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Fiber sensors based on the Bragg gratings in security systems

***Abstract**. Fiber optic sensors have a number of advantages, the most important of which are resistance to electromagnetic interference, low weight and the ability to be embedded in the measured structure. The most promising are sensors based on fiber Bragg gratings. They have a number of advantages, for example they allow to create distributed measurement arrays that contain multiple sensors. In addition, they are insensitive to vibrations of the optical power source. The variety of applications for fiber Bragg grating based sensors has resulted in production of Bragg fiber grating with different spectral characteristics. Homogeneous fiber Bragg gratings have sharp side spectra that can influence the processing characteristics of a temperature sensor. An apodization method is used to align the side lobes, which is one of the means of modifying the spectral shape.*

***Streszczenie.** Czujniki światłowodowe posiadają szereg zalet, z których najważniejsze to odporność na zakłócenia elektromagnetyczne, niska waga i możliwość wbudowania w mierzoną strukturę. Najbardziej obiecujące są czujniki oparte na światłowodowej siatce Bragga. Mają one szereg zalet, np. pozwalają na tworzenie rozproszonych macierzy pomiarowych, które zawierają wiele czujników. Ponadto są one niewrażliwe na drgania źródła zasilania optycznego. Różnorodność zastosowań czujników z światłowodowymi siatkami Bragga spowodowała, że produkowane są siatki o różnych charakterystykach spektralnych. W siatkach jednorodnych granice widma są bardzo ostre, mogą wpływać na charakterystykę przetwarzania czujnika temperatury. Do wyrównania wstęg bocznych stosuje się metodę apodyzacji, która jest jednym ze sposobów modyfikacji kształtu spektrum. (**Czujniki światłowodowe oparte na siatkach Bragga w systemach bezpieczeństwa**)*

Keywords: fiber sensors, fiber Bragg gratings, security system, apodization.
Słowa kluczowe: czujniki światłowodowe, światłowody siatki Bragga, system bezpieczeństwa, apodyzacja.

Introduction

Fiber optic sensors have significant advantages over traditional devices. They have high mechanical strength, resistance to elevated temperatures, vibrations and other environmental influences, the absence of electromagnetic interference, they are chemically inert, allow contactless and remote measurements. Fiber-optic sensors can conditionally be divided into three types: point, distributed and quasi-distributed [1, 3-5]. Point sensors allow you to measure and control parameters at a specific point in the object, like most non-fiber sensors. As a rule, such sensors are small in size and have high measurement accuracy. Most often, point sensors based on Bragg fiber gratings, long-period gratings and interferometers are used. They can be used as local thermometers, strain gauges, pressure sensors, accelerometers, etc. The indisputable advantage of distributed sensors is the ability to constantly monitor the parameters along the length (volume) of the object at any point where the fiber sensor is installed. The principle of operation of such sensor systems is based on the analysis of parameter changes along the waveguide and non-linear effects. The disadvantage of the distribution of the measured parameter along the length is the relatively low accuracy of determining the localization of disturbances (several meters long) and the relatively low accuracy of measuring the value. Distributed sensor systems can be used to monitor large areas, such as radiation and temperature sensors, allow you to analyze temperature gradients, etc.

Measuring systems based on quasi-distributed sensors combine the advantages of the first two schemes. A quasi-distributed sensor is an array of point sensor elements combined by one common waveguide. Each element has its own unique characteristics, which allows you to analyze its state independently of other sensory elements. The accuracy of such systems is determined by the accuracy of individual sensors, and an array can combine more than 100 elements. Sensor arrays allow you to control complex objects, engineering structures, bridges, tunnels, hulls of ships and aircraft, oil wells, etc., analyze the gradient of the distribution of temperature, loads, pressure, control a large number of point objects. However, quasi-distributed sensors still do not allow measurements at an arbitrary point on the object along the entire length of the fiber, and thus do not replace completely distributed sensors. In addition, to transmit data from a set of sensors over a single fiber, it is necessary to use signal multiplexing systems and a set of photodetectors. In addition, the number of sensor elements is limited by the number of channels along wavelengths.

Fiber sensors for security systems

Currently, such sensors are increasingly used in modern security systems. A security system is a combination of means and methods of maintaining a safe condition of an object, preventing, detecting and eliminating threats to life, health and the environment, property and information. Today, technical means of protection are very diverse and generally very effective. However, almost all of them have one significant drawback: they detect an intrusion signal only after an attacker penetrates the territory of the object.

A simple example of this is video surveillance systems. These systems, for the most part, with the help of video recorders can confirm the fact of an invasion only after it has already occurred. Often, an attacker relies on this delay, which passes from the moment of penetration to the object until an alarm is triggered.

The root factor determining the effectiveness of any security system is the minimization of this time interval, and in this sense, the attractiveness of perimeter security systems that record the fact of border crossing in real time is undeniable. These requirements are met by the most modern and efficient systems - fiber optic security systems.

The use of fiber optic technology in security systems is determined by several factors. As mentioned above, these sensors are immune to electromagnetic radiation and are electrically safe. Security systems with fiber optic sensors use different physical effects. But the technical implementation is one. A miniature semiconductor laser that generates coherent radiation is connected to one end of the cable. The second end of the cable is connected to the radiation receiver. The receiver converts the optical signal into an electrical one and feeds it to the analyzer. The analyzer compares the received signal with the reference, that is, with the signal from the sensor without any impact on it. When a fiber-optic cable is deformed, its optical parameters change, namely: the refractive index and characteristics of the laser radiation passing through the fiber. If the received and reference signals are different, the device registers an external mechanical effect on the fiber optic sensor (displacement, vibration, cable compression). The sensor cable of existing fiber optic security systems is usually mounted on a metal fence. The vibrations of the fence are transmitted to the sensitive optical fiber and affect the properties of the light wave, which at the output of the sensitive cable is converted into electrical signals that are sent to the processor. The processor, in accordance with a predetermined algorithm, emits an intrusion signal against ambient noise and generates an alarm.

Today, another type of security system has appeared and is actively developing, in which a more modern and promising method of signal registration is used, based on the use of Bragg gratings used in fiber sensors.

The Fiber Bragg gratings (FBG) is a region with periodic modulation of the refractive index of the fiber core. When light propagates in such a structure, it is reflected. The grating period determines the wavelength at which constructive interference of reflected light will occur.

The fiber Bragg gratings is a cross section of a fiber waveguide (usually a single-mode fiber), in the structure of which a periodic structure of the refractive index with a period Λ with a certain spatial distribution is induced. As a rule, fiber Bragg gratings have a length of the order of several millimeters or centimeters [6].

Figure 1 shows the basic principle of FBG operation with an indication of a typical profile refractive index.

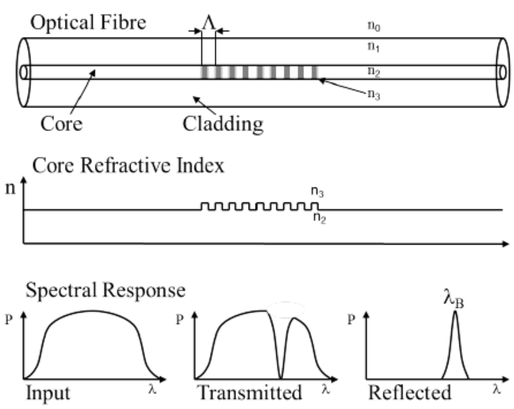

Fig.1. The principle of operation of FBG

One of the main advantages of fiber Bragg gratings is a unique way to convert the measured value into a change in the wavelength of radiation passing through and/or reflected from the grating, as well as ease of manufacture. FBG are well established and widely used in construction, oil production, energy, aerospace engineering, etc.

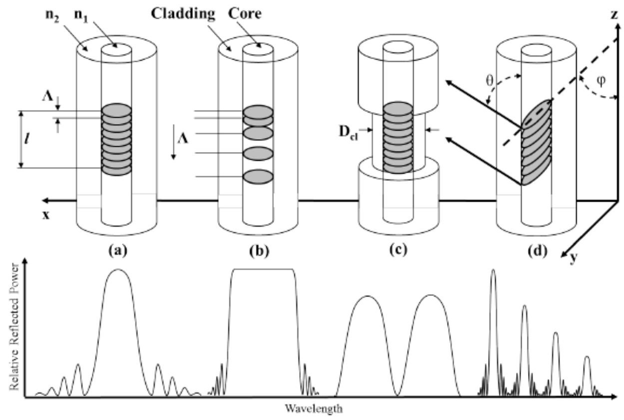

Fig.2. Various types of gratings and their spectral characteristics

There are three types of gratings that differ in photosensitivity and, consequently, index changes. They are known as types I, II, and IIA with a detailed description of each type in [7]. In addition, there are various physical types of lattices, such as inclined, apodized, long-period, and twitter. The structure and profile of the refractive index of some different types are shown in Figure 2.

Many factors contribute to the active use of FBG in various fields: miniature – individual structures have an outer diameter of the working part of less than 100 microns, which allows them to be used in hard-to-reach places without significant structural changes. In the devices in which they operate, the temperature response is a multiplicative response, humidity, mechanical loads, etc., the absence of electromagnetic interference, the preservation of performance, in case of various coatings at a temperature from –100 to +300°C, etc.

2. The principle of the system

Let us consider the principle of operation of a fiber optic system based on the fiber Bragg grating. The principle of the system is as follows. The Bragg reflective gratings in the core of a single-mode optical fiber can be created by ultraviolet radiation of an excimer laser by irradiation through an appropriate mask or by a holographic method (under the action of two interfering rays). The optical fiber segment between the two Bragg gratings is an interferometer whose reflection (and transmission) depends on the optical phase difference reflected from the first and second gratings of the optical signal. Under the influence of deformation and acoustic vibrations, the phase difference of two rays reflected from two neighboring gratings changes. As a result, the interference pattern of two reflected rays changes.

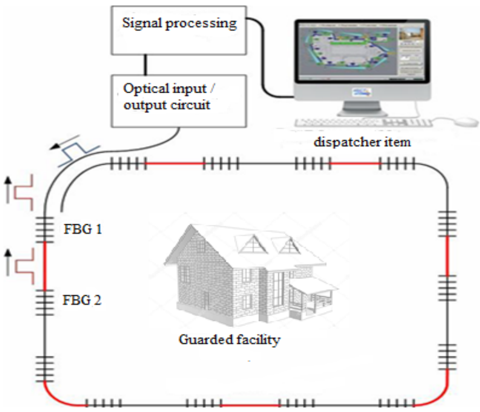

Fig.3. The principle of operation of a fiber-optic security system based on Bragg gratings

Interferometric sensors are most sensitive to changes in fiber segment length due to external factors. A single-frequency single-mode semiconductor laser operating in a pulsed mode is used as a radiation source. The pulses from each lattice system come with a different delay. To separate the signals from each section, time multiplexing is used. For signal demodulation, synchronous detection is used; for this, a phase modulator is introduced into the circuit. The optical delay line forms a series of time-shifted pulses, each of which interferes with the pulse reflected from the corresponding part of the fiber. Fiber coating material plays an important role in the real application of such fiber-optic security systems. It provides an increase in the sensitivity of the sensor by 30dB compared to uncoated fiber.

Structurally, the fiber-optic security system based on Bragg gratings consists of the active part (radiation inputoutput unit and information processing board) and passive. The fiber-optic security system based on Bragg gratings is universal, because it is a single cable and does not contain active elements in the multi-zone section. Therefore, this system can be used both covertly (underground) and on existing fences along the perimeter of the protected area. A feature of such security and monitoring systems is not only the ability to determine the exact location of the violation of the protected border, but also the identification and identification of the intruder by analyzing the acoustic spectrum of the intruder's noise

3. Experimental results

Various configurations of fiber Bragg gratings can be applied. We will consider apodized fiber Bragg gratings as they are the most effective for security systems. The parameter, making the certain influence at the Bragg grating spectrum is apodization. In the simplest case we differentiate homogeneous gratings, in which the modulation depth of interference fringes fracturing factor is the same along the structure's whole length. Multitude of the fiber-optic homogeneous structures definite applications made introducing the apodised function into their production methods, which led to modulation variable depth of grating fringes refraction index.

One of the most frequently used interrogation methods of temperature sensor based on the Bragg fiber gratings is the filtration by means of the second grating with the same wave length, having been created in the identical primary conditions [12]. In such system an important parameter, conditioning the given cyclical structure's practicality is the minimization of the so called side lobes [13]. One of the means to reach the effect thereof is the apodization through changing the modulation depth of refraction factor alterations in the core of the optical fiber along its axis. Cyclical structures production with any apodization functions often linked with the necessity to redesign the system and therefore the possibility to use mathematical models for simulating grating spectrum with a denoted apodization is justified.

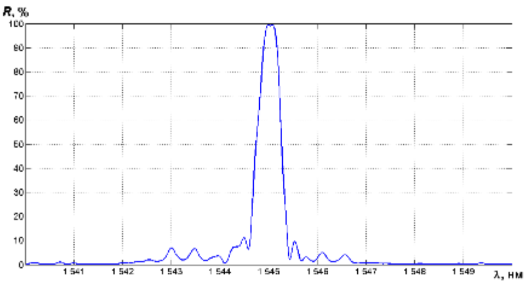

Fig. 4. The reflection spectrum of the apodized Bragg grating

In our case, we can use apodized fiber Bragg gratings with different periods, capable of reflecting radiation at different wavelengths. So, for the central resonant reflection wavelength λ_w = 1550 nm, the width of the FBG reflection spectrum is 1–2 nm at the base for single-mode wavelengths and can reach values up to 10 nm when forming the FBG in multimode wavelengths, and the reflection coefficient at the resonant wavelength is 0.92. In this case, the attenuation of neighboring lobes in the diagram of the relative spectral reflectance of the FBG is at least 30 dB.

4. Conclusions

Fiber sensors are widely used for security systems. The undoubted advantages of fiber-optic systems include their immunity to electromagnetic radiation and electrical safety. Fiber sensors built from dielectric elements can be used not only on fences or walls, but also on explosive objects or under water. Namely, the use of fiber sensors based on Bragg gratings.

The maximum length of one security zone can reach tens of kilometers. An attractive feature of the systems is the lack of active electronic equipment; this reduces the cost of installing and maintaining the security system.

The security system on the Bragg gratings is devoid of most of the shortcomings of the sensors and surpasses most of the existing analogues in all its characteristics. At the same time, the most interesting is the use of this system as an underground system, which will allow secretly monitoring all objects crossing the security zone, as well as creating multi-level security systems.

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