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INVESTIGATION OF THE TEMPERATURE DEPENDENCE OF TFBG WITH TILT ANGLES OF 2⁰ AND 4⁰

Due to advantages such as electromagnetic stability, durability, and high sensitivity, fiber Bragg gratings have found application as sensors of physical quantities. A special place in the line of such devices is occupied by Bragg gratings with tilted strokes (Tilted fiber Bragg grating- TFBG). At the moment, TFBGs are used to estimate the velocity of two-phase flows, to create a torsion sensor, as temperature and deformation sensors, etc.

This article examines the possibility of implementing a temperature sensor based on TFBG with an angle of inclination of 2° and 4° inscribed in a single-mode optical fiber. For this purpose, experimental studies of the dependence of the wavelength of the Bragg resonance on temperature have been carried out. The grating period is 540 nm and the length is 10 mm. The temperature ranged from 30 °C to 85 °C in increments of 5 degrees.

The results of the experiment are to find a linear dependence of the minimum wavelength of the Bragg resonance λ_B on the change in ambient temperature.

Keywords: Optical fiber, optical fiber sensors, inclined Bragg gratings, temperature sensors, grating period, wavelength

Introduction

Fiber-optic sensors of various physical quantities based on Bragg gratings are now widely used and are actively used in various fields of industry to solve a number of engineering problems. The general principle of operation of such sensors is based on the change in the Bragg wavelength under the influence of external influences.

The most widely used of the passive elements today are fiber optic sensors. Most fiber optic sensors are based on the scattering of light along the fiber. Defects in the main lines of the optical fiber are detected by reflectors based on this stimulated Brillouin scattering (SBS) effect. However, this sensor can only detect changes in the temperature or pressure of the medium. The feature of the sensor based on the Bragg grid allows you to accurately determine the exact information about the change in temperature or pressure.

Because sensors based on the Bragg lattice are more linear in their temperature dependence than temperature sensors based on other physical phenomena, the temperature accuracy determined by the first fiber Bragg grating is also more accurate. Therefore, the main goal of the work is to propose new methods for correctly determining the temperature dependence of the first fiber Bragg grating sensors and to develop a mathematical model for these sensors. This is because it is not possible to design a universal model suitable for all sensors based on all Bragg grids, as each sensor is designed to take into account different temperature ranges and other external influences.

Ways to solve this problem have been identified in many scientific publications and are now widely used. The modeling of the Bragg grid and its design should take into account the basic parameters of the grid, depending on each purpose

The most important work on the manufacture of the first fiber Bragg grating (FBG) by K. O. Hill et al. in the second half of the 1970s, it greatly influenced the success of optical fiber technology on a global scale [1]. Due to several advantages, such as electromagnetic stability, durability, stability and high sensitivity, since the mid-1990s, FBGs have found wide and important applications, mainly for the stabilization of laser pump diodes, which are used in erbium-doped fiber amplifiers [2], for distributed arrays of strain, sound and temperature sensors [3]. And, to a lesser extent, for wavelength multiplexing [4], for attenuation of gain in optical communication systems [5,6], for dispersion compensation [7-9] , and increasingly as resonator mirrors for fiber lasers [10–12].

However, the range of possible sensor element designs is not limited to classical Bragg structures. A special place in the line of such devices is occupied by Bragg gratings with inclined strokes (Tilted fiber Bragg grating-TFBG). Due to the oblique strokes in the light guide, a discrete set of shell modes is excited on such a lattice, which manifests itself on the transmission spectrum in the form of a series of spectral dips in a wide range of wavelengths.

Unlike FBG, the TFBG wave vector has a certain angle with respect to the fiber axis, and therefore the lattice has different structural geometry in radial, azimuthal and axial orientations, which makes TFBG a good contender for a multifunctional fiber component with new characteristics. Thus, TFBG has been the subject of numerous studies since its inception [1].

Currently, TFBGs are used for the detection of ammonium in wastewater [13], for the assessment of the two-phase flow rate, which is important in the oil and gas industry and medicine, as well as in microfluidic analyses [14], for the creation of a twisting sensor that demonstrates high sensitivity to twisting [15], as temperature and strain sensors [16, 17] , etc.

In [18], a fiber-optic sensor capable of distinguishing temperature and deformation using a single-fiber Bragg lattice is presented. This method uses the Tilted Fiber Bragg Grating (TFBG) core-shell coupling mode. The core and shell modes exhibit different thermal sensitivity, while the sensitivity to deformation is approximately the same. Monitoring the resonance of the core-to-core mode coupling and the resonance of the core-to-shell mode coupling of the TFBG spectrum makes it possible to separate the wavelength shifts caused by temperature and deformation.

A similar work was carried out by the authors of [19], where an tilted FBG (TFBG) was used with lattice planes tilted at an angle of 3° corresponding to the fiber axis, shows the core mode and a large number of resonances in the shell mode during its transmission. The possibility of simultaneous determination of temperature and deformation using a single TFBG is proposed and experimentally demonstrated. Shifts of the TFBG wavelength depending on temperature and deformation are investigated. The results show that the shell and core modes have different sensitivity to deformation, while the temperature sensitivity is the same. Thus, it is possible to track resonances in the core mode and resonances in the envelope mode of the WBR spectrum, allowing to separate the wavelength shifts caused by temperature and deformation

In contrast to the temperature sensors proposed above, in our work we offer a sensor based on an inclined Brag grating with an angle of inclination of 2^0 and 4^0.

Unlike the temperature sensors proposed above, in our work we investigated the possibility of implementing a temperature sensor based on an tilted fiber Brag grating with an angle of tilt of 2^0 and 4^0 inscribed in a single-mode optical fiber.

Based on the purpose of the work, the need for several main tasks is defined, such as:

1 Review of the conducted scientific papers on the main characteristics of the Bragg grating sensor;

2 The minimum length wave resonance of Bragg λ_B from changing the temperature surrounding the environment to use it in the quality of the temperature sensor.

3 In order to identify these patterns, organize an experimental laboratory and determine the spectral characteristics of the sensor in temperature ranges.

Materials and methods

The practical part of this work was carried out in the optical fiber laboratory at the Lublin Technical University (Lublin, Poland).

For the experiment, two optical light-sensitive fibers were used with TFBGs applied to them by the phase mask method. The fibers were coated with a grid: one - with an inclination angle of 2 degrees, and the second – with an inclination angle of 4 degrees. The lattice period is 540 nm and the length is 10 mm. The TFBG structure is shown in figure 1.

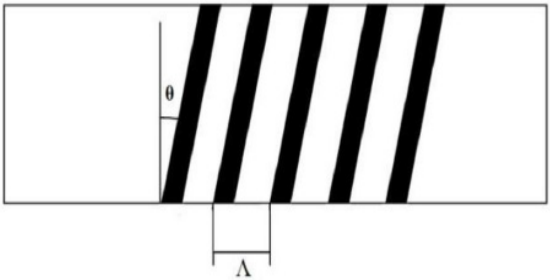

Figure 1 – The structure of the TFBG: θ is the tilt angle,
Λ is the grating period [18]

For the experiment, the scheme shown in Figure 2 was used. Both fibers were connected to a light source (fig.3) on one side and to the optical spectrum analyzer (fig.4) on the other side. The fibers were placed in a climate chamber (fig. 5). The light was launched into the TFBG from a light source that is connected to each grid using two single-mode optical fibers. The temperature ranged from 30^0C to 85^0C in increments of 5 degrees. The transmission spectra of the gratings were recorded using an optical spectrum analyzer.

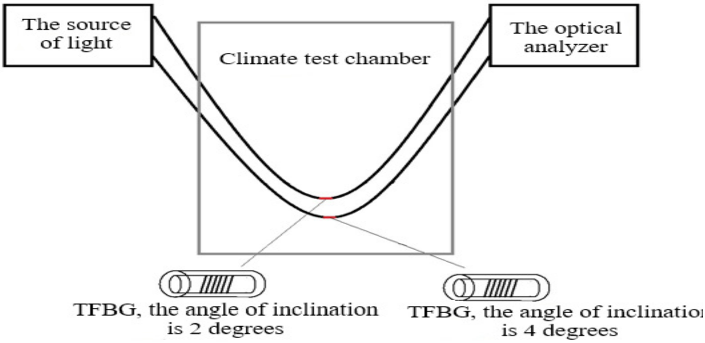

Figure 2 – Experimental setup

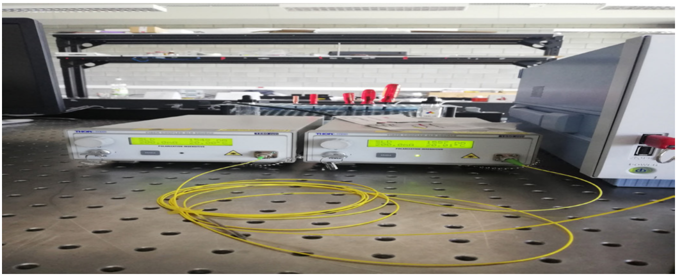

Figure 3 – The source of light Fiber coupled SLD (Superluminescent Diodes) source from the company Thorlabs

Light source – Fiber coupled SLD (Superluminescent Diodes) source from the company Thorlabs (Fig.3) contains broadband SLD that is connected to the SM or PM fiber. The SLD is powered by a high-precision, low-noise DC power source, and the SLD temperature is independently controlled by an internal TEC element. The display and controls on the front panel allow the user to view and set current and temperature parameters.

The YOKOGAWA AQ6370D optical spectrum analyzer (Fig.4) allows high-speed measurements, has high reliability and performance, and has the following characteristics:

- Range of measured wavelengths: from 600 to 1700 nm;
- Wavelength measurement accuracy: ± 0.01 nm;
- Wavelength resolution: 0.02 nm;
- Dynamic Range: 78 dB;
- The range of power level from +20 to -90 dBm;

- Measurement speed: 0.2 s (100 nm pulse);
- Work with single-mode and multimode fibers.

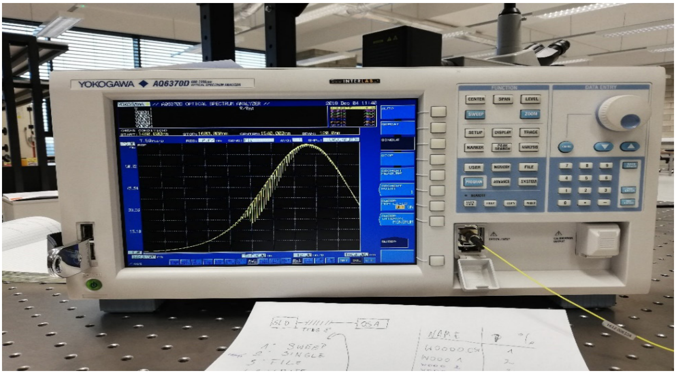

Figure 4 – Optical Spectrum Analyzer YOKOGAWA AQ6370D

Votsch temperature test chambers (Fig.5) have been developed for laboratory use and allow reproducible temperature and climate tests to be performed directly in the workplace. The high-temperature range from -70 ° C to + 180 ° C, as well as high-quality processing and construction, are crucial for obtaining reliable measurement results and have the following characteristics:

Rated voltage: 380 V, +-10%, 3/N, 50 Hz
Rated power: 9.0 kW Rated current: 13.5A
Fuse, in place: 16 A with slow blowing
Floor load: max. 150 kg/m2
Load per shelf: max. 20 kg
Total load per shelf: max. 80 kg
Sound level at a distance of 1 m (measurement in a free field) 58 dB(A)
Temperature test
Temperature range from -70°C to + 180°C
Side passage channel 9 cm

The high-quality processing and design of this model are crucial for obtaining reliable measurement results.

Figure 5 – Climate chamber VCL 4003 from the company Vötsch

Results and discussion

After the experiment, the normalized spectra of each TFBG in the Matlab environment are constructed from the obtained data. These spectra are shown in Figures 6 and 7, for TFBG with an inclination angle of 4^0 and 2^0, respectively, for 30^0C. In the figures, the wavelengths corresponding to the Bragg resonance are highlighted

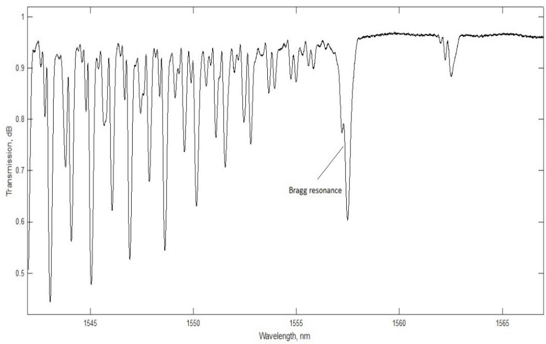

Figure 6 – Transmission spectrum for TFBG with a tilt angle of 4^0

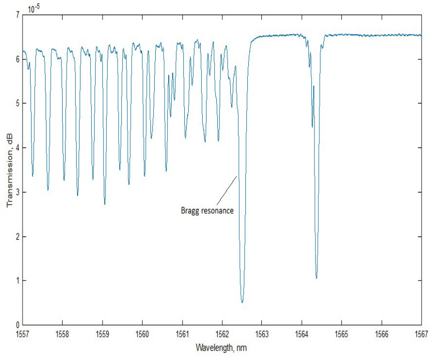

Figure 7 – Transmission spectrum for TFBG with an inclination angle of 2^0

The aim of our experiment is to find the linear dependence of the Bragg resonance wavelength λ_b on the change in ambient temperature to use it as a temperature sensor. This relationship is shown in figure 8.

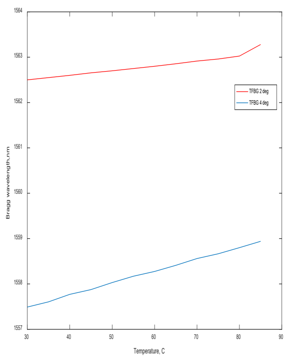

Figure 8 – Dependence of the Brag wavelength on the ambient temperature

In this paper, laboratory measurements are organized to determine the regularity of temperature dependence of the sensor based on the selected brag grid, according to which the normalized spectrum of each TFBG is obtained in Matlab. Since the main function of the model is the connecting link between grid developers and users, the correspondence of real mathematical calculations and paramatres is put first.

Conclusion

In this paper, the study of a temperature sensor based on a Bragg grating. The main characteristics of the Bragg grating, the characteristics of the main parameters used in its creation were studied, in particular, literary reviews of scientific works directly related to the problems raised on the topic were determined, works related to the assembly and operation of sensors for recording various phenomena in society using the Bragg grating were determined.

Based on the purpose of the work, the need for several main tasks is defined, as follows:

1 An overview of the conducted scientific papers on the main characteristics of the Bragg grating sensor is presented;

2 The laws of temperature dependence of the sensor wavelength based on an inclined brag grid recorded on a single-mode fiber with an angle of inclination of 2^0 and 4^0 are determined;

3 In order to identify these patterns, the organization of an experimental laboratory and the spectral characteristics of the sensor in temperature ranges were approved.

The linear dependence obtained as a result of this work was observed only at a short range of wavelengths. This interval can make it difficult to use the TFBG as a sensor with tilt angles of 2^0 and 4^0. Therefore, the goal of future work will be to increase the tilt angle of the TFBG and reconstruct this work.

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КӨЛБЕУЛІК БҰРЫШТАРЫ 2° ЖӘНЕ 4° БОЛАТЫН TFBG ТЕМПЕРАТУРАЛЫҚ ТӘУЕЛДІЛІГІН ЗЕРТТЕУ

Электромагниттік тұрақтылық, беріктілік, төзімділік және жоғары сезімталдық сияқты бірнеше артықшылықтардың арқасында талшықты Брэгг торлары әртүрлі шамалардың сенсорлары ретінде кең қолдануды тапты. Мұндай құрылғылардың желісінде көлбеу соққылары бар Брэгг торлары ерекше орын алады (tilted fiber Bragg grating - TFBG). Қазіргі уақытта TFBG екі фазалы ағындардың жылдамдығын бағалау үшін, бұралуға жоғары сезімталдықты көрсететін бұралу сенсорын құру үшін температура мен деформация датчиктері және т. б. қолданылады.

Бұл мақалада бірмодалы оптоталшыққа 2°және 4° көлбеу бұрышы бар көлбеу Брэгг торының негізінде температура сенсорын іске асыру мүмкіндігі қарастырылған. Ол үшін Брэгг резонансының толқын ұзындығының 2° және 4° көлбеу бұрыштары бар TFBG үшін температураға тәуелділігі, оны температура сенсоры ретінде пайдалану мүмкіндігі туралы эксперименттік зерттеулер жүргізілді. Торлардың периоды-540 нм және ұзындығы –10 мм. Температура 30 °С-тан 85 °С-қа дейін, 5 градус қадаммен өзгерді.

Эксперимент нәтижелері болып көлбеу Брэгг торларын температура сенсоры ретінде пайдалану үшін Брэгг резонансының толқын ұзындығының минималды мәнінің $\lambda_Б$ қоршаған орта температурасының өзгеруіне сызықтық тәуелділігін табу табылады.

Кілтті сөздер: Оптикалық талшықтар, талшықты-оптикалық сенсорлар, көлбеу Брэгг торлары, температура сенсорлары, тор периоды, толқын ұзындық

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ИССЛЕДОВАНИЕ ТЕМПЕРАТУРНОЙ ЗАВИСИМОСТИ TFBG С УГЛАМИ НАКЛОНА 2° И 4°

Благодаря преимуществам, таким как электромагнитная устойчивость, долговечность, высокая чувствительность волоконно Брэгговские решетки нашли применение в качестве датчиков физических величин. Особое место в линейке подобных устройств занимают Брэгговские решетки с наклонными штрихами (Tilted fiber Bragg grating- TFBG). На данный момент TFBG используются для оценки скорости двухфазных потоков, для создания датчика скручивания, в качестве датчиков температуры и деформации и т.д.

В данной статье расматривается возможность реализации датчика температуры на основе TFBG с углом наклона 2° и 4° вписанных в одновомодовое оптоволокно. Для этого проведены экспериментальные исследования зависимости длины волны резонанса Брэгга от температуры. Период решеток равен 540 нм и длина 10 мм. Температура варьировалась от 30 °С до 85 °С с шагом в 5 градусов.

Результатами эксперимента является нахождение линейной зависимости минимума длины волны резонанса Брэгга $\lambda_Б$ от изменения температуры окружающей среды.

Ключевые слова: Оптоволокно, оптоволоконные датчики, наклонные Брэгговские решетки, температурные сенсоры, период решетки, длина волны

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