ABSTRACT

Dissertation for the degree of Doctor of Philosophy (PhD) in the specialty 6D071600 – Instrumentation

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Development and research of the combined temperature and humidity sensors

General characteristics of the work. The latest developments and applications in the field of production in a strict environmental zone using fiber bragg gratings by laser radiation, as well as certain prerequisites of the theory of femtosecond interaction between the laser and materials are analyzed. The exposure conditions were analyzed in accordance with the Bragg grating developed on optical fibers based on silicon dioxide by femtosecond infrared and visible lasers using a phase mask or the point-by-point method. Using the specific geometry of the fiber Bragg grating and fibers allows to take into account various light parameters. Pure silicon dioxide, fluoride doped radiation-resistant dioxide, or photonic crystal fiber and fiberglass sensors with pure silicon dioxide are less damaged in the oil and gas industry from hydrogen penetration, radiation ionization, and therefore can be used in the nuclear industry. At a temperature of above 1300°C, gem is detected using bragg grating in the optical fiber. FBG sapphire jet engines are suitable for strict combustion conditions in the coal gasification reactors and power generation, natural gas turbines.

To determine the humidity based on crystalline fibers, numerous types of fiber sensors presented. Application of optical fiber to temperature measurement methods shown. Optical fiber based on Bragg grating reflections and Fabry-Perot interferometers, homogeneous optical fibers are discussed in publications. The loss of agrose gel is low, the fabrication is easy and has good performance in the corresponding calculations, therefore it is widely used for relative humidity. To improve the optical sensitivity of fiber-optical fibers, they are made of hygroscopic materials, such as: Agrose gel, graphene oxide, polyvinyl alcohol, SiO2, WS2 and SiO2, WS2, etc. Currently, many optical sensors function with a passive and broadband light source. In recent years, sensors based on the internal sensitivity of optical laser have been extensively studied, since their spectral resonance improved peak visibility and throughput reached 3 dB. Thanks to the development of internal sensitivity based on optical fiber-optic lasers, the sensor-to-noise ratio improved, and 3 dB throughput in a narrow range increased the capacity of the sensor circuit.

Based on these analyzes, operation of the sensor proposed in the thesis paper is based on two basic sensitivities: agrose reflection, which is sensitive to humidity using the Fabry-Perot interferometer method. Bragg fibers of fiber optic gratings with a deformational change of the fiber, depending on temperature variation is based on certain reflection spectrum of the inverse effect.

Preparation of agrose gel for humidity sensors. Currently, many materials, such as metal oxides, graphene, divinylbenzene and cellulose are used to create moisture-sensitive materials. These sensitive materials are usually divided into inorganic semiconductor materials and organic polymer materials. However, no humidity sensor

meets all requirements for sensors, such as a wide range of operating temperature, good linearity, high sensitivity, low hysteresis, fast operation and recovery time, easy activation and stability. Therefore, in recent years, many studies of moisture-sensitive materials are carried out with focus on inorganic semiconductor materials and organic polymer materials, in particular, hybrid composites, which mutually eliminate their disadvantages, rationally combining their respective advantages. In addition, there is evidence that the sensors based on nanostructures have good sensitive properties than large copies of ortonal film, due to the fact that the surface-volume ration is quite large. Until now, various CdS nanostructures have successfully synthesized and their sensitive properties are actively studied. Remote monitoring using the above optical sensors is possible. To create active sensors based on a laser TBT structure with femtosecond infrared radiation (FS-IR), it is necessary to use active fibers doped with rare alkaline elements. FBG with inner core for active fiber can be used as a resonator mirror in a fiber laser or used as NIR with a common configuration from the Bragg reflector or feedback. These active sensor based on fiber laser are implemented only using type I FBG. For high temperature conditions or high optical power, type I FBG does not withstand rough conditions. Thermally resistant regenerated meshes were used to create a cavity of the fiber laser that are capable to operate at high temperature. As a rule, regenerated gratings have low reflection and accordingly, some resonator settings of the laser fiber are not appropriate.

Femtosecond laser FBG is manifested in special properties developed by various methods, and can also be used under strict conditions for various zone applications. Regenerated Bragg gratings are one of the thermally stable FBG structures that provide for temperature measurement using a femtosecond mesh as a permanent alternative in temperature.

The spectral response of the Fabry-Perot resonator is based on the interference between the illumination placed on it and the illumination around the resonator. Two laser phases reflected in the structural interference result in resonant improvement of illumination inside the resonator. If the phase of the two beams is opposite, then the switched on light attenuates and a certain part remains inside the resonator. The remaining light passing through the glass changes in the spectral form in comparison with the reflected light. According to this basic principle, we used a thin moisture-sensitive film instead of the second mirror, the principle of moisture determination in accordance with the increased illumination. Mathematical modules of fiber-optic sensors for measuring humidity in units of temperature and humidity were developed. Following the results of the experiment, the measuring range of the sensor discussed.

Actuality of work. Temperature and humidity sensors are widely used in the process control of microelectronic production, chemistry, biology, meteorology, electronics, automobile meteorology, agriculture, power supply systems and many areas of measurement and control of medical equipment. Currently, there are many digital sensors using different physical principles. However, it is necessary to further improve the sensitivity, selectivity, reliability and response time of the sensors.

In connection with the constant improvement of technical processes, strict requirements for product quality and energy saving, raising of quality and quantity requirements in the field of electronics, film technology, materials science, air quality, that is, humidity and temperature are becoming one of the most crucial issues.

When implanted electronic devices intended for operation in a humid environment enter the body, condensation and corrosion due to humidity occur in the core of the integrated circuit. This will entail loss of efficiency of this tool and the device will not work. The most direct way to check the dryness of microcable functions is to use a sensor to measure its internal relative humidity. Currently, the chip has an additional humidity sensor based on a metal-oxide semiconductor with electronics. It is covered with a layer of inorganic passivation, has a mutually separated capacitor, covered with a polyimide palpak, humidity sensor. It requires advanced processing steps. At the same time, the zone required for the sensor is very large (4~2 mm). For example, stimulators implanted by microapparatus should supply a small sensor. Our goal is that the sensor, which measures temperature and humidity in units, must be simplified and requires that the necessary area of the chip was significantly reduced and jointly determine the relative humidity and temperature.

Familiarization with temperature and humidity measuring methods, types of temperature and humidity sensors and analyzing them. Currently, there are operating sensors measuring humidity and temperature in units. However, a sensor measuring humidity and temperature based on optical fiber in a single measurement was studied with interest due to its high sensitivity, fast response, compact size and advantages such as anti-electromagnetic resistance.

Fiber-optic sensors do not accept internal electromagnetic effects. Fiber-optic materials are widely used and cheap materials. Currently, the price of quartz fiber-optics is lower than the price of copper wire.

In recent years, sensors based on the internal sensitivity of optical laser have been extensively studied, since their spectral resonance improved peak visibility and throughput reached 3 dB. Thanks to the development of internal sensitivity based on optical fiber-optic lasers, the sensor-to-noise ratio improved, and 3 dB throughput in a narrow range increased the capacity of the sensor circuit.

Purpose and tasks of work. Analysis of the temperature and humidity sensor based on the internal sensitivity of the fiber optic laser

In the course of the study, it is necessary to address the following problems:

1. Overview of basic research papers, relevant to the subject of research work used in environmental sensing based on the optical fiber laser;
2. Monitoring the temperature variation by analyzing the phase displacementt of the femtosecond laser emanating from the Bragg gratings placed in a fiber with a functional variance factor depending on the temperature in the optical unidirection mode.
3. Moisture determination as a result of resonant amplification under the influence of moisture-sensitive agrose gel, based on FPI interferometer.
4. Test in practice using mathematical models, temperature and humidity measuring methods based optical fiber are considered.

New concepts for defense:

1. Fiber optical unidirection mode and it includes the Bragg grating, the cross section of which is covered with semi-reflex glass and is connected to the vacuum

cavity of FPI. FPI contains moisture-sensitive agrose gel in the vacuum cavity, prepared by pouring into the silicon diaphragm. The anterior and posterior cavity, defined by the length h, has two reflective surfaces, while the second is moisture-sensitive agrose gel. This is the definition of moisture variation through change of the interference between illumination from two surfaces.

2. Analysis of temperature determination method with a phase displacement of the femtosecond laser with reverse bias from the Bragg gratings placed in a functionally varying fiber depending on the temperature in the optical unidirection mode.

3. Providing operation of microcontrollers, immunity to internal electromagnetic effects, temperature and humidity measured in units, based on the experimental results made on the basis of the above analyzes.

4. Determination of the measurement range of the temperature and humidity sensors based on the experimental and actually given values.

Object of research. Determine the operation of the sensor for that measures the temperature and humidity based on the internal sensitivity of the optical fiber laser.

The method presented in the study. Detection a humidity sensitivity based on Fabry–Perot interferometer (FPI). Intracavity sensing of an optical fiber is proposed and experimentally demonstrated. Characterized the optical fiber sensor sensitivity mechanism and its sensitivity. The analysis for the change in the strain of the fibers, depending on the temperature, based on the fiber Bragg grating (FBT) reflective effect. Providing the principle of working optical fiber sensor, which measures the humidity and temperature by uniformity based on these analyzes.

Approbation of paper. Main findings and research results of the dissertation presented at the conferences listed below:

Published at the XII International Scientific and Practical Internet Conference “Youth, Science and Innovation” (Penza 2016);

Non-state educational institution of continuing professional education. At the conference published by the Project Management Institute (St. Petersburg 2016);

International Scientific and Technical Conference “Winter scientific readings” (Ukraine, Kiev 2016)

International Scientific and Technical Conference “Education, scientific and practical modern information and telecommunication technologies” (Almaty, 2015);

Scientific and practical value. The scientific value of the thesis paper is the presentation of the immune sensor operation against microstructural electromagnetic effects, measured in units of temperature and humidity. The practical value of the research results is that the linear increase of the reflected resonance of VPI based on moisture-sensitive agro-gels depending on humidity, increased reliability of temperature determination by means of a phase displacement of the femtosecond laser and the inverse reflection of the Bragg gratings is based on the submission of the thesis paper results to international media. The practical value of the research results is to increase the reliability of temperature determination by means of a phase displacement of the femtosecond laser and submission of the thesis paper results to international media.

Article. In accordance with the topic of the thesis paper, 10 articles were published, 4 of them in scientific journals recommended by the Committee for Control of Education and Science, Ministry of Education and Science of the Republic of Kazakhstan, 1 in the publications included in the Scopus information base, 5 in the proceedings of international scientific conferences.

Volume and structure of paper. The dissertation consists of 70 pages and 5 tables from 122 pages. The work consists of an introduction to the literature review, research results and their analysis and conclusions. In the dissertation there are used 129 literature.

Reliability and validity of the results. Reliability and validity of the results of the thesis paper - all the experimental studies are consistent with modern scientific and theoretical methods based on the internal sensitivity of the optical fiber.

Based on the results of the dissertation research, the following conclusions. In the fabrication of the Fabry-Perot interferometer, the production of the silicon diaphragm employs mature micro-electromechanical system fabrication techniques, which provide capability of batch-production and we have reported in. The thickness of the silicon diaphragm is about 10 μm with dimension 2.5 mm × 2.5 mm. The two reflecting surfaces the medium in a vacuum environment. Then, the 2% Agarose gel deposited on the silicon diaphragm by a pipette. Agarose gel is prepared by dissolving the agroz powder in distilled water in the beaker. In the deposition process, the thickness of the Agarose is about 1μm.

In order to obtain the optimized SNR of the proposed humidity sensor, the sensor fabrication should ensure the spectral overlap between the peak in the spectrum of the FPI. In the experiments, the gain peak at about 1500 nm is selected for the intracavity sensing. Derived by and formula, the peak wavelength and the wavelength spacing of the FPI can be designed by changing the h length of the FP cavity. When the ambient humidity is 35 %RH, the reflection spectrum of the FPI is measured in Fig. 4 by an amplified spontaneous emission (1510 nm-1590 nm). In the reflection spectrum of the Fabry-Perot interferometer, the peak with maximum intensity is at about 1530 nm and the reflection loss is -12.2 dB. The change in temperature of the fiber Bragg grid, depending on the temperature, varies from -50 ° C to 130 ° C deformation ξ ranging from 8.75×10^{-4} m to 0.00122м.

Based on the FPI method, the relative humidity range is 20% -98% RH. As the ambient humidity changes, the output spectra of the optical fiber laser are measured. Output power of the optical fiber laser increases from -36.78 dBm to -22.61 dBm as the ambient humidity changes from 25%RH to 95%RH with the resolution of 10 %RH. The humidity sensitivity is measured to be 0.202 dB/%RH. It shows the sensor has a good linear response. Formula shows the humidity response of the proposed sensor is nonlinear. The refractive index of Agarose is measured to be from 1500 to 1520 as the ambient relative humidity increases from 20 % to 90 % . The result of the experiment showed that the sensor is linear response. The humidity and temperature resolution of the chamber is 2 %RH and ± 1 ° C . The estimated response time of the sensor is as fast as 72 ms. The recovery time is about 357 ms, which depends on the time of the humid air removed from the sensor.