ABSTRACT

dissertation for the PhD degree by specialty 6D071900 – “Radio engineering, electronics and telecommunications”

ORAZALIYEVA SANDUGASH KUDAYBERGENOVNA

Analysis of the effect of photosensitization on the spectral characteristics of fiber-optic Bragg gratings

Relevance of the topic.

The oil and gas industry occupies a special place in the energy system of Kazakhstan. With the development of the fuel and energy complex, the extraction of hydrocarbon raw materials, the joint deformation of the underground pipeline and the ground mass in complicated conditions is a little-studied problem, which often leads to accidental destruction of the pipeline.

In modern engineering geology, the analysis of terabytes and even petabytes of seismic, geophysical, and field data becomes an everyday task.

The above determines the need to monitor the stress state of the pipe walls, in order to quickly apply preventive measures.

The most complete and promising technical solution for extreme operating conditions is the use of optical measurement principles, on which fiber-optic sensors (FOS) are based. The use of sensitive optical fibers as sensors and measuring communication lines is an effective solution for both the mechanical properties and the radiation resistance properties of optical fibers.

According to the “Digital Kazakhstan” Program, bringing fibre-optic connection lines (FOCL) to more than two thousands rural settlements is planned by the end of 2021.

Nowadays, fiber Bragg gratings derived from photoinduced, doped with a high concentration of germanium oxide GeO2 (35 mol%) optical fibers are widely used as highly sensitive temperature and strain sensors, as cutting filters in the telecommunications industry, multiplexers/demultiplexers with an optical circulator, as an optical I/O multiplexer. However, it is worth noting the significant drawback is that the technology for manufacturing optical fibers doped with germanium is expensive. When writing Bragg gratings in a standard SMF-28 telecommunication fiber, when the molar concentration of germanium in the fiber core is from 3% to 5%, interference occurs due to very low and insufficient light sensitivity for efficient recording of refractive index (RI) gratings. Thus, the consideration of existing methods for solving the problem of low photosensitivity matters, which prevents the recording of a fiber Bragg grating (FBG) with the required characteristic on an optical fiber, as well as a comparison of the advantages and disadvantages of these methods.

In this regard, the writing of highly sensitive Bragg gratings in a standard telecommunication optical fiber by photosensitivity and an increase in the spectral characteristics of fiber Bragg gratings are the important and urgent issues.

Objective of the work. Creation of a new version of a fiber Bragg grating based on an experimental study with an effective parameter of spectral characteristics by photosensibility of a standard telecommunication optical fiber.

Tasks of studies. According to the objective of the work, this work identifies the following scientific tasks that need to be solved:

1. Analyze the existing methods of writing a fiber Bragg grating and choose the appropriate method;
2. Research the photosensibility process of optical fibers;
3. Increasing the light sensitivity of optical fibers based on an experiment for recording a fiber-optic Bragg grating with an effective spectral characteristic;
4. Experimental comparison of the spectral characteristics of fiber Bragg gratings based on optical fibers, highly sensitive doped with germanium oxide and pre-saturated in hydrogen according to the experimental results;
5. Development of a model of a fiber-optic Bragg grating using the MatLab software environment.

Research object: fiber-optic Bragg grating.

Research methods. To solve the tasks posed, we used classical methods of the theory of signal distribution, methods of numerical, experimental modeling.

The scientific novelty of the work consists of the following:

1. For the first time, a block diagram of a measuring system for recording a fiber Bragg grating on a hydrogen-saturated standard telecommunication optical fiber was created.;
2. For the first time, a method for recording a photosensitive fiber Bragg grating with an effective spectral characteristic on a standard telecommunication optical fiber preliminarily saturated in hydrogen has been developed;
3. The effective exposure time for recording a fiber Bragg grating with an ArF excimer laser (193 nm) by saturating optical fibers in hydrogen for several days has been experimentally established for the first time;
4. For the first time, the spectral characteristics of a fiber-optic Bragg grating, recorded on a high-sensitivity optical fiber, the core of which is doped with germanium oxide, and the spectral characteristics of fiber-optic Bragg gratings, recorded by preliminary hydrogenation of a standard telecommunication optical fibe were compared;
5. A simulation model of a fiber-optic Bragg grating was developed and processed in the MatLab system.

The practical significance of the work lies in the fact that the experimental results obtained make it possible to use the Bragg fiber lattice recorded on a standard telecommunications optical fiber saturated with hydrogen in the field of telecommunications, seismology, engineering geology as fiber-optic sensors of pressure, temperature, rotation and rotation, also under extreme environmental conditions in measuring devices for direct measurement of the influence of external pressure, temperature and seismic vibrations and flow.

Personal investment of the author. All original results presented in the dissertation were obtained by the author with direct participation in the experiment..

Approbation of the work. The main results of the work were reported and discussed at the X International Scientific and Technical Conference dedicated to the memory of the first rector Gumarbek Daukeev in Almaty, at the international conference "16th INTERNATIONAL SCIENTIFIC CONFERENCE INFORMATION TECHNOLOGIES AND MANAGEMENT 2018" (Riga, Latvia), at the international foreign conference "International Conference on Information Science and Communications Technologies ICISCT 2019" (Tashkent, Uzbekistan), at the international conference "XLIV-nd IEEE-SPIE Joint Symposium Wilga 2019" (Wilga, Poland).

Implementation of research results. The results of this study are implemented in the Laboratory of "Optoelectronics" of the Lublin University of Technology (Lublin, Poland), in the research of methods for recording Bragg gratings, spectral characteristics, the process of photosensitization and its influence on the spectral characteristics of fiber Bragg gratings, and as a training material for the discipline "Measuring transducers" for the study of elements of fiber-optic sensors at the Department of "Electronics and Robotics" of the Almaty University of Energy and Communications named after Gumarbek Daukeev.

Publications. Based on the main results of the research and development performed, more than 10 scientific works were prepared and published, 9 of which works were published in publications included in the international Scopus database, 3 works were published in publications recommended by the Committee for Control in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan.

The structure and scope of the thesis: the thesis consists of an introduction, four chapters of the main content, conclusions and appendices, a bibliographic list of 146 titles and consists of 120 pages, 53 figures and 10 tables.

The introduction substantiates the relevance of the topic of the dissertation, formulates the goal and objectives of the study, defines the scientific novelty, practical significance and provides the main provisions of the work submitted for defense.

In the first chapter, a review of the main methods of recording diffractive structures in optical fibers is carried out, and modern achievements in the formation of refractive index gratings using various sources of recording radiation are considered.

An overview of the main methods of recording FBGs (step-by-step method, phase mask (PM) and interferometric method) is given and a comparative characteristic is given. Due to a number of advantages, such as ease of use, the possibility of single-pulse recording, constant period, the phase mask method is chosen for recording a fiber Bragg grating. In addition, this section discusses the radiation of ultraviolet laser systems and describes the efficiency of the application of radiation from ArF excimer lasers..

In the second chapter, the physics of the formation of a fiber Bragg lattice under the action of optical radiation is analyzed. The influence of the production conditions of a fiber light guide on the concentration of primary defects of the optical fiber responsible for photosensitivity is investigated. A review of studies on

the photosensitivity of germanium-silicate optical fibers is carried out. Models of the formation of a fiber Bragg lattice under the action of optical radiation are briefly described.

Methods of increasing the photosensitivity of standard optical fibers are described: increasing the concentration of germanium dioxide in the fiber core, doping with such chemical elements as boron, tin, nitrogen, phosphorus, antimony. However, despite the fact that a number of compositions with high photosensitivity are proposed, there are disadvantages that arise in the doping process. In order to increase the photosensitivity of optical fibers without significantly changing their specific characteristics, the dissertation paper proposes the saturation of standard telecommunications fibers with hydrogen, which can significantly increase the refractive index of standard optical fibers.

This section also describes the mechanism of photoinduction of fiber Bragg gratings by femtosecond laser pulses and provides a comparative analysis of the dynamics of the growth of the PP lattice under the irradiation of OM by femtosecond and nanosecond laser pulses.

In the third chapter, a method for recording fiber Bragg gratings in a standard telecommunications single-mode optical fiber using the photosensitization process is developed. For this purpose, the laboratory "Optoelectronics" of the Lublin University of Technology used a measuring system to record the types of fiber Bragg gratings on optical fibers and to study the influence of various factors on the spectral characteristics.

To achieve this goal in the dissertation work, a block diagram of an experimental setup for recording a fiber Bragg grating is constructed on the basis of this measuring system.

The experiment used photosensitive optical fibers, the core of which is doped with germanium (35 mol%), and standard telecommunications single-mode optical fibers.

Several standard telecommunications optical fibers with a length of 10 m were placed in a hydrogen chamber for 20 days, under a pressure in the chamber of 180 bar and a temperature of 25^0C. The fiber Bragg grating was formed by a 100 MJ excimer laser operating at a wavelength of 193 nm at a frequency of 100 Hz during the exposure time of 15s, 30s, and 60s. The spectral characteristics of the induced structure are obtained from the results of experimental measurements using the Yokogawa AQ6370D spectrum analyzer.

The depth of modulation of the refractive index depends on the time of saturation of the optical fiber with hydrogen.

There is a significant shift in the VBR wavelength with an increase in the exposure time and an increase in the depth of modulation of the refractive index, depending on the time spent by the optical fiber in hydrogen.

To evaluate the effectiveness of the experimental results obtained, a comparison was made with an optical fiber with high photosensitivity. To do this, a photosensitive optical fiber, the core of which is doped with germanium (35 mol%), is recorded by the VBR method described above.

All experimental measurements were carried out in the wavelength range of 1545.6 – 1555 nm with a step of 0.02.

According to the results of the experiment, the amplitude Δn of the Bragg lattice refractive index modulation and the wavelength of the Bragg resonance were determined for a standard telecommunications OM doped with germanium and pre-saturated with hydrogen.

The greater the reflection coefficient of the fiber Bragg grating, the greater the modulation depth of the PP.

Under the influence of UV radiation in the presence of hydrogen, the photosensitivity of the fiber increases. The amplitude of the modulation of the PP VBR obtained during the exposure time of 60 s of the pre-saturated fiber Bragg lattice in hydrogen was effective Δn=1.2. And the modulation amplitude of the induced PP VBR recorded in the germanium-doped OM is Δn=0.8. This proves that within 12 days it is possible to increase its photosensitivity by recording the VBR on the OM with a sufficient level of saturation in hydrogen.

The article describes the use of an experimentally obtained photosensitive optical fiber with a Bragg grating as a fiber-optic sensor of temperature, rotation and rotation for solving monitoring problems in engineering geology.

In the fourth chapter, the main methods of mathematical description of Bragg fiber lattices are considered and analyzed. In the MatLab environment, a matrix method for solving coupled mode equations is implemented, which is used to model fiber Bragg lattices.

The effective coefficients of the refractive index of the UBR obtained by experiment (n_{eff}=1.438) and simulation (n_{eff}=1.442) are compared.

Confirmation of the results of modeling the spectral characteristics of lattices by experimental studies (for selected lattices) shows the validity of the application of the matrix transfer method for analyzing the spectral properties of lattices and proves the possibility of their use for sensor applications.

In the conclusion of the dissertation, the main results of the work based on the results of the presented and discussed developments and research are summed up.