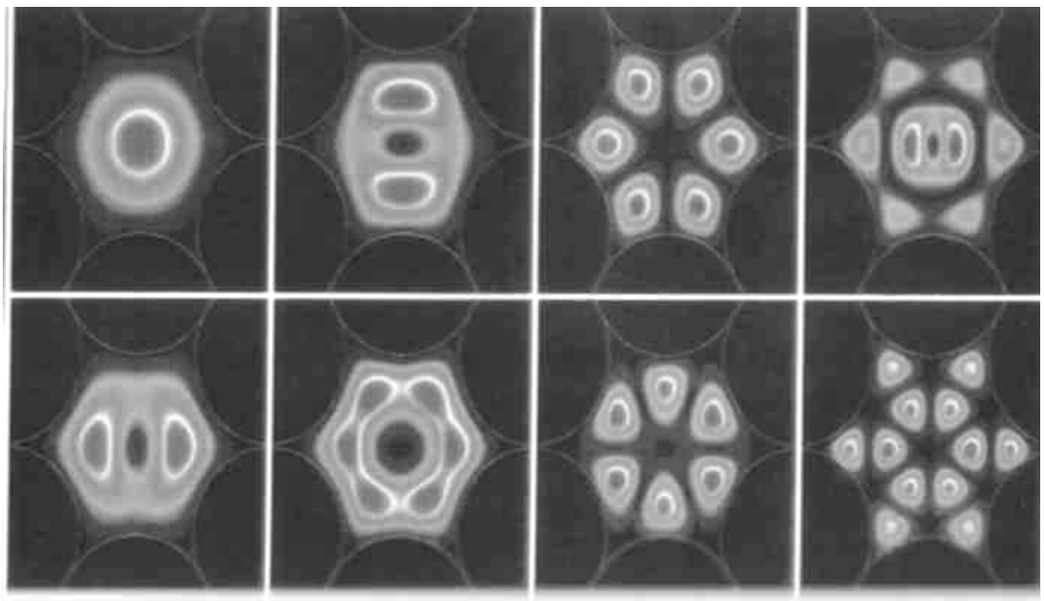


Fig. 12. Modes of photonic crystal fibers.

In a fig. 12 are shown the cross sections of some phylums photonic crystal of fibers having the special properties. The maiden phylum of a fiber a multimode fiber with the solid heart and large numbered aperture NA. Such fibers can be applied to pumping fiber lasers. In monomode photonic crystal fibers by selection of diameter of channels it is possible over a wide range to change dispersion. The similar fibers have the expressed non-linear - optical behaviour and are applied in fiber lasers, and also to control of optical signals.
In too time, theoretically photonic crystal of a fiber with empty by a core the losses at a level of 0.0005 db/kms can have.
Unique property of optical photonic fibers is strong dependence of dispersion properties from geometrical parameters of a fiber. The selection of geometry of a fiber allows to realise.

Positive, negative and zero dispersions, and also to vary a slope dispersion by a curve. Therefore photonic crystals of a fiber are perspective for usage in multiway fiber communication circuits for indemnification of a broadering of optical impulses. Photonic crystal of a fiber with a small chromatic dispersion can be utilised in rebuilt lasers, and also optical multiplexers and demultiplexers.

2.2.4.1 Common views about photon chips and their properties

Photonic crystal waveguides and the fibers are new phylum of optical waveguides. Their occurrence is connected to creation and research of new optical objects - photon chips.
Three types of optical fibers with frame of photon chips are now known. It is optical fibers with solid light-guided habitation, optical fibers with hollow light-guided habitation and optical fibers with coaxial frame (fig. 13). Between them there is a relevant distinction in gears ensuring wave properties of optical waveguides (fig. 14).

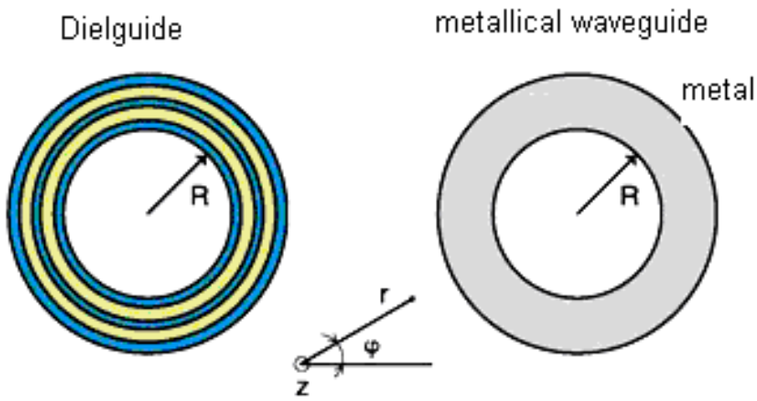


Fig. 13. A coaxial fiber of a Bragg type.

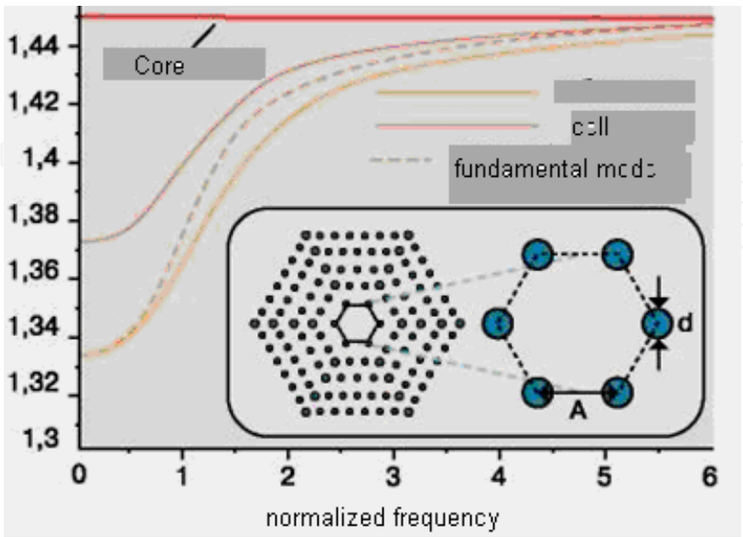


Fig. 14. Relation of effective refractive indexes and fundamental mode from the normalized frequency **A/λ**.

The perforated optical waveguide with solid light-guiding habitation represents a core from a quartz glass in a shell from a photon chip (quartz glass with air-vessels by channels), having lower mean factor of an interception in relation to a vein. Therefore wave guiding of property of such optical waveguides are provided simultaneously with two effects: full internal reflection, as in customary optical waveguides, and zonal properties of a photon chip. The availability of a shell by the way of photon chip essentially distinguishes perforated fibers from customary optical fibers.

The photon chips represent periodic frames from dielectrics with distinguished refractive index. The season of these frames - about a wavelength. Unidimensional (1D) the photon chip represents interleaving dielectric layers with high and low refractive indexes. As a rule, the optical distance of these layers is aliquot. From here is apparent, that the Bragg reflector and Bragg waveguide are at the same time unidimensional photon chips. Elementary bivariate (2D) the photon chip represents a dielectric lamina with the in batches arranged foramens. Three-dimensional (3D) the photon chip can be formed, for example, from dielectric spheres. The similar photon chip is called as a simulated opal, as his frame and the optical behaviour are close to frame and properties natural precious of a rock of an opal.

The title of photon chips is called by that the properties of photons in such periodic frames are look-alike to properties of electrons in a periodic electrical field of atoms of customary chips. It is known, that the electron has wave properties. In a customary chip there is an interference between «surge "- electron" and periodic electrical field of atoms. It results in occurrence of allowed and forbidden wave bands or energies of electrons in a chip. So there are a valence band and conduction band - ranges of energies, allowed for an electron, and forbidden region - area of energies, which one an electron in a chip receive can not. In a photon chip takes place the similar situation. The photon, which one simultaneously is an electromagnetic wave, interferes with periodic frame of a photon chip. In outcome there are ranges of allowed and forbidden energies of photons (or lengths of surges of an electromagnetic wave) in a photon chip. The photons with forbidden energies are mirrored from a photon chip; and the photons with allowed energies in him in pour. For such photons he is transparent.

2.2.4.2 Property and application photonic crystal of fibers

In photonic crystal a fiber properties of a photon chip has only medium ambient his core. In dielguides regular style channelling is provided with effect of full internal reflection from border of a core of the waveguide with medium. In photonic crystal waveguides the channelling descends as a result of an interference of a surge in medium with photonic crystal by properties and reflection from it.

The representative frame of an optical fiber with a double shell is submitted in a fig. 15. He consists of three layers: a monomode core 1, doped both fissile impurity of a rare earth member, and impurity reshaping a structure PP; an internal quartz shell 2; an external polymer shell 3 with PP, under as contrasted to PP of a quartz glass. The internal quartz shell has the representative size 0.1 - 1 mm, that provides a capability of input of radiation of pumping from semiconducting sources with power some tens watt. At distribution on a quartz shell the radiation of pumping is occluded by fissile ions of a rare earth member, invoking luminescence, which one if there is a resonator formed VBR 4, develops in a lasing localized in a core of the optical waveguide, diameter by which one makes 5-10 microns. For more effective absorption of pumping the quartz shell, as a rule, has rectangular or Δ. Figurative cross section.

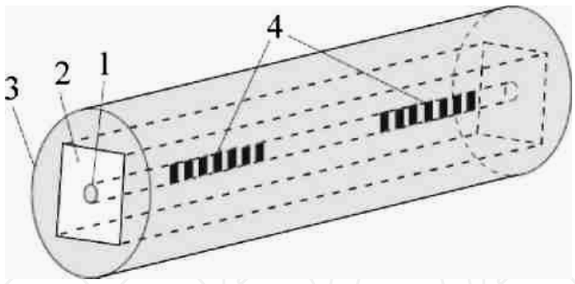


Fig. 15.

Already now on the basis of optical waveguides with a double shell are designed the laser systems have output power ~1 kW. Such systems are applied to processing of different stuffs, and also as sources of pumping for fiber lasers operating a phenomenon of an enforced Raman effect of light (VKR-LASERS).

2.2.4.3 Photonic crystal coaxial optic fiber

The transfer of a potent laser radiation for the technological purposes at the help fiber of optical waveguides is an actual problem of modern optoelectronics. An interrupting in implementation of fiber optic transmission systems of a potent laser radiation is the occurrence of undesirable non-linear effects: enforced dissipation VRMB and VKR and four-photon mixture. The solution of the given problem results in mining optical fibers with the increased section of a field of a dominant mode.

The photon chip, in particular unidimensional (fig. 16), is a periodic dielectric frame, the season by which one consists, as a minimum, of two layers. Let's consider the elementary example of unidimensional infinite periodic frame. The refractive index of such frame (fig. 16) is determined with the help of a periodic function:

$$\mathbf{n\ (x) = n1,\ 0 < x < h1} \tag{1}$$

$$\mathbf{n\ (x) = n2,\ h1 < x < h} \tag{2}$$

Where $\mathbf{\Lambda = h_1 + h_2}$ the season of a grating.

Electrical and magnetic permeability depend on a parameter interceptions by a conventional mode:

$$\mathbf{n_m = (\varepsilon_m\ \mu_m)^{-0.5},\ m = 1, 2.} \tag{3}$$

Thus, the uni-dimensional photon chip is anything diverse as a Bragg's mirror, consisting from alternate layers with low and high refractive index. Such frame precludes with an illumination in a definite wave band dependent on a pitch angle of a plane wave on frame. In other words for photonic crystal frames there is an area of frequencies, where the illumination is forbidden inside a stuff particulate or completely. This area is called as a forbidden region, by analogy with a solid (chip), where the areas of possible energy of electrons "are sorted out" by forbidden regions.

The effect reflection of light in such frame will be used in multilayer dielectric mirrors. Thus the optical distance of layers should be comparable to a wavelength, and also at an angular variation of dip the area of forbidden lengths of frequencies displaces.

On the other hand, the radiation can be diffused in bridge to layers and such frame represents the multiway planar waveguide, in which one there is an essential

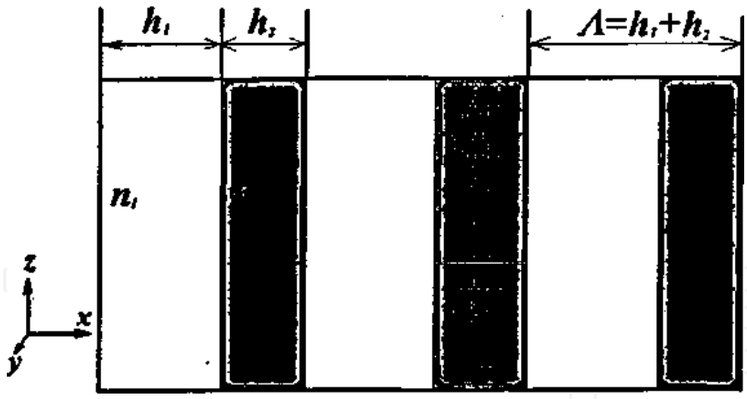


Fig. 16. An arbitrary segment of a unidimensional photon chip.
n_1 Refractive indexes and h of depth of the conforming layers, $\Lambda = h_1 + h_2$ the season of frame. [5].

communication of channels. This communication conducts to "spreading" of dispersion curves separately taken the planar waveguide and formation of a zone, similar zones of a solid (zone of passing). The similar situations descend and in bivariate photon chips (FC), Bragg optic fibers consisting, for example, from the regularly arranged parallel dielectric barrels. The illumination perpendicularly to axes of barrels nor is always possible, while along barrels the routed surges can be diffused at any frequency. Thus, at inclined dip the excitation and routed modes of multiway waveguides and partial passing is possible.
For a qualitative analysis of properties of natural modes of a photonic crystal fiber the model of the coaxial waveguide can be utilised. The physical gear of wave-guide propagation of electromagnetic radiation in waveguides of the given type is similar to the gear of wave-guide propagation in hollow FK-fibers and is connected to availability of photon forbidden regions in a transmission spectrum of a shell of the waveguide. The bivariate periodic frame of a shell of a FC-fiber is changed within the framework of this model with a system of coaxial glass barrels (fig. 17) by depth b c by an inner radius N-th of the waveguide

$$r_N = r_0 + N(b+c), \tag{4}$$

Where r0 - radius hollow of a core, with - depth of a backlash between walls of barrels.
The geometrical sizes of layers which are generatrix the coaxial waveguide, are selected with allowance for of space factor by air of a FK-envelope of the microstructured fiber (MS). Space factor of a shell of a fiber by air is under the formula:

$$\eta = \pi a^2 / 4\Lambda. \tag{5}$$

With allowance for of this factor are selected the parameters of the coaxial waveguide b and from (fig. 15).
The similar model allows using visual physical submissions for an estimation of dispersion properties and obtaining of a qualitative picture of distribution of intensity of electromagnetic radiation in waveguide modes localized in hollow to a core of a fiber. The relevant characteristic of waveguide modes of MS-fibers is the degree of localization of a light field in a core of a fiber. For increase of efficiency of non-linear - optical interplays in a central lode of a fiber it is required to reach, probably, higher localization of a field by reduction an effective area of a mode. This problem can be resolved by the conforming

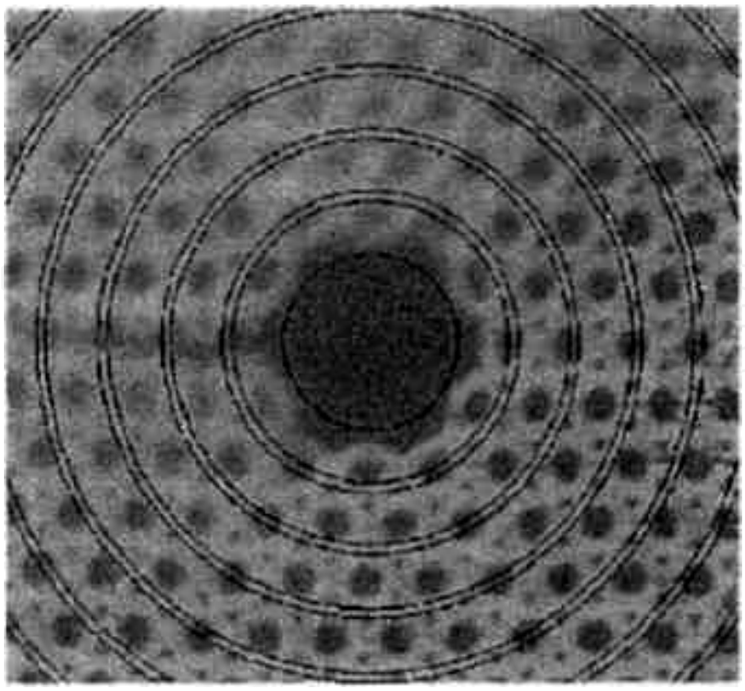


Fig. 17. The possible scheme of selection of parameters of the coaxial waveguide for simulation of a transmission spectrum of a FC-fiber. The black circles figure borders of periodic layers with different refractive indexes.

selection of attitude of the size of a core of a fiber to a wavelength of radiation and usage of a fiber with the greater difference of refractive index of a shell and core.

In a fig. 18 the schedule of a dispersion of group velocities (DGV) is submitted. The MS-fibers with two cycles of air foramens around of a central waveguide channel about a diameter about 3 microns provide an abnormal mode of a dispersion for radiation with a wavelength less than 900 nm. The wave band (from 1,05 up to 1,35 microns) with near-zero by a dispersion actuates some lengths of surges of standard radiation 1,06 microns and 1.3 microns. The affinity of a wavelength of a laser radiation to a wavelength conforming to zero value of a dispersion of a group velocity, allows to reduce to minimum influencing effects of dispersion bleed at distribution femto second of momentums impulses in a fiber and to supply fulfilment of conditions of the phase coordination for parametric processes of four-wave interplay.

To the similar requirements effectively there corresponds coaxial frame of an optic fiber with a condition of synchronization of modes [2,3]. According to the solution of characteristic equation the condition of self-conformity of a light field gives the solution for distribution of waveguide modes. The distribution optical waveguide of modes descends at a strictly definite ratio of the sizes of a layer. In the designed metalized optic fiber the light guide mode is channelled at the expense of distribution between in layers with a factor of an interception n_c and spacing interval from a stimulus source - and, instituted from a ratio:

$$n_c = (n_N^2 - r_N^2 / (a^2 + r_N^2))^{0,5} \quad (6)$$

At such ratio there is a surface wave-guide radiative transfer. For normalization of distribution of radiation and exception of non-linear local effects the principle of equality of

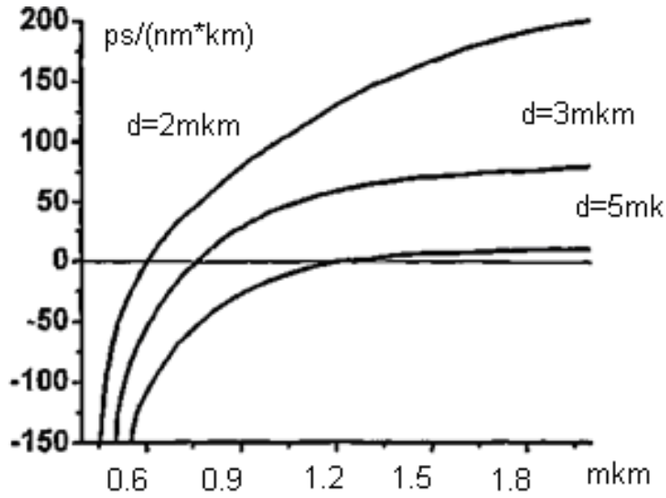


Fig. 18. A dispersion of a group velocity of a dominant mode of a MS-fiber with two cycles of ring structures around of a central wave-guide lode (d - diameter of a core).

the areas between light guide zones will be used, and the area corresponds theoretically to defined value:

$$S_N = 0{,}5 * 3{,}14 * \lambda * (0{,}5\ M)^{0,5} * (r_{N1} + r_{N2}), \quad (7)$$

Where λ - wavelength of radiation, N - of a ring-type zone, M - number of modes of radiation, rN1, rN2 - external and inner radius N- й of a ring-type zone. The layer between zones is executed from a condition of a ratio for full internal reflection with a factor of an interception nc. At a mode of distribution of refractive index conforming to the law of Gauss, there is a coordination between irradiance both refractive index and the directivity of modes are increased. As such frame was earlier represented the multiway planar waveguide, in which one there is an essential communication of channels. At which one there is "spreading" of dispersion curves separately of taken planar waveguide by the way of ring-type zone and formation of a zone, similar zones of a solid (zone of passing). Due to full filling the light guide ring-type zones of all cross section of an optic fiber descend sharp increase of skipped power up to more than in 100 times.

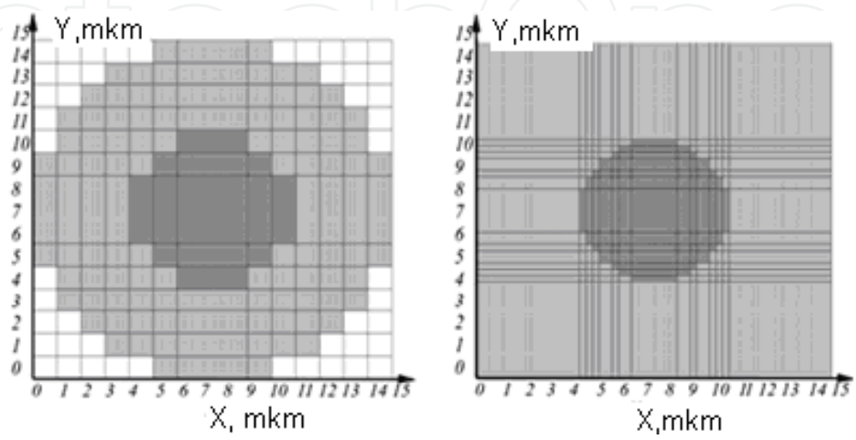


Fig. 19. Model of a standard fiber with a stepwise structure of refractive index.

The simulation of frame of an optical field conducted on a method of matched sine waves has shown the different configuration of a field pattern for a standard and coaxial optic fiber (fig. 19-22).

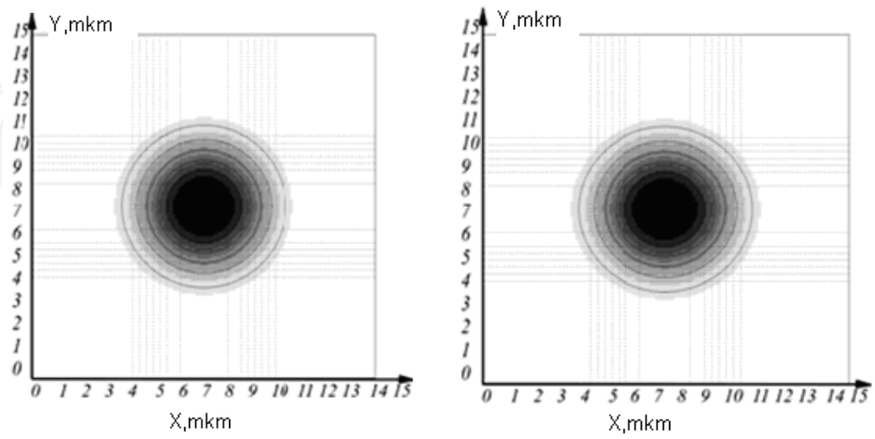


Fig. 20. Distribution of an optical field on an output of a standard fiber.

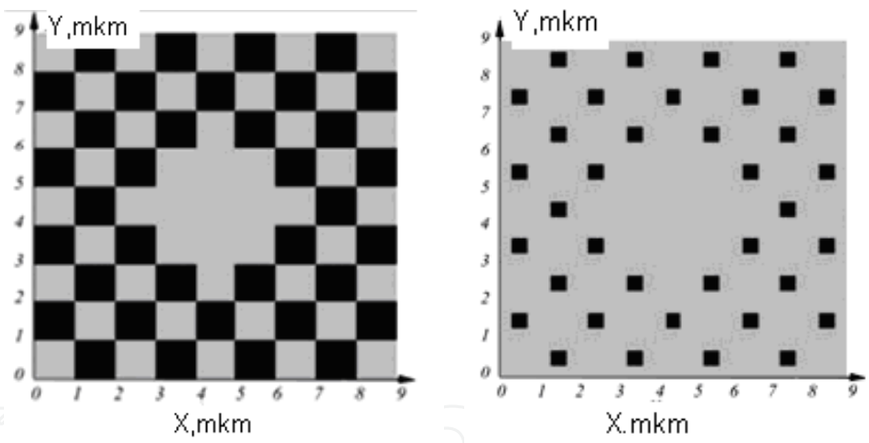


Fig. 21. Model of a coaxial fiber, diameter of a member -1 microns and diameter of a member 0.4 microns, size of section cross-section 9 mkm* 9 mkm.

The simulation has shown reduction diameter of an output field for coaxial frame, that corresponds to allocation of directional modes with high coherency (fig. 19-22).
The optical metalized fiber executed on coaxial frame has a minimum dispersion, by minimum non-linear effects and maintains heightened heat loads accompanying distribution of potent optical radiation. Allows to augment a numbered aperture and to transmit a heightened radiated power. Last researches demonstrate the friend recursive approach in the analysis of a radiative transfer in a photon chip [4,5]. The development of this direction allows to use new operating characteristics of such models for phylum of Cantor fractal.

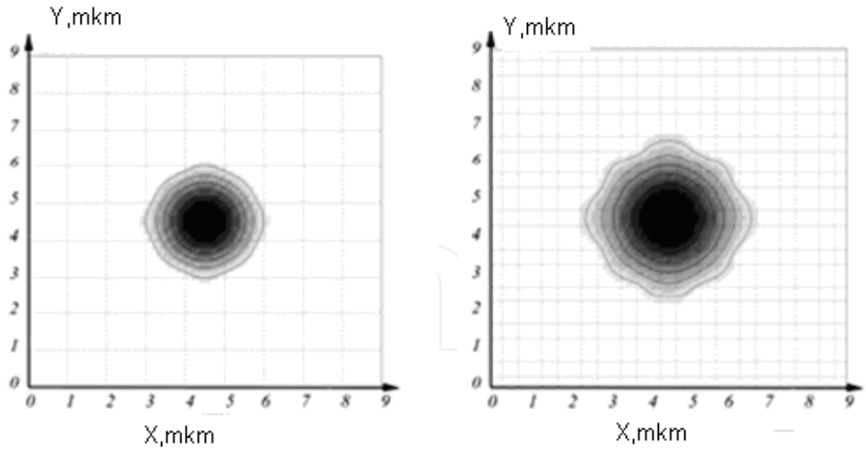


Fig. 22. Distribution of an optical field in the conforming models.

2.3 Anisotropic monomode optical waveguides

Alongside with trunk links of communication the optical fibers will widely be used in the diversified measuring, diagnostic and highly sensitive monitoring systems and control. On the basis of anisotropic monomode optical fibers there are sensors for measurement of different physical quantities and such unique devices as fiber optic gyros.

Most reasonable phylum anisotropic OF for a commercial production is the optical waveguide with an elliptical exerting shell.

The production process of such optic fiber lies in manufacturing of bar MSVD by a method with concentric frame of internal layers, abrasive processing of round bar and hyper thermal round off. The exerting shell contains 15-20 mol. % B_2O_3 and GeO_2, in quantity indispensable for indemnification of change of refractive index conditioned by the introducing of a boron. The isolating shell, ambient a core, is indispensable for a decrease of optical losses on a wavelength more than 1 micron conditioned by oscillation of atoms. The containment shell isolates deposited layers from hydrogen diffusing from a reference quartz tube. All shells in fiberglass have value of refractive index close to refractive index of a quartz glass.

The abrasive work on a work piece is encompass byed grooving of two flutes with diametrically opposite of the parties. At the subsequent hyper thermal round off of a flute peter, the bar becomes round, and exerting shell elliptical.

The optical waveguides with an elliptical core or exerting shell succumb on an optical behaviour OF such as "«PANDA" a little, however, is expedient differ under the cost, and also simplicity and stability of a master schedule of their manufacturing. Effecting of such optical waveguides in world practice bases, basically, on MSVD a method of manufacturing of bars. The optic fibers with elliptical members of frame can be received by one of three methods: to hyper thermal compression of a handset with marked in layers at rarefaction in some mm of a water pile; by parallel plate grinding with round off at 2100-2200^{o}C and pressing of round bar at series heating of sites up to 1800-2000^{o}C.

The design of an optic fiber with an elliptical shell MSVD by a method can also be produced BC such as “tie - bowtie” with application of unilateral internal etching of layers of an exerting shell on an internal surface of a handset which is heated up from the diametrically opposite parties.

Now most perspective OF for sensors are the anisotropic fibers, in which one there are pressure by definite building blocks essentially distinguished by coefficient of thermal expansion from a base material.

In the customary monomode optical waveguide with round cross section of the heart and axisymmetrical distribution of refractive index two are diffused orthogonally polarized modes HE_{11}, which one are accepted for meaning HE^{x}_{11} and HE^{y}_{11}. At the introducing in a fiber of one of these modes the condition of polarization changes because of transformation to an orthogonal mode under effect of external factors: pressure, temperature, chatterings and etc. Linearly polarized radiation becomes ellipse polarized. The swapping of a quantity of light from one mode in other is conditioned by that they are vacuous, that is their propagation coefficients px and py are identical.

The condition of polarization of radiation can be kept if to break a symmetry of the form or refractive index of a core. In this case Px Py will differ, limiting a degree of metamorphosis of orthogonal modes. The optic fibers of such type are called as anisotropic monomode optical waveguides. The geometrical anisotropy forms by metamorphosis of the round form of a core in elliptical, and the anisotropy of refractive index is provided with orthogonal orientation of pressure (voltage, stresses) at usage of stuffs with miscellaneous coefficients of thermal expansion. A measure of an anisotropy of such optical waveguide is the modal birefringence:

$$B = (p_x - p_y)/(2tc\mathbf{A},) \tag{8}$$

On which one count the basis of measurement of length of beats of orthogonal modes (length, on which one the phase phase progression of polarization modes makes 2π) L_b:

$$B = L/L_b \tag{9}$$

Than less than length of beats, the more birefringence and, therefore, is less communication(connection) between polarization modes.

The lobe of power gated in in the optical waveguide of linear-polarized radiation Px, passed on an orthogonal (spurious) mode Py, is characterized by an extinction coefficient m:

$$m= 10 \lg (Py/Px) = 10 \lg (hL) \tag{10}$$

Where h - degree of preservation of polarization of radiation, L - length of the optical waveguide.

From this equation follows, that:

$$h = (P_y/P_x)L^{-1} \tag{11}$$

The birefringence OF with an out-of-round core having large (a) and small (b) an axes, at an ellipticity (a/b-1) more unit is proportional to a square of a difference of refractive indexes of a core and shell (An^2).

Conclusions: The photonic crystal fiber allows to increase the characteristics of fiber-optic links of communication and to create a new generation of telecommunication instrumentation.

3. References

[1] Optical fiber amplifiers. Materials, devices and applications. by ed. Shoichi Sudo // Artech House, Inc, Boston, 1997, 627 p.

[2] Becker P.C., Olsson N.A., Simpson J.R. Erbium-doped fiber amplifiers/ Fundamentals and technologies // Academic Press, SanDiego, 1999, 460 p.
[3] Canning J. Fiber laser and related technologies // Optics and lasers in engineering, 2006, №44, p.647-676
[4] Snitzer E. Proposed fiber cavities for optical masers // J. Appl. Phys., 1961, Vol.32, №1, p.36-39.
[5] Koester C. J. and Snitzer E. Amplification in a fiber laser // Appl. Opt., 1964, Vol.3 №10, p.1182.
[6] A.M. Zheltikov. Optician of the microstructured fibers // M.: science, 2004.
[7] Y. V. Sorokin. Optical fiber with plating of surface. Works collection "Optical fiber technics", 1998, p. 29-33.
[8] Y. V. Sorokin, V. V. Sorokin " Optical fiber ", Patent Russia, № 2060520, 01.04.1994
[9] Y.V. Sorokin "Metallized optical fiber", patent of Russia № 2178192 (2002.01.10)
[10] W.Takeda, S.Kirihara, Y.Miyamoto, K.Sakoda, and K.Honda, «Localization of electromagnetic waves in three-dimensional fractal cavities», Phys. Rev. Lett., (5 March 2004), DOI: 10.1103/PhysRevLett.92.093902, PACS number: 42.70. Qs, 63.20. Pw
[11] Y.Miyamoto, et all, "Smart Processing Development of Photonic Crystals and Fractals", Int. J. Applied Ceramic Technology, 1., 40-48 (2004).
[12] Y. V. Sorokin "The optical summator with Photonic Crystal". Patent Russia u.m. № 86761, 2010.
[13] Y. V. Sorokin "Optical source on the generator of supercontinuum". Patent Russia u.m. №86800, 2010.
[14] Y. V. Sorokin "The fiber optical multiplexer - demultiplexer with Photonic Crystal". Patent Russia u.m. № 86826 , 2010.
[15] Y. V. Sorokin "The fiber optic filter on Photonic Crystal". Patent Russia u.m. № 86825, 2010.

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Recent Progress in Optical Fiber Research

Edited by Dr Moh. Yasin

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This book presents a comprehensive account of the recent progress in optical fiber research. It consists of four sections with 20 chapters covering the topics of nonlinear and polarisation effects in optical fibers, photonic crystal fibers and new applications for optical fibers. Section 1 reviews nonlinear effects in optical fibers in terms of theoretical analysis, experiments and applications. Section 2 presents polarization mode dispersion, chromatic dispersion and polarization dependent losses in optical fibers, fiber birefringence effects and spun fibers. Section 3 and 4 cover the topics of photonic crystal fibers and a new trend of optical fiber applications. Edited by three scientists with wide knowledge and experience in the field of fiber optics and photonics, the book brings together leading academics and practitioners in a comprehensive and incisive treatment of the subject. This is an essential point of reference for researchers working and teaching in optical fiber technologies, and for industrial users who need to be aware of current developments in optical fiber research areas.

How to reference

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