2. Onoichenko, S. A. (2003). Primeneniye oksigenatov pri proizvodstve perspektivnux avtomobilnux benzinov. Moscow, Techtika, 64.

3. Kempen, V. X. (2002). Ispolzovaniye spirtov v kazhestve topliva dlya dvigateley vnutrennego zhoraniya. Neft`, gaz i neftechimiya za rubezhom, 34.

4. Putilov, A. V. (2005). Sovremennoye sostiyanie i perspektivu ispol`zovaniya spirtovyx motorlyx topliv`. Otchet po NIR. Moscow, Computer Model Center, 56–59.

5. Lapidus, A. L, Kryliv, I. F, Zagfarov, F. G, Emel`yanov, V. T (2008). Al`ternativnyie motorniye topliva. Uchebnoye posobiye. Russian State Oil and Gas University named by Gubkin. ZentrLitNefreGas, 84–88.

6. Barannik, V. P., Emel`yanov, V. E., Makarov, V. V., Onoichenko, S. I., Petrukin, A. A., Shamonina, A. V. (2005). Etilovui spirt v motornom toplive. Pod` redakziyei doktora nauk V. V. Makarova. Moscow, 92.

7. Braunstein, B. A., Klimenko, V. L., Zerkin, E. B. (2004). Proizvodstvo spirtov iz neftyanogo i gazovogo sur`ya. Nedra, Saint-Petersburg, 136.

8. Lidin, R. A., Molotshko, V. A., Andreeva, L. L. (2000). Spravochnik po neorganicheskoy chimii, konstanty neorganicheskyx veshestv. Moscow, Chemistry, 480.

9. Kulikov, A. B. (2004). Sintez i svoystva gidroksosulphatov` medi, medi-nickelya i medi-kobalta. Peoples' Friendship University of Russia, Moscow, 14.

10. Proskurina, O. V. (2001). Issledovaniye otkrytyx phasovux prozessov v chetyrioxkomponentnoy` vodno-solevoy sisteme, sodershashey sulphaty magniya, nichelya i zunka pri 25 °C. St. Petersburg, Saint Petersburg State Institute of Technology, 6.

Дата надходження рукопису 25.12.2014

Блинков Николай Андреевич, аспирант, кафедра общей и неорганической химии. Национальный технический университет «Харьковский политехнический институт», ул. Фрунзе, 21, г. Харьков, Украина, 61000
E-mail: nikolayblinkov@yahoo.com
Бутенко Анатолий Николаевич, доктор технических наук, профессор, кафедра общей и неорганической химии, Национальный технический институт «Харьковский политехнический институт», ул. Фрунзе, 21, г. Харьков, Украина, 61000
Рыщенко Игорь Михайлович, доктор технических наук, профессор, кафедра общей и неорганической химии, Национальный технический институт «Харьковский политехнический институт», ул. Фрунзе, 21, г. Харьков, Украина, 61000

UDC: 621.373.826
DOI: 10.15587/2313-8416.2015.36233

PHOTONIC-CRYSTAL FIBERS GYROSCOPE

©Haider Ali Muse

In this paper we proposed to use of a photonic crystal fiber with an inner hollow defect. The use of such fibers is not affected by a material medium on the propagation of optical radiation. Photonic crystal fibers present special properties and capabilities that lead to an outstanding potential for sensing applications

Keyword: *fiber optical gyroscope, photonic crystal fiber , Sagnac effect*

В этой статье мы предложили использовать оптоволокно на фотонных кристаллах с дефектом внутренней полости. На использование таких волокон не воздействует материальное средство на распространении оптической радиации. Фотонные кристаллы обладают специальными свойствами и возможностями, которые приводят к огромному потенциалу для приложений зондирования

Ключевые слова: *оптический гироскоп, оптоволокно на фотонных кристаллах, эффект Саньяка*

1. Introduction

It is generally recognized as promising fiber optic gyroscopes (FOG) for the control and navigation systems, moving objects of various kinds (ground transportation, ships, aircraft, etc.). At the same time demand are (fiber optical gyroscope) in a wide range of characteristics of accuracy – 10.0 deg/h to 0, 001 deg/hr. In Russia, the leader in the production of a number of FOG accuracy class 10,0–1,0 deg /hr is LLC "Physoptic". However, there is a gap from the foreign level in FOG navigational accuracy class (0.01–0.001 deg/hr).

Performance characteristics of fiber-optic gyroscope. Increased accuracy is largely dependent on the characteristics of its basic elements and features of its assembly techniques. Thus, the development of fiber-optic gyroscope and methods of its production is an urgent task. A large number of parameters and events affect the phase of the optical radiation, which provide additional phase shifts not associated with the rotation of the interferometer. Therefore, the main problem discussed in this paper is related to the appearance of additional signals at the output of a fiber ring interferometer identical, but are not associated with rotation. Since the high pressure sensitivity join with temperature insensitivity makes this sensor suitable to work in a harsh environment such as the ocean bottom [1]. The diversity of unusual features of photonic crystal fibers, beyond what conventional fibers can offer, leads to an increase of possibilities for new and improved sensors. There is a huge interest of the scientific community in this original technology for applications in a variety of fields. The aim of this work was to conduct theoretical studies of the conditions of use of photonic crystal fiber (PCF) as a part of the fiber optical gyroscope. Photonic crystal fibers are a kind of fiber optics that present a diversity of new and improved features beyond what conventional optical fibers can offer.

2. Literature review

Fiber optical gyroscope ring laser and both operate by sensing the difference in propagation time between beams of light traveling in clockwise and counter-clockwise directions about some closed optical path. A rotationally induced variance in path length produces a phase difference between the light beams propagating in opposing directions [2].

Conventional sensors are often difficult to apply due to the high temperatures, highly corrosive agents or electromagnetic interference that may be present in those harsh environments. Fiber optic sensors have been proved themselves successful in such harsh environments due to their high sensitivity, wide bandwidth, high operation temperature, immunity to electromagnetic interference, lightweight and long life [3].

In this paper we proposed to use of a photonic crystal fiber with an inner hollow defect.Due to their unique geometric structure, photonic crystal fibers present special properties and capabilities that lead to an outstanding potential for sensing applications

3. Basic conditions of work fiber optical gyroscope

Fiber optical gyroscope is based on the Sagnac effect [4]. Sagnac effect generates an optical phase difference, Δφ, between two counter propagating waves in a rotating fiber coil (optical path) [1]:

$$\Delta\varphi = \frac{8\pi S}{\lambda c}\Omega \ , \tag{1}$$

where Ω – angular velocity, (Δφ) – phase difference, *C* – light -/signal velocity, λ – wavelength

Fig. 1 – Open-loop fiber optic gyros are the simplest and lowest cost rotation sensors. They are widely used in commercial applications where their dynamic range and linearity limitations are not constraining.

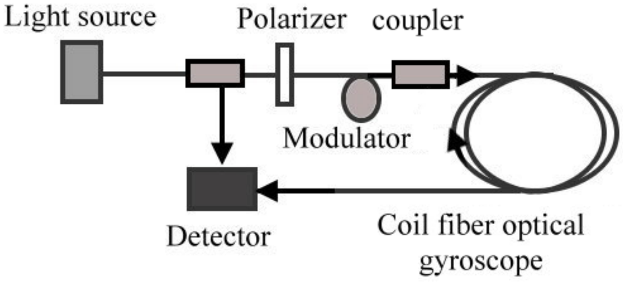

Fig. 1. Scheme of fiber optic gyroscope

However, a clear and precise definition of the angular velocity is necessary to exclude the possibility of additive and multiplicative effects of other physical effects on the measured value of the phase difference of counter propagating waves. The main challenge to the realization of high-precision phase measurements is a zero drift, which is manifested in the fact that physically stationary gyroscope gyro output signal there, which is due to physical phenomena not related to the rotation of the loop. In the fiber material in a medium to obtain a stable optical phase oscillations is practically impossible. Therefore, fiber optic gyroscopes may occur an additive phase noise. One of the reasons for the appearance of these signals is the scattering and reflection in a fiber loop.

During the rotation of angular velocity contour (Ω), an apparent distance between points A and B for the oppositely traveling beams changes. For a wave traveling from point A to point B, i.e., in a direction similar to the direction of rotation of the contour, the distance is extended, as in a time dt point B moves to the angle (dφ=Ω.dt), go to point C.

This is for lengthening the path of the light beam is equal to dt, since at each instant the beam is directed at a tangent to the contour at that same tangential linear velocity directed projection ($\vec{\upsilon} = \vec{\upsilon}.\cos\alpha = \Omega.r.\cos\alpha$). Thus, the length of the path traversed by the beam is equal to Dl + ύ dt. Arguing similarly, for opposing traveling light beam will be a reduction in the apparent path segment Dl – ύ dt

Considering the speed of light invariant quantity, apparent elongation and reduction paths for opposing beams can be considered equivalent to extensions and contractions of time intervals, i.e.,

$$\Delta t_1 = \frac{1}{c}(\Delta l + v.dt) \ , \tag{2}$$

$$\Delta t_1 = \frac{1}{c}(\Delta l - v.dt) \ . \tag{3}$$

If the relative time delays of counter propagating waves occurring during the rotation, expressed in terms of the phase difference of counter propagating waves, it will be

$$\Delta\varphi = \omega.\Delta\tau = \frac{4.\omega.S}{c^2}.\Omega = $$

$$= \frac{8.\pi.v.S}{c^2}.\Omega = \frac{8.\pi.S}{\lambda.c}, \tag{4}$$

where ω=2.π.ν, $\lambda = \frac{c}{v}$

Basic conditions of work listed FOG not allow us to understand the constraints that are imposed on the accuracy of measurements made with it. Hitherto used fiber optic gyroscopes quartz fibers used in optical communications. In these fibers, is an amorphous, almost homogeneous and isotropic medium can propagate transverse optical waves. Light reflected from the interface "core-shell" as a result of total internal reflection propagates along the core as its own wave of the optical waveguide. Light wave as electromagnetic wave propagates along the fiber with a phase velocity is inversely proportional to the refractive index. Even a weak inhomogeneity can lead to cumulative effect and change the measurement result. Since the optical radiation propagates in a material medium, and it refers to the optical fiber, which is made of quartz or quartz glass, such physical phenomena as the birefringence effect, Kerr effect, Faraday effect, etc. adversely affect the angle of rotation loop fiber optic gyroscopesand registered phase of the optical signal. These effects associated with the process of optical radiation propagation in the material of the optical medium, leading to a phase shift of counter propagating waves, which is not associated with the rotation of the closed loop. The negative effects are also associated with the processes of scattering and reflection of light in an optical path, the polarization non-reciprocity effect associated with the asymmetric arrangement of anisotropic elements, relative to the centre of the fiber loop, or anisotropic fiber properties. However, the main problem of the FOG is that as the measuring accuracy and reducing the magnitude of the angular velocity measured is increasingly influenced by the optical effects not related to the angular displacement of the optical loop fiber optical gyroscope. Since the optical radiation propagates in a material medium, and it refers to the optical fiber, which is made of quartz or quartz glass, such physical phenomena as the birefringence effect, Kerr effect, Faraday effect, etc. adversely affect the angle of rotation loop fiber optic gyroscopesand registered phase of the optical signal. These effects associated with the process of optical radiation propagation in the material of the optical medium, leading to a phase shift of counter propagating waves, which is not associated with the rotation of the closed loop. The negative effects are also associated with the processes of scattering and reflection of light in an optical path, the polarization non-reciprocity effect associated with the asymmetric arrangement of anisotropic elements, relative to the center of the fiber loop, or anisotropic fiber properties. This problem was solved and solved by the use of frequency and phase modulation of the optical radiation is used, which allows to shift the zero point on the slope with the maximum slope of the interference signal. However, to get rid of the phase shifts, non-rotation circuit fails. Effects associated with locally mutual, non-stationary changes in the parameters of fiber, when they are excited asymmetrically with respect to the middle of the fiber loop. The main effects are the Faraday effect, Fresnel-Fizeau and nonlinear optical Kerr effect. The use of non-monochromatic radiation SLD (super luminescent diode with a coherence length of 10-20 microns) is practically eliminates the problem of the influence of the reflected and scattered radiation on the phase of the output signal of the FRI. However, the use of SLD removed only part of the problems leading to additional signals.

5. Photonic crystal fiber as a part fiber optical gyroscope

The photonic crystal fiber (PCF) has since it was first proposed [5] attracted growing attention due to its many unique properties. One of the first special characteristics to be reported for the PCF was its potential to be endlessly single-mode (ESM) [6] referring to the absence of higher-order modes regardless of the optical wavelength. In the case of conventional fibers, the effective area is limited by the fact that an increasing core size requires a correspondingly decreasing index step between the core and the cladding in order to maintain single-mode operation. This imposes requirements on the control of the index profile which is difficult to realize with index-raising doping of the glass. Photonic crystal fibers which is ESM can in principle be scaled to an arbitrary dimension and remain single-mode. However, since the numerical aperture (NA) decreases within creasing mode size, the scaling of the Photonic crystal fibers is in general limited by macro-bending loss and micro-deformation loss due to the decreasing mode spacing between the guided mode and leaky cladding-modes [7, 8]. In contrast to conventional fibers, the bend-loss edge for the PCF is located at lower wavelengths compared to the transmission window [6] which is due to the fact that the mode spacing decreases with decreasing wavelength. In solid core Bragg fibers, effective areas of more than 500 μm^2 at 1550 nm have been demonstrated but with attenuation levels in the order of dB/m [9]. PCFs with large mode-area have also been demonstrated [10, 11] but only for structures which are intrinsically susceptible to loss caused by bending and other perturbations. The main argument in favor of a replacement optical fiber to another medium is that the first Sagnac experiments conducted in the hollow pipe and the low pressure air is not observed effects are manifested in the optical fiber. In this regard, it is evident that the use of such optical media, which on the one hand, would allow optical radiation to channel, and on the other hand did not change to its frequency and phase characteristics. Such environments include photonic crystals with defects. In such environments the defect is a hollow waveguide, wherein the produced photonic crystal fibers have a refractive index of 1.82 at wavelength 500 nm for this fiber type Kagome effective single-mode propagation occurs in a wavelength range from 750 to 1050 nm at substantially 30 microns diameter and a loss of about 0.7 dB/m [12]. Example of photonic crystal fiber with hollow core diameter of about 30 microns. These fibers, inheriting the properties of photonic crystals, allow to form photonic band gaps, which opens up new perspectives in the management of the properties of agents. It becomes possible to control the dispersion of the waveguide by shifting the zero dispersion wavelength in the visible region of the spectrum, and effective refractive index of the shell, forming an "infinitely" single mode fibers including fibers having a large effective core area, the required capacity of the day pass large luminous flux; forming air channels not only in the shell (which makes it easier fiber), but also in the core, opening opportunities to further reduce fiber attenuation has reached the limits .To solve the above problems, the fibers are under development based on photonic crystals. Photonic crystal fiber is a two-dimensional photonic crystal structure based on the song "quartz glass-to-air" formed in the shell OB .Photonic crystal fibers- a fiber whose cross section is constant along the length and a two-dimensional photonic crystal (PC) with a point defect disposed usually at the centre of symmetry RH. Two-dimensional photonic crystal structure is formed in the shell by means of symmetrically arranged around the core in the form of hollow capillaries of circular or hexagonal closely packed dielectric tube, creating a two-dimensional periodic lattice micro see (Fig. 2).

The main feature of the photonic crystal fibers that the energy distribution of the light wave is along the linear defect (which is usually the core region), and the wave is in the form of transverse modes TE0, t. E. in the cross section of the fiber (or a photonic lattice plane crystal).

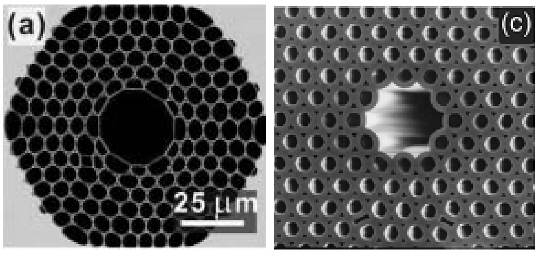

Fig. 2. Hollow-core photonic crystal fiber

6. Conclusion

Photonic crystal fibers are a kind of fiber optics that present a diversity of new and improved features beyond what conventional optical fibers can offer. Due to their unique geometric structure, photonic crystal fibers present special properties and capabilities that lead to an outstanding potential for sensing applications.The article discusses the conditions of realization of the structure of the fiber gyroscope using a photonic crystal fiber. With this fiber and methods and devices for forming fiber interferometers can be solved the problem of creating a fiber-optic gyroscope based on photonic – crystal fiber.

References

1. Shinde, Y. S. Dynamic pressure sensing study using photonic crystal fiber: application to tsunami sensing [Text] / Y. S. Shinde, H. K. Gahir // IEEE Photonics Technology Letters. – 2008. – Vol. 20, Issue 4. – P. 279–281. doi: 10.1109/lpt.2007.913741

2. Nuttall, J. D. Optical Gyroscopes [Text] / J. D. Nuttall // Electronics and Power. – 1987. – Vol. 33, Issue 11-12. – P. 703–707. doi: 10.1049/ep.1987.0426

3. Bock, W. J. Pressure sensing using periodically tapered long-period gratings written in photonic crystal fibres [Text] / W. J. Bock, J. Chen, P. Mikulic, T. Eftimov, M. Korwin-Pawlowski // Measurement Science and Technology. – 2007. – Vol. 18, Issue 10. – P. 3098–3102. doi: 10.1088/0957-0233/18/10/s08

4. Andronova, I. A. Physical problems of fibergiroscope based on the Sagnac effect [Text] / I. A. Andronova, G. B. Malykin // Physics-Uspekhi. – 2002. – Vol. 45, Issue 8. – P. 793–817. doi: 10.1070/pu2002v045n08abeh001073

5. Knight, J. C. All-silica single-mode optical fiber with photonic crystal cladding [Text] / J. C. Knight, T. A. Birks, P. St. J. Russel, D. M. Atkin // Optics Letters. – 1996. – Vol. 22, Issue 19. – P. 1547. doi: 10.1364/ol.21.001547

6. Birks, T. A. Endlessly single-mode photonic crystal fiber [Text] / T. A. Birks, J. C. Knight, P. St. J. Russel // Optics Letters. – 1997. – Vol. 22, Issue 13. – P. 961. doi: 10.1364/ol.22.000961

7. Mortensen, N. A. Low-loss criterion and effective areaconsiderations for photonic crystal fibers [Text] / N. A. Mortensen, J. R. Folkenberg // Journal of Optics A: Pure and Applied Optics. – 2003. – Vol. 5, Issue 3. – P. 163–167. doi: 10.1088/1464-4258/5/3/303

8. Nielsen, M. D. Reducedmicrodeformation attenuation in large-mode-area photonic crystal fibers forvisible applications [Text] / M. D. Nielsen, N. A. Mortensen, J. R. Folkenberg // Optics Letters. – 2003. – Vol. 28, Issue 18. – P. 1645. doi: 10.1364/ol.28.001645

9. Février, S. Very large effective area singlemode photonic bandgab fibre [Text] / S. Février, P. Viale, F. Gérôme, P. Leproux, P. Roy, J.-M. Blondy, B. Dussardier, G. Monnom // Electronics Letters. – 2003. – Vol. 39, Issue 17. – P. 1240. doi: 10.1049/el:20030841

10. Knight, J. C. Large Mode area photonic crystal fibre [Text] / J. C. Knight, T. A. Birks, R. F. Cregan, P. St. J. Russel, J.-P. de Sandro // Electronics Letters. – 1998. – Vol. 34, Issue 13. – P. 1347. doi: 10.1049/el:19980965

11. Baggett, J. C. Comparative Study of large-mode holey and conventional fibers [Text] / J. C. Baggett, T. M. Monro, K. Furusawa, D. J. Richardson // Optics Letters. – 2001. – Vol. 26, Issue 14. – P. 1045. doi: 10.1364/ol.26.001045

12. Jiang, X. Single-modehollow-corephotonic crystal fiber madefrom siftglass [Text] / X. Jiang, T. G. Euser, F. Abdolvand // Optics express. – 2011. – Vol. 19, Issue 16. – P. 15438–15444.

References

1. Shinde, Y. S., Gahir, H. K. (2008). Dynamic pressure sensing study using photonic crystal fiber: application to tsunami sensing. IEEE Photonics Technology Letters, 20 (4), 279–281. doi: 10.1109/lpt.2007.913741

2. Nuttall, J. D. (1987). Optical Gyroscopes. Electronics and Power, 33 (11-12), 703–707. doi: 10.1049/ep.1987.0426

3. Bock, W. J., Chen, J., Mikulic, P., Eftimov, T., Korwin-Pawlowski, M. (2007). Pressure sensing using periodically tapered long-period gratings written in photonic crystal fibres. Measurement Science and Technology, 18 (10), 3098–3102. doi: 10.1088/0957-0233/18/10/s08

4. Andronova, I. A., Malykin, G. B. (2002). Physical problems of fibergiroscope based on the Sagnac effect. Physics-Uspekhi, 45 (8), 793–817. doi: 10.1070/pu2002v045n08abeh001073

5. Knight, J. C., Birks, T. A., Russel, P. St. J., Atkin, D. M. (1996). All-silica single-mode optical fiber with photonic crystal cladding. Optics Letters, 22 (19), 1547. doi: 10.1364/ol.21.001547

6. Birks, T. A., Knight, J. C., Russel, P. St. J. (1997). Endlessly single-mode photonic crystal fiber. Optics Letters, 22 (13), 961. doi: 10.1364/ol.22.000961

7. Mortensen, N. A., Folkenberg, J. R. (2003). Low-loss criterion and effective areaconsiderations for photonic crystal fibers. Journal of Optics A: Pure and Applied Optics, 5 (3), 163–167. doi: 10.1088/1464-4258/5/3/303

8. Nielsen, M. D., Mortensen, N. A., Folkenberg, J. R. (2003). Reducedmicrodeformation attenuation in large-mode-area photonic crystal fibers forvisible applications. Optics Letters, 28 (18), 1645. doi: 10.1364/ol.28.001645

9. Février, S., Viale, P., Gérôme, F., Leproux, P., Roy, P., Blondy, J.-M., Dussardier, B., Monnom, G. (2003). Very large effective area singlemode photonic bandgab fibre. Electronics Letters, 39 (17), 1240. doi: 10.1049/el:20030841

10. Knight, J. C., Birks, T. A., Cregan, R. F., Russel, P. St. J., de Sandro, J.-P. (1998). Large Mode area photonic crystal fibre. Electronics Letters, 34 (13), 1347. doi: 10.1049/el:19980965

11. Baggett, J. C., Monro, T. M., Furusawa, K., Richardson, D. J. (2001). Comparative Study of large-mode holey and conventional fibers. Optics Letters, 26 (14), 1045. doi: 10.1364/ol.26.001045

12. Jiang, X., Euser, T. G., Abdolvand, F. (2011). Single-modehollow-corephotonic crystal fiber madefrom siftglass. Optics express, 19 (16), 15438–15444.

Рекомендовано до публікації д-р техн. наук Мичехін Ю. П.
Дата надходження рукопису 25.12.2014

Haider Ali Muse, Faculty of electronic engineering, Department of Physical Foundations of Electronic Engineering, Kharkiv national university of radio electronics, ave. Lenina, 14, Kharkov, 61000
E-mail: Hadr_2005@yahoo.com