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Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Физикалық-математикалық сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын усынады. ҚР ҰҒА Хабарлары. Химия және технология сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді химиялық ғылымдар бойынша контентке адалдығымызды білдіреді.

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MODELING SPECTRAL CHARACTERISTICS OF FIBER-OPTIC SENSOR WITH TILTED BRAGG GRATING IN MATLAB MEDIUM

Abstract. In the work herein there has been worked out modeling of spectral characteristics of fiber-optic Bragg tilted grating sensor in MatLab medium. There have been analyzed mathematical models and methods, allowing to compute parameters of Fiber Bragg gratings. As well there have been presented possibilities to measure bend angle of optical fiber by means of tilted fiber Bragg grating (TFBG). Moreover, there has been shown, that for simultaneous measuring the bend angle, there might be used one and the same TFBG element. There have been presented laboratory results of measuring spectral characteristics of fiber-optic Bragg sensor with tilted grating. Apart from that, there has been developed the method, which allows the sensors system be independent on the temperature. In the result of experimental works, there has been developed remote monitoring system of the sensor, where signals processing is implemented in Matlab medium. Fiber optic sensors are one of the important areas due to their advantages over electronic counterparts, which raises interest in using the differential but simultaneous response of modes transmitted in an optical fiber to various disturbances as a means of increasing bandwidth, sensitivity or decreasing detection limits. in optical sensor systems. Fiber optic sensors are a relatively new and extremely versatile technical application in optoelectronics, fiber optics and integrated optics.
Key words: Fiber optics, fiber Bragg gratings, theory of coupled modes, effective index method, scattering matrix method.

Introduction. Sensors are used in many industry branches, such as aviation and construction. The main types of the sensors for measuring displacements are inductive, impulse, potentiometric and capacitance transducers. Example of fiber-optic transducers for measuring the bend is LPFG – long-period fiber gratings. There known the methods of tilt measuring, when LPFG is registered on standard single mode fiber and placed into composite from carbon fibers [1]. But temperature changes influence much at operation of the sensors, based on TFBG. FBG, as well, is used for measuring mechanical parameters. To use elements as bend sensors, it is necessary, for example, to place them in photon fibers with bandgap photon fibers with photon gap (solid fibers with photon bandgap) [2]. But such solution is extremely sensitive to geometry deficiencies of micro structured fibers. Bend measuring systems, using both LPFG and FBG, as well, have been studied [3]. Fall of cross sensitivity to temperature is often fulfilled by means of hybrid structures, consisting also of two types of fiber-optic gratings: LPFG and TFBG. Thus, bend radius change might be considered as in [4]. Some sensors, using TFBG elements, might also be considered as independent on temperature [5], inserting multi-mode fiber segment between single mode fiber and TFBG element. As well, there known the constructions, used as bend sensors [6], in which FBG grating is stored in the same place as TFBG (construction with tilted grating). In such system the signal, reflected from FBG grating, is modeled by TFBG, sensitive to the bend [7]. For the sensors, using Bragg gratings for displacement measuring, there is usually used construction of subsidiary hook or mechanical element, transferring displacement from the tested object to optical fiber [8]. The main problem in such solutions is Bragg gratings sensitivity to axial elongation and temperature. Therefore, measuring systems, using that sensor type, require temperature compensation upon measuring other physical magnitudes. Unfortunately, very frequently, techniques of lowering cross sensitivity to the temperature, decrease the range of measuring the systems with TFBG and FBG gratings. There known the solutions, extremely sensitive to deformation, but having narrow range of measurements, for instance, of 1 Nm order [9]. Measurement range is, as well, changed in the result of fiber covering with TFBG grating, for example, with additional protecting layer [10]. Spectral properties are the most important characteristics of fiber Bragg gratings. As a rule, upon manufacturing and operating FBG there registered the spectra of gratings reflection/ transmission, and also spectra change dynamics. Primarily, attention is drawn to such spectral parameters, as position of reflection/transmission peak, its width and depth. With that, of interest are other characteristics, for example, depth and side lobes offsets, selective short wave losses, conditioned by the link with cladding modes, etc. To understand and compute those characteristics, we use mathematical modeling.

Initially, coupled modes theory has been developed for uniform gratings, but Kogelnik [11] expanded the model also to nonperiodic structures. Coupled modes formalism method is used only in most general cases, as the system of coupled differential equations for non-uniform gratings will not have analytical solution. As well, for gratings analysis there have been developed matrix techniques, such as effective index method – EIM [12] transfer matrix method – TMM) [13]. In EIM the grating is divided into sections, the length of each of them is much less, than the least perturbation period magnitude. The fields are computed inside each section, using effective refraction index method from integrated optics. At that, it is considered, that refraction index within its limits remains constant. Fields inside each section cohere with the fields of preceding and subsequent sections, forming the relational matrix between left and right parts of every section. The general matrix, obtained by product of those sections individual matrices, characterizes complete structure. That approach is extremely applicable for describing integral-optical gratings, where maximum structure length constitutes only several millimeters. However, in case of fiber gratings, the length of which often reaches several centimeters, that method might demand overwhelming time for computing.

In scattering matrix method, the grating is broken down into sections, the length of each of them is much bigger, than the highest perturbation period. Inside every section refraction index modulation is considered to be constant. Each such section is described with scattering matrix, corresponding to uniform grating, and total structure is characterized by general matrix, obtained from partial matrices. That approach is suitable for periodic and non-periodic structures, and also for long gratings. For gratings analysis there, as well, have been offered several less known techniques.

Materials and methods. For modeling tilted fiber Bragg gratings in MatLab media there will be applied the scattering matrix method. Method thereof is the most suitable for modeling spectral characteristics of fiber Bragg gratings. Matrix method can be successfully used not merely for computing uniform FBG with constant parameters along total length, but also for computing non-uniform FBGs. In scattering matric method [11,14, 15] the grating is broken down into N areas with length Δ_j(j = 1,...,N), in each of them parameters Δn_{ac}, Δn_{dc} and Λ are considered to be constant. Thereupon the grating is defined by N sections with coupling factors q_j and physical width Δ_j.

Knowing the fields u_j and v_j at section entry point j, we can find the fields u_{j+1} and v_{j+1} at its outlet. That circumstance might be presented in the form of expression with transport matrix:

$$\begin{bmatrix} u_j \\ v_j \end{bmatrix} = T_j \begin{bmatrix} u_{j-1} \\ v_{j-1} \end{bmatrix} \quad (1)$$

where

$$T_j = \begin{bmatrix} \cosh(\gamma_j\Delta_j) + i\frac{\delta}{\gamma_j}\sinh(\gamma_j\Delta_j) & \frac{q_j}{\gamma_j}\sinh(\gamma_j\Delta_j) \\ q_j^*\sinh(\gamma_j\Delta_j) & \cosh(\gamma_j\Delta_j) - i\frac{\delta}{\gamma_j}\sinh(\gamma_j\Delta_j) \end{bmatrix} \quad (2)$$

where $\gamma_j^2 = |q_j|^2 - \delta^2$. Fields u_1, v_1 and u_{N+1}, v_{N+1} belong, consequently, to grating input and output. Against each other they match up as

$$\begin{bmatrix} u_{N+1} \\ v_{N+1} \end{bmatrix} = T_N \cdot \ldots \cdot T_j \cdot \ldots \cdot T_1 \begin{bmatrix} u_1 \\ v_1 \end{bmatrix} = T \begin{bmatrix} u_1 \\ v_1 \end{bmatrix} \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} u_1 \\ v_1 \end{bmatrix} \quad (3)$$

Refractive index amplitude r(δ) is defined with boundary conditions u_1 and $v_{N+1} = 0$:r(δ) = v_1 = -T_{21}/T_{22}. Transmission index amplitude t(δ) is at boundary conditions u_1 = O and v_{N+1} = 1: t(δ) =v_1= 1/T_{22}.

Offered scattering matrix formulation takes into account overlap integral 77, which is often neglected [13,14], and accents visibility effect might be included into distributions definition Δn_{dc} and $\Delta п_{ac}$.

Fiber-optic sensors represent an optic-fiber fragment, subjected to certain modification. Upon using optic fibers as sensitive elements there is no influence at electromagnetic fields measuring results, side electromagnetic radiation, channels crosstalk, no problems, connected with ground loops and displacement voltage at joints of dissimilar conductors, electric safety sufficiently increases, no problems of arcing and sparking. Fiber-optic sensors have high resistivity to environment adverse effects; they have small sizes and weight; high mechanical strength; resistivity to elevated temperatures, vibration, etc.; high data transmission speed. Moreover, fiber-optic sensors might be used in explosive environment due to their absolute explosion safety. They are chemically inert, have simple construction and high reliability. Fiber Bragg gratings turn out to be different due to dissimilarities in structure and photo-sensitivity of fibers being used, additionally to peculiarities of recording conditions and lasers, by means of which recording is fulfilled. Recording peculiarities are exposition time and recording dynamics, that is, irradiation density. There exists a lot of different techniques of constructing sensor systems, based on Bragg gratings. The simplest scheme of fiber-optic sensor is presented in the Figure 1.

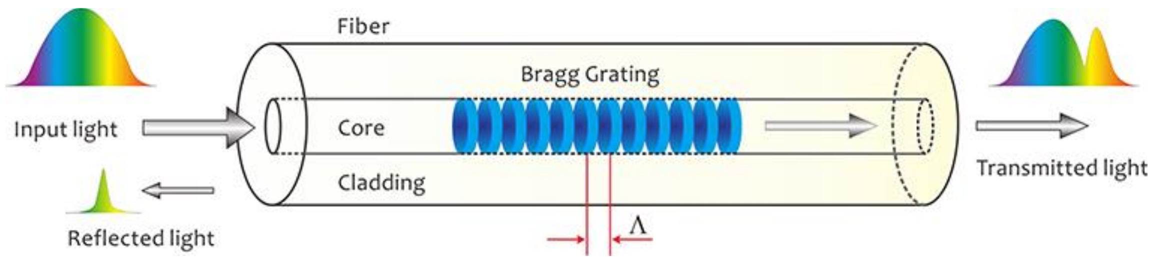


Fig.1 - Presents remote sensor monitoring system. Being offered remote sensor monitoring system operates as follows

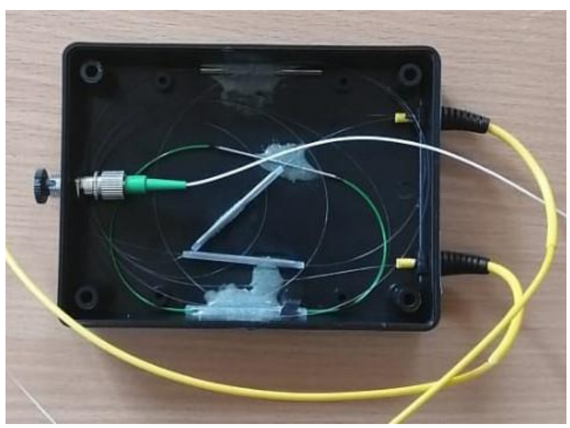
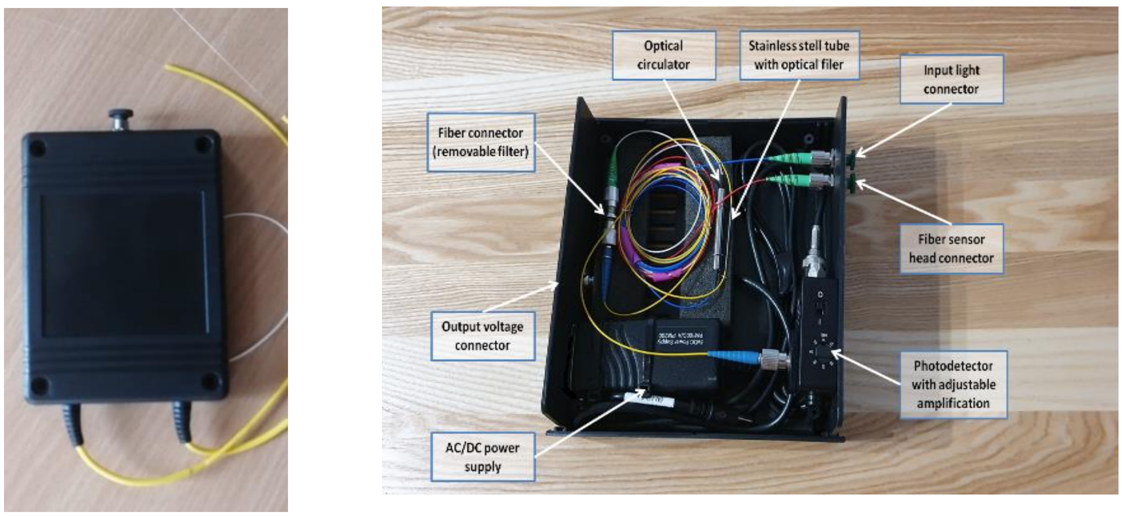


Fig.2 - Conventional Bragg fiber-optic sensor

Figure 2 shows Bragg fiber-optic sensor. Novelty of the given fiber-optic refractometer is the fact, that the given fiber-optic refractometer, connected to Bragg tilted grating is considerable simplification of environment refraction index measuring system, as well, it does not demand using of spectrophotometers and optical spectrum analyzers and algorithms for optical spectrum analysis. Invention's important feature is measurements independence on ambient temperature and electromagnetic field influence at measuring point, which is achieved by the fact, that gratings are recorded on one and the same multi-mode fiber. Application of fiber-optic refractometer also eliminated the problem of light sources power fluctuations, as the reflective index measure is the ratio of power, measured with two photo receivers.

As well, distinction is the fact, that fiber-optic refractometer consists of a wideband light source with a wide beam, connected via multimode optical fiber to Bragg tilted grating, which is doubled by means of multimode optical fiber with optical connector, and outlet of the first optical connector is linked, by means of multimode optical fiber to the first optical circulator, with which the first Bragg grating with linear variable period is connected with the help of multimode optical fiber, which is additionally linked through the first optical circulator via multimode optical fiber with the first photo receiver, whereas the optical connector second outlet is switched on for multimode optical fiber to the second optical circulator, which by means of multimode optical fiber is connected to the second Bragg with linear variable period, which is additionally switched on through the second optical circulator, it uses one photoreceptor (1,5 hours), to the second photo receiver.

In fiber-optic refractometer the light source might have high coherence and might be fabricated in the form of fiber or helium-neon laser.



a) b)

Fig.3 - Fiber-optic sensor for monitoring engineering and building structures health a) mockup; b) sensor interiority

Developed fiber-optic sensor to monitor engineering and building structures health consists of:

- Power supply unit of alternate / direct current with 230-240V coupler
- Inlet light coupler
- Connector of fiber sensor head
- Optical circulator
- Optical filter, adjusted to sensor properties, coated with stainless steel tube
- Fiber connectors, maintaining filter removal
- Photo receiver with controlled gain
- Output pressure coupler

Table 1–Technical specifications of fiber –optic sensor to monitor engineering and building structures health

Parameters	Value
Inlet light capacity	No more, than 10 mW
Working wavelength	1520-1570 Nm
Fiber couplers	FC / APC, contact square under 7° angle protects from back reflection
Optic fibers	Single mode and multimode fiber SMF-28
Optical filtering material	Photosensitive fiber THORLABS GF1.
Outlet pressure coupler	from 0 to 10 V of direct current
Bayonet connector	BNC
Inlet pressure	230-240 V of alternate current

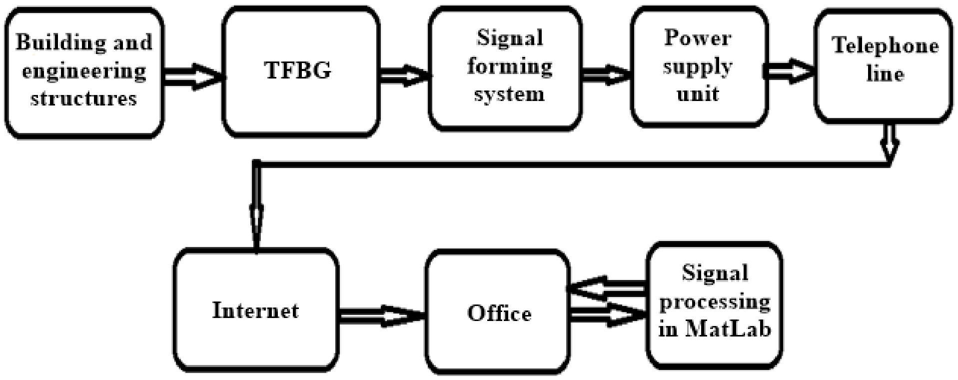


Fig.4 - Remote system for distant monitoring

Results. Offered system of distant monitoring operates as follows. Embedded Bragg fiber-optic sensors with tilted grating transfer data into own system of signal conditioner along the fiber-optic cables, located in the channels for protecting from the environment. Signal from the power source is reliably switched on through telephone to the internet, from where the data might be easily extracted and processed from the office by means of MatLab software.

Embedded fiber-optic Bragg sensors with tilted grating transfer the data to own system of signal conditioner along fiber-optic cables, located in the channels for protecting from the environment. The signal from feed source is reliably switched on via telephone to the Internet, from where the data might be easily extracted and processed from the office by means of MatLab software.

MATLAB represents the medium, which integrates and allows make calculation, visualization and programming, in which the problems and solutions are presented in the known mathematical notation.

Upon modeling fiber Bragg grating in MatLab medium there has been implemented mathematical model, based on matrix method.

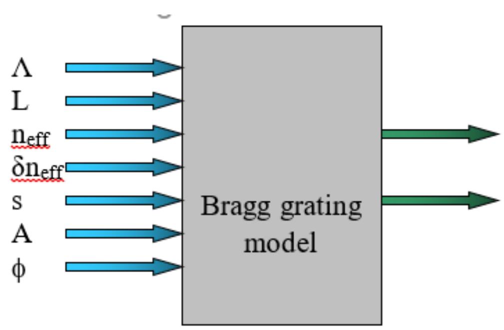


Fig.5 - Algorithm input parameters

Λ – grating period; L – length, n_{eff} - effective refractive index; δn_{eff} – average modulation refractive index value (constant component); s – fringe clearing, connected with refractive index modulation; A - apodization profile line; ϕ - phase displacement; and grating spectral characteristics: A^+ and B^+ in the result of algorithm operation.

To study FBG spectral characteristics at apodization various functions there has been written the program in MATLAB medium. Program interface is given in the Figure 6.

Figure 7 demonstrates code of the software, written in MatLab program language for spectral characteristics of fiber-optic sensor.

In NET software Ethernet_MAC_COL LOC are local MAC addresses for connecting with Web Server. NET LED[0] LOC- ports for sensors control. NET uart1_sin LOC- ports for data exchange. NET "CLK_100MHZ" TNM_NET = sys_clk_pin - speed of connecting Ethernet module with Web Server. TIMESPEC TS_sys_clk_pin = PERIOD sys_clk_pin 100000 kHz - period NET "RESET" LOC = "B6" | IOSTANDARD = LVCMOS33 | DRIVE = 8 | SLEW = FAST | PULLDOWN = TRUE - ports for resetting connection with the Web Server.

Software operation is based on reading temperature data via Ethernet and Web Server. In the software there is subsidiary smart program, which depends on temperature data of fiber-optic Bragg sensor.

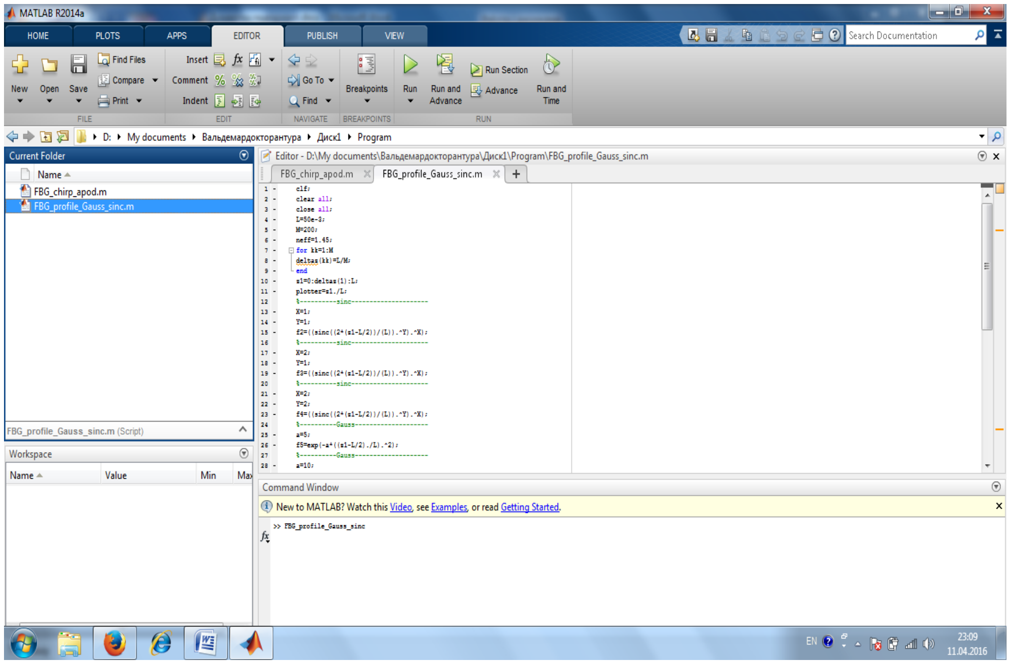


Fig.6 - Program interface in MATLAB

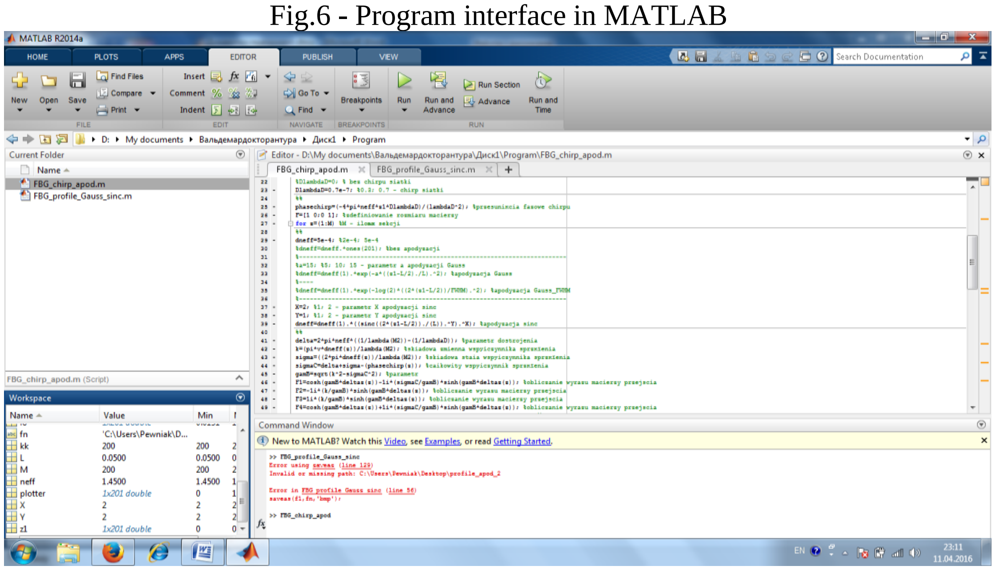


Fig.7 - MatLab software code for defining spectral characteristics of fiber-optic Bragg sensor

Measuring systems based on optoelectronic systems are used in the diagnostics of machines and processes. A special place is occupied by optical fiber sensors, which are characterized by a number of advantages, among which the most important are immunity to electromagnetic interference, low weight and the possibility of their integration into the measured structure. In the case of sensor systems based on fiber Bragg gratings, important advantages are the independence of the measurement accuracy from the fluctuations of the light source and the possibility of creating more complex measuring systems by placing several sensors on one optical fiber. Fiber Bragg gratings in sensitive applications have enjoyed unrelenting interest from scientists around the world for many years. Their main property is the ability to reflect light with a well-defined wavelength, while simultaneously being transparent to light of different wavelengths. We pose the direct problem here, and we view it as an experience from modulating the refractive index to the grating spectrum. After representing the forward problem in this way, the reverse problem looks like a pair of problems. The challenge for our grating is to go from grating spectra to refractive index modulation. We use a genetic algorithm to solve the inverse problem.

Genetic algorithm code for reconstruction of applied strain distributions from the reflected spectrum of the Bragg fiber grating sensor.

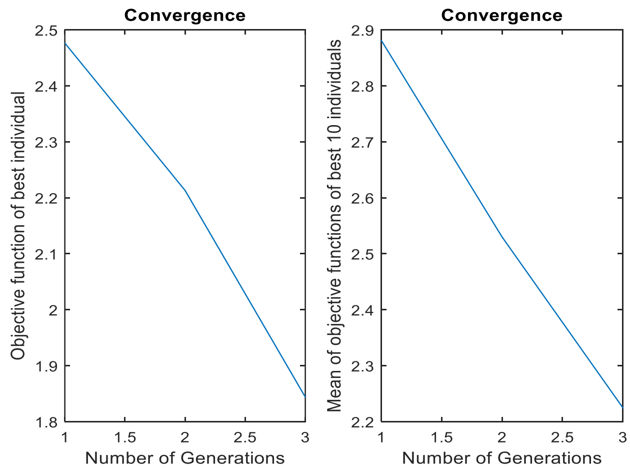


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Fig.8 - Genetic algorithm results

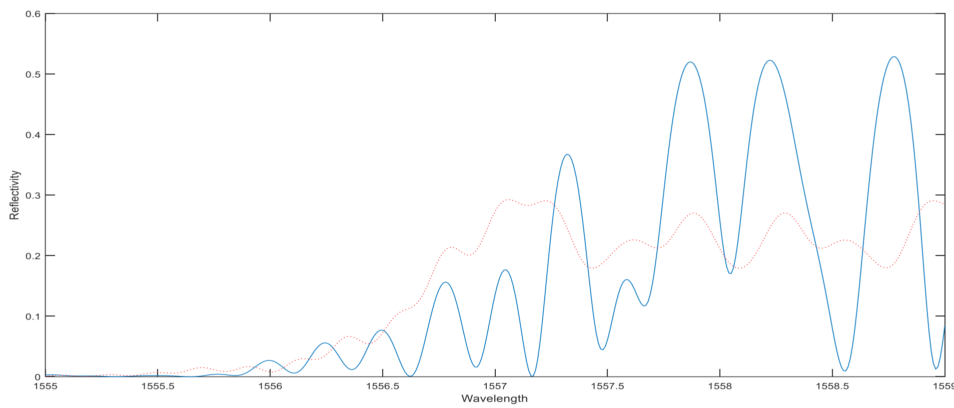

Fig.9 - Reflection wavelength

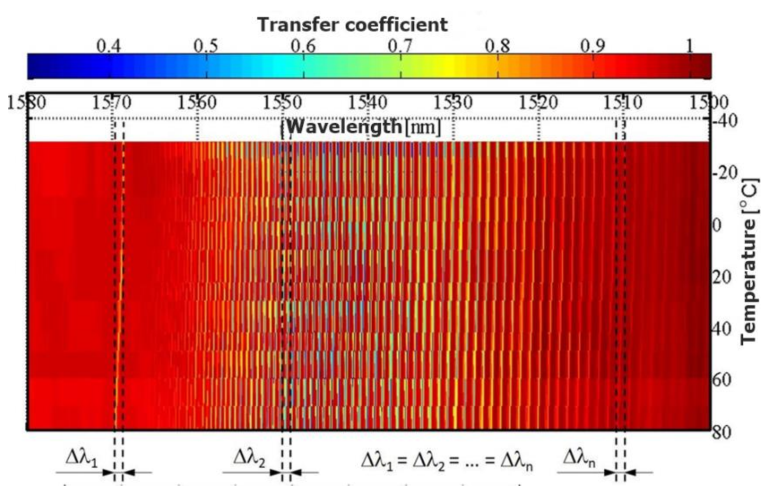

Fig.10 - Transmission spectra of fiber-optic Bragg sensor, measured at different temperatures

Fig. 10 shows transmission spectra of fiber-optic Bragg sensor, measured at different temperatures. As it is seen from the Figure, the red area corresponds to transmission capacity of ~5·10-5 W with the wavelength about 1550 Nm, has distinctive maximum on SLD irradiation curve. In measurements there has been used Thorlabs semiconductor photodetector, made of gallium-indium type PDA10CF. Results, obtained upon first temperature measurements and shown in the Figure 10, considerably defined by spectral characteristics of light source. Fig. 11 demonstrates transmission coefficient changes of fiber-optic Bragg sensor, measured at various temperatures.

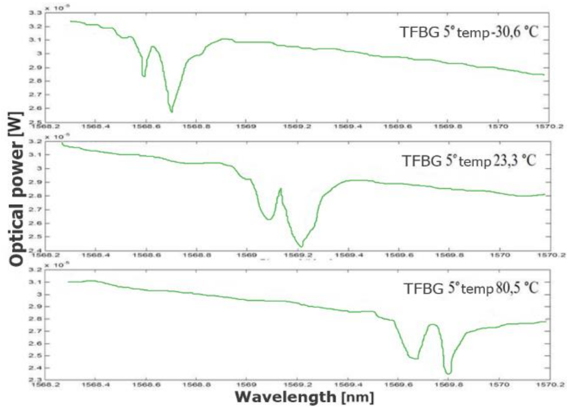

Fig.11 - Transmission index of fiber-optic Bragg sensor, measured at different temperatures

Figure 11 presents dependence of Bragg fiber –optic sensor's transmission index, measured at various temperatures. As it is seen from the figure the form of spectral part on sensor transmission characteristics, connected with Bragg resonance does not change. There is changed only the wavelength for which there is the minimum transmission.

Figure 12 presents outcomes of spectral testing, which show, that temperature sensitivity of all sensor's resonances is equal and does not depend on cladding modes order. Therefore, here have been marked three selected resonances on spectral transmission characteristics: main resonance (obtained from the main mode – the so-called Bragg resonance, Fig. 12), cladding resonance of # 1 mode type (obtained from selected expansion mode in cladding, marked as 1 according to Figure. 12)

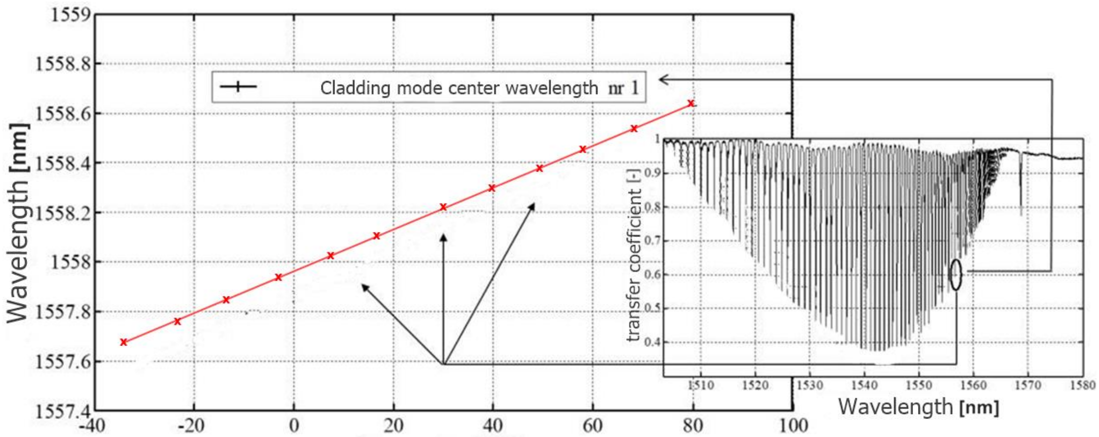

Fig.12 - Wavelength change in relation to cladding temperature in 1 regime

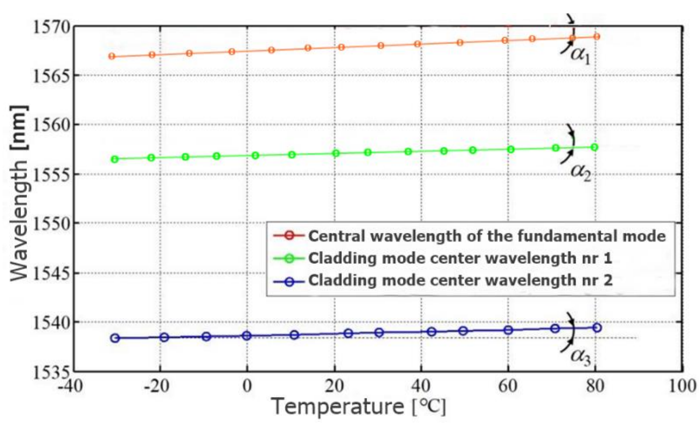

Fig.13- Characteristic of temperature effect on wavelength for three selected resonances

Fig. 13 presents generalized characteristics of temperature effect upon minimums displacement for three selected resonances. As it is seen from the Figure, temperature increases along the wavelength, higher the spectrum temperature, longer the wavelength. Also it is seen, that experimental data proved, that the main mode central wavelength was longer, than that of cladding modes 1 and 2. This points to the fact, that the main mode sensor's temperature effect has high thermal fiber expansion, which is an important for spectral analysis.

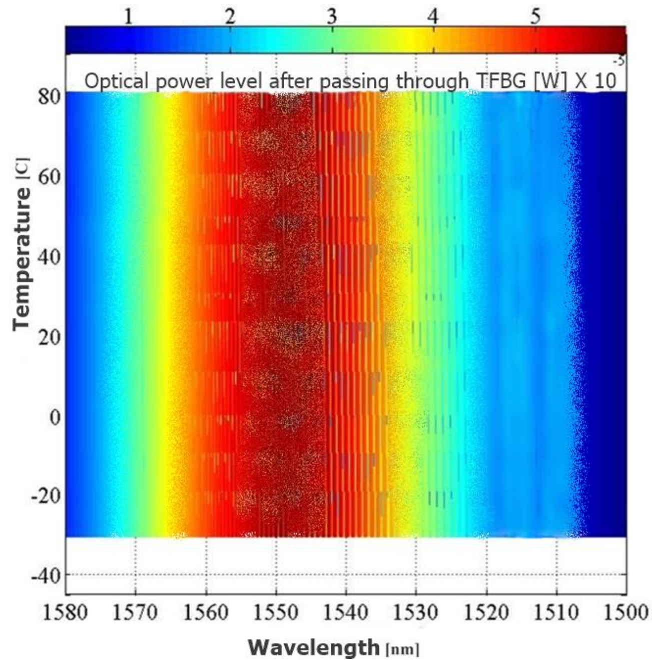

Fig.14 - Transmission spectrum of fiber-optic Bragg sensor, measured at variable temperatures

Fig. 14 shows spectrum displacement sideward to longer waves due to temperature increase. That phenomenon is occasioned, like in case of simple Bragg gratings, by thermal expansion of optical fiber, on which the grating has been recorded and change of photo elastic constant with dominant effect of thermal expansion of the fiber.

Discussion. The use of measuring elements in the form of tilted fiber Bragg grating (TFBG) structures and filtering elements in the form of linearly variable fiber Bragg grating (FBG) structures also eliminates the problem of power fluctuations in light sources. This is also achieved due to the fact that the refractive index is the ratio of the power measured by two photodetectors. In the case of two TFBGs, this process should be repeated. Therefore, the described method for producing TTFBG is technologically simpler, and the parameters of structures of this type in the context of insensitivity to light polarization seem promising.

Conclusion. In the result of modeling there have been obtained fiber Bragg gratings spectral characteristics, as well, carried out analysis and computation of grating spectrum length with account of different parameters impact, where red area corresponding to ~5·10-5 W transmission capacity, with wavelength about 1550 Nm has distinctive maximum on SLD irradiation curve. In measurements there has been used Thorlabs semiconductor photodetector, made of gallium-indium type PDA10CF. There has been offered remote monitoring system, from where the data can be easily extracted and processed from the office by means of MatLab software. Developed interface and program code for reading temperature data via Ethernet and Web Server. The software has subsidiary smart program, which depends on temperature and spectral data of fiber-optic Bragg sensor with tilted grating.
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MATLAB ОРТАСЫНДА КӨЛБЕУ БРЭГГ ТОРЫ БАР ТАЛШЫҚТЫ -ОПТИКАЛЫҚ СЕНСОРДЫҢ СПЕКТРЛІК СИПАТТАМАЛАРЫН МОДЕЛЬДЕУ

Аннотация. Бұл жұмыста MatLab ортасында Брэгг көлбеу торлы оптикалық-талшықты датчиктің спектрлік сипаттамаларын модельдеу құрылды. Талшықты Брэгг торларының параметрлерін есептеуге мүмкіндік беретін математикалық модельдер мен әдістерге талдаулар жасалынды. Сондай-ақ, оптикалық талшықтың иілу бұрышын Брэгг көлбеу талшықты торымен (КТБТ) өлшеу мүмкіндігі ұсынылды. Сонымен қатар, иілу бұрышын бір уақытта өлшеу үшін бірдей TFBG элементін қолдануға болатындығы көрсетілді. Көлбеу торлы оптикалық-талшықты Брэгг датчигінің спектрлік сипаттамаларын өлшеуде алынған зертханалық нәтижелері ұсынылған. Сонымен қатар, сенсор жүйесіне температурадан тәуелсіз болуға мүмкіндік беретін әдіс алынды. Тәжірибелік жұмыстардың нәтижесінде Matlab ортасында сигналдарды өңдеу жүзеге асырылатындай датчиктерді қашықтан бақылау жүйесі құрылды. Талшықты-оптикалық сенсорлар маңызды бағыттардың бірі болып табылады, өйткені олардың электронды аналогтармен салыстырғанда артықшылығы бар, оптикалық талшықта әртүрлі қобалжуларға берілетін дифференциалды, бірақ бір мезгілде жауап беру модасын оптикалық сенсорлық жүйелерде өткізу қабілетін, сезімталдықты арттыру немесе анықтау шегін азайту құралы ретінде қолдануға қызығушылық тудырады. Талшықты-оптикалық датчиктер оптоэлектроника, талшықты және интегралды оптика үшін салыстырмалы түрде жаңа және өте көп функцияналды техникалық қолдану болып табылады.

Түйін сөздер: талшықты оптика, талшықты Брэгг торлары, байланысты модтар теориясы, тиімді индекстеу әдісі, шашырау матрицасының әдісі.

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МОДЕЛИРОВАНИЕ СПЕКТРАЛЬНЫХ ХАРАКТЕРИСТИК ВОЛОКОННО-ОПТИЧЕСКОГО ДАТЧИКА С НАКЛОННОЙ РЕШЕТКОЙ БРЭГГА В СРЕДЕ MATLAB

Аннотация: В работе проведено моделирование спектральных характеристик волоконно-оптического датчика с наклонной решеткой Брэгга в среде MatLab. Проанализированы математические модели и методы, позволяющие рассчитывать параметры волоконных решеток Брэгга. Также были представлены возможности измерения угла изгиба оптического волокна с помощью наклонной волоконной решетки Брэгга (НВРБ). Более того, было показано, что для одновременного измерения угла изгиба может использоваться один и тот же элемент TFBG. Представлены лабораторные результаты измерения спектральных характеристик волоконно-оптического датчика с наклонной решеткой Брэгга. Разработан метод, который позволяет системе датчиков быть независимой от температуры. В результате экспериментальных работ была разработана система удаленного мониторинга датчика, в которой обработка сигналов реализована в среде Matlab. Оптоволоконные датчики являются одной из важных областей из-за их преимущества по сравнению с электронными аналогами, что вызывает интерес к

использованию дифференциального, но одновременного отклика мод, передаваемых в оптическом волокне на различные возмущения, в качестве средства увеличения пропускной способности, чувствительности или уменьшения пределов обнаружения в оптических сенсорных системах. Волоконно-оптические датчики являются относительно новым и чрезвычайно многофункциональным техническим применением оптоэлектроники, волоконной и интегральной оптики.

Ключевые слова: волоконная оптика, волоконные брэгговские решетки, теория связанных мод, метод эффективных показателей, метод матрицы рассеяния.

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REFERENCES

[1] Laffont G., Ferdinand P., Tilt short-period fibre-Bragg-grating-induced coupling to cladding modes for accurate refractometry, Meas. Sci.Technol. 12, 765-770 (2001). doi: 10.1088/0957-0233/12/7/302.

[2] Tan D., Sharafudeen K. N., Yue Y., Qiu J., Femtosecond laser induced phenomena in transparent solid materials: Fundamentals and applications. Progress in Materials Science 76, 154-228 (2016). doi: 10.1016/j.pmatsci.2015.09.002.

[3] Jin L., Wang Z., Fang Q., Liu Y., Liu B., Kai G., Dong X., Spectral characteristics and bend response of Bragg gratings inscribed in all-solid bandgap fibers, Optics Express 15(23), 15555-15565 (2007). doi:10.1364/OE.15.015555.

[4] Swanson A. J., Raymond S. G., Janssens S., Breukers R. D., Bhuiyan M. D. H., Lovell-Smith J. W., Waterland M. R., Development of novel polymer coating for FBG based relative humidity sensing. Sensors and Actuators A 249, 217-224 (2016). doi: 10.1016/j.sna.2016.08.034.

[5] Shao L. Y., Albert J., Compact fiber-optic vector inclinometer. Optics Letters 35(7), 1034-1036 (2010). doi: 10.1364/OL.35.001034.

[6] Jin Y. X., Chan C. C., Dong X. Y., Zhang Y. F., Temperature- independent bending sensor with tilted fiber Bragg grating interacting with multimode fiber, Optics Communications 282(19), 3905-3907 (2009). doi: 10.1016/j.optcom.2009.06.058.

[7] Amanzadeh M., Aminossadati S. M., Kizil M. S., Rakić A. D., Measurement 128, 119-137 (2018). doi: 10.1016/j.measurement.2018.06.034.

[8] Dong X., Liu Y., Shao L. Y., Kang J., Zhao Ch. L., Temperature-Independent Fiber Bending Sensor Based on a Superimposed Grating, IEEE Sens. J. 11(11), 3019-3022 (2011). doi: 10.1109/JSEN.2011.2157124.

[9] An J. L., Liu T., Ji Y. G., Fiber optic vibration sensor based on the tilted fiber bragg grating. Advances in Materials Science and Engineering 2013, 346-349 (2013). doi: 10.1155/2013/545013.

[10] Shen C., Lou W., Shentu F., Wang Y., Tong L., Tilted fiber Bragg gratings and its fiber humidity and twist sensing applications, 2016 15th International Conference on Optical Communications and Networks (ICOCN), Hangzhou, 1-3 (2016). doi: 10.1109/ICOCN.2016.7875786.

[11] H. Kogelnik, "Filter response of nonuniform almost-periodic structures", BellSystem-Technical-Journal., 55(1), p. 109-26 (1976)

[12] Winick, "Effective-index method and coupled-mode theory for almost periodic waveguide gratings: A comparison", Applied Optics, Vol.31, 1992, pp. 757-764

[13] Yamada, Sakuda, "Analisis of almost-periodic distributed feedback slab waveguide via a fundamental matrix approach", Applied Optics, Vol.26, 1987, pp. 3474-3478

[14] J. Skaar, PhD dissertation, The Norwegian University of Science and Technology, Ch. 2, 5-15 (2000)

[15] M. McCall, "On the Application of Coupled Mode Theory for Modeling Fiber Bragg Gratings", JLT, 18(2), p. 236-242 (2000)

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МАТЕМАТИКА

СОДЕРЖАНИЕ

ФИЗИКА

ИНФОРМАТИКА

МАТЕМАТИКА

CONTENTS

PHYSICS

COMPUTER SCIENCE

MATHEMATICS

Publication Ethics and Publication Malpracticein
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