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3D HOLOGRAM OPTICAL ELEMENT FOR ANGLE MEASURING DEVICES AND SIGHTING SYSTEMS

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Abstract. *In this work, a hologram optical element is proposed for optical-electronic angle measuring devices and sighting systems, which is a combination of four three-dimensional diffraction gratings registered in the volume of a photosensitive medium.*

The method of measuring the angular displacement and sighting of objects is based on the properties of changing the intensity of the information light signal of volumetric hologram optical elements, in accordance with the modulating effect of the object under study.

The sensitivity of the proposed device for the measurement range of ±150 ang. min was 5 ang.s. In sighting mode with a range of 3 ang. min. the sensitivity was 0.1 ang. s.

Key words: *optical element, crystals, hologram, optoelectronic device.*

Introduction.

Currently, high-precision remote measurements of angular displacements are carried out mainly with the help of optoelectronic angle measuring systems (OAMS), which are based on the autocollimation method of measurement [1]. The essence of this method is that the sent light flux with a known orientation is deflected by the object at the desired angle, due to which this flux acquires the necessary information. Of all the parameters of the light flux for remote measurement of the angular position of objects in the autocollimation method, only the property of rectilinear propagation of the light flux in a homogeneous medium and a change in its direction of propagation in accordance with the modulating effect of the object under study is used.

The results of measurements made using such OAMS largely depend on the parameters of the photoelectric converter (position-sensitive sensor) - a device that measures linear coordinates in the OAMS image plane and converts it into electric current (voltage).

To implement the measuring functions, the OAMS are equipped with various optical elements (lenses, prisms, diaphragms, etc.), mechanical and electromechanical units. Thus, obtaining the necessary data with the help of the OAMS is a multi-link procedure for the physical transformation of the information signal, which is a significant drawback, especially when building high-precision systems, since the presence of additional conversion links leads to an increase in the number of error components of this measuring system. Traditional methods of increasing accuracy, based on improving the stability of the characteristics of the elements of the measuring circuits and their converting links, have their limits and currently no longer lead to a further noticeable improvement in the quality of the OAMS.

Promising in this regard is the use of other measurement methods that would reduce the number of converting links. This can be, for example, a method for measuring the angular displacement of objects based on changing the intensity of the information light signal in accordance with the modulating effect of the object under study, and not on changing the spatial position of the light beam, as in the autocollimation method.

In this case, to implement the measuring functions of the OAMS, there is no need to use position-sensitive sensors - it is enough to use only photodetectors for photoelectric signal conversion, since the effect of information conversion for this method depends only on the intensity of the incoming light flux. Currently, there are various receivers that make it possible to implement almost all the requirements for modern OEMS in terms of accuracy, speed and other technical design parameters.

It is possible to implement such a method if three-dimensional (3D) transmissive diffraction structures (TTDS) are used in the OAMS, which are a combination of the simplest 3D diffraction gratings. A three-dimensional diffraction grating has the properties that when the angle of incidence of the object beam on the grating changes, the intensity of the transmitted and diffracted beams changes without changing their spatial arrangement [2].

The presence of such distinctive properties in TTDS allows them to be used as hologram optical elements (HOE) for various optoelectronic devices that have unique properties that are unattainable in other ways [3,4,5]. The purpose of our further presentation is to consider two-coordinate angle-measuring optoelectronic devices and sighting systems using HOE, which are TTDS of four 3D diffraction gratings registered in the volume of a photosensitive medium.

Currently, various three-dimensional light-sensitive media have been proposed, in the volume of which it is possible to register a combination of 3D gratings [6, 7, 8].

A special place in the development of photosensitive media for recording 3D diffraction gratings is occupied by photochromic systems based on colored alkali halide crystals (AHCs) and chalcogenide glassy semiconductors (CGSs) [9]. These materials have many advantages over other media: ease of manufacture, high resolution at the molecular level, a variety of photoinduced changes [10–13], the ability to implement both dynamic and "archival" recording, as well as optically reverse recording, which does not require fixing the stage of chemical-photographic processing [14,15].

Thus, photochromic systems open up another physical possibility for obtaining a new class of 3D diffraction gratings - amplitude-phase gratings. In addition, most of the photochromic transformations in AHA and CGS are electron-ion photochemical processes and, therefore, are amenable to thermal activation. It is these photochromic systems that we used to fabricate HOEs, which are TTDSs of four 3D diffraction gratings. The diffraction efficiency of each of the gratings reached up to 20%.

Methods.

The manufacture of a hologram optical element (HOE), which is a combination of four three-dimensional diffraction gratings registered in the volume of a photosensitive medium, was carried out on the setup shown in Fig. 1. As a bulk photosensitive medium, we used additively colored alkali halide crystals and chalcogenide glassy semiconductors, the technology for recording three-dimensional diffraction gratings on which we described in [1, 2]. The process of recording a combination of four three-dimensional diffraction gratings in the volume of a photosensitive medium was as follows:

1. The sample (light-sensitive medium) prepared for recording was set up so that beam 23 (Fig. 1) was incident along the normal to the sample surface. Then the sample was rotated by 4–6 *ang.min*. in the direction of beam 24. In this position, beams 22 and 23 recorded the first grating.

2. After recording the first grating, the sample was rotated by 7–12 *ang.min*. around an axis perpendicular to the plane of incidence of the beams in the direction of beam 22, and in this direction, beams 23, 24, the second grating was recorded.

3. The sample was rotated by 90^0 around an axis lying in the plane of incidence of the rays and coinciding with the direction of the beam 23. After that, the third grating was recorded using the beams 23, 24.

4. After the sample, at the end of recording the third grating, was rotated in the direction of beam 24 by 7–12 *ang.min*., around the axis perpendicular to the plane of incidence of the rays, rays 22 and 23, the last, fourth grating was recorded.

Determination of the parameters of the registered 3D diffraction gratings: amplitude and phase modulations and their phase shift; thickness and diffraction efficiency was carried out according to the method developed by us and described in [17, 18].

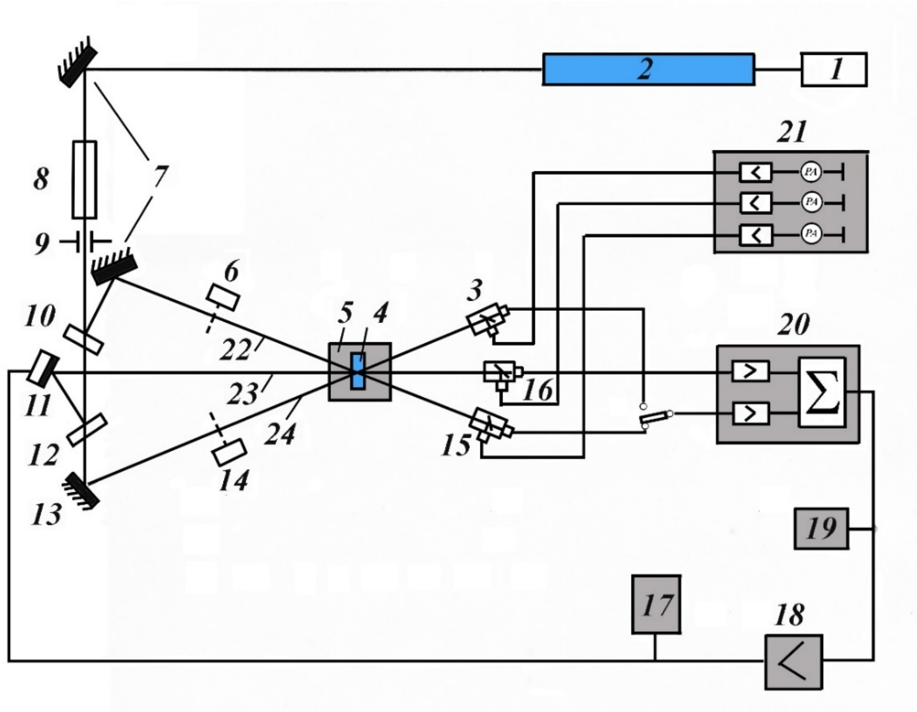

Fig. 1. Schematic diagram of the installation for recording HOE:
1 – laser power supply; 2 – laser; 3, 15, 16 – photodiodes; 4 – photosensitive medium; 5 – oven-thermostat mounted on a turntable; 6, 14 – shutters; 7, 13 –mirrors; 8 – beam expander; 9 – diaphragm; 10, 12 – beam splitters: 11 – mirror fixed on piezoceramic; 17, 19 – oscilloscopes; 18, 20, 21 – electronic blocks of the system for stabilizing and determining the holographic characteristics of gratings; 22, 23, 24 – recording beams.

Result.

When such a combination of four three-dimensional diffraction gratings is illuminated with a monochromatic light beam in the direction of beam 23, as a result of diffraction, four diffracted light beams are formed, located in pairs in mutually perpendicular planes (Fig. 2).

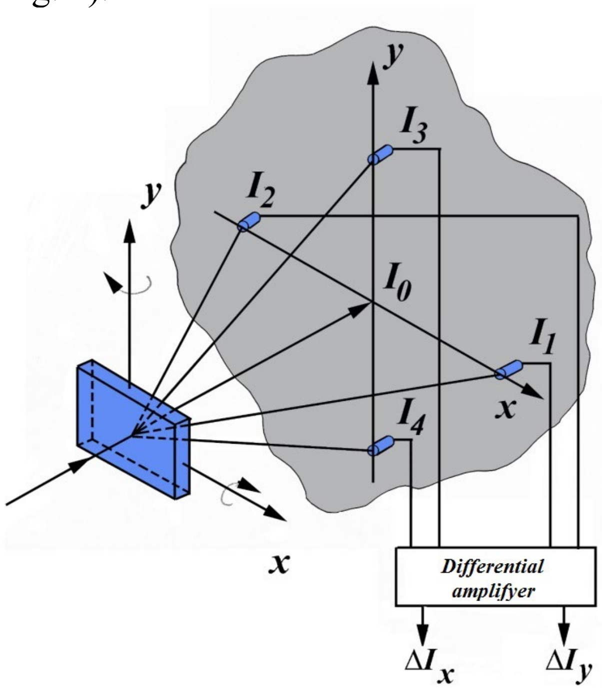

Fig. 2. Diffraction of light on the HOE: I0 - passing beam of light; I_1, I_2, I_3 and I_4 are light beams diffracted by 1, 2, 3, 4 gratings, respectively.

The intensities of the diffracted rays I_1, I_2, I_3 and I_4 depend on the orientation of the HOE relative to the incident light beam in the direction I_0 (Fig. 2). When the HOE rotates around the O*y* axis (Fig. 2), the intensity of the beams I_3 and I_4 remains unchanged, and only the intensity of the beams I_1 and I_2 changes. When the HOE rotates around the O*x* axis (Fig. 2), the intensity of only beams I_3 and I_4 now changes, while the intensities of beams I_1 and I_2 remain unchanged.

The angular dependences of the intensities I_1, I_2, I_3 and I_4 when the HOE is rotated around the O*y* and O*x* axes, respectively, are shown in Fig. 3.

The level of intersection of the curves of the angular selectivity I_1, I_2, I_3 and I_4 is determined by the values of the intensities I_1, I_2, I_3, I_4 at normal incidence of radiation on the HOE.

In this case, the intensities of all beams are the same, and this position of the HOE corresponds to the zero-count. When changing the angle of incidence, as follows from Fig. 3, as a result of the energy exchange between the diffracting beams, there is a redistribution of intensities with opposite signs.

Thus, the diffraction of light on the HOE has such properties that each pair of gratings, by changing the intensities of the beams diffracted by them, can provide independent measurements of the angular displacement of the object along the corresponding coordinate. For this purpose, it is only necessary to install photodetectors in the path of each of the diffracted beams (Fig. 2), respectively, connected in pairs according to the differential scheme. Then the value of the output signal of the differential amplifier $\Delta I_y = I_2 - I_1$ и $\Delta I_x = I_4 - I_3$ will be related to the magnitude and direction of the angular displacement of the grating relative to the incident beam by the dependence, which is determined by the properties of the diffraction structure of the grating and is shown in Fig. 4.

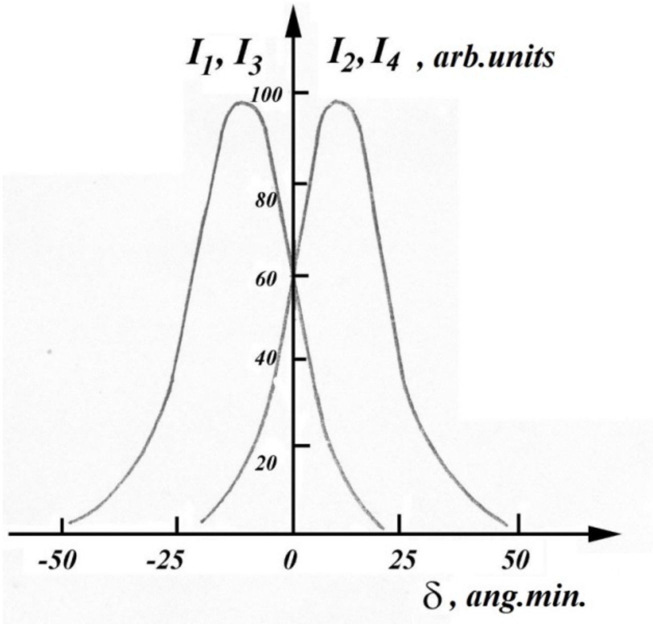

Fig. 3. Angular dependence of the intensity of diffracting beams on the first *I*1, second *I*2, third *I*3 and fourth *I*4 gratings:

I_1, I_2 – when the HOE rotates around the "Oy" axis;

I_3, I_4– around the "Ox" axis.

Optoelectronic device for measuring angular displacements in two coordinates

For this purpose, it is only necessary to install photodetectors in the path of each of the diffracted beams (Fig. 2), respectively, connected in pairs according to the differential scheme (Fig. 4).

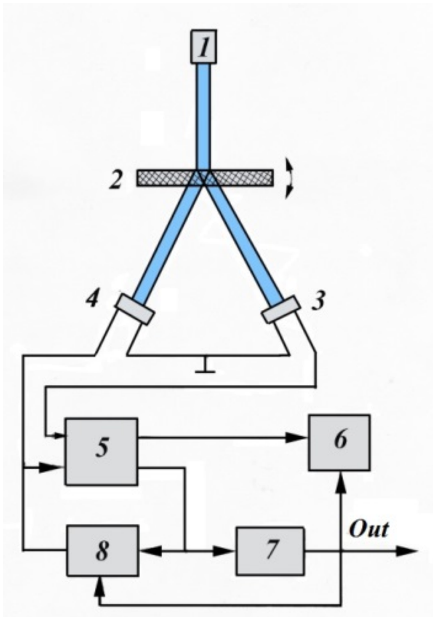

Fig. 4. Principal diagram of measurements along one of the coordinates:

1 – emitter; 2 - HOE; 3, 4 - photodetectors; 5 - differential amplifier; 6 - display unit; 7 – tristable comparator; 8 - gain control.

Then the value of the output signal $\Delta I_y = I_2 - I_1$ and $\Delta I_x = I_4 - I_3$ will be related to the magnitude and direction of the HOE angular displacement along the corresponding coordinate relative to the incident beam by the dependence, which is determined by the properties of the HOE diffraction structure [16] and is shown in Fig. 5.

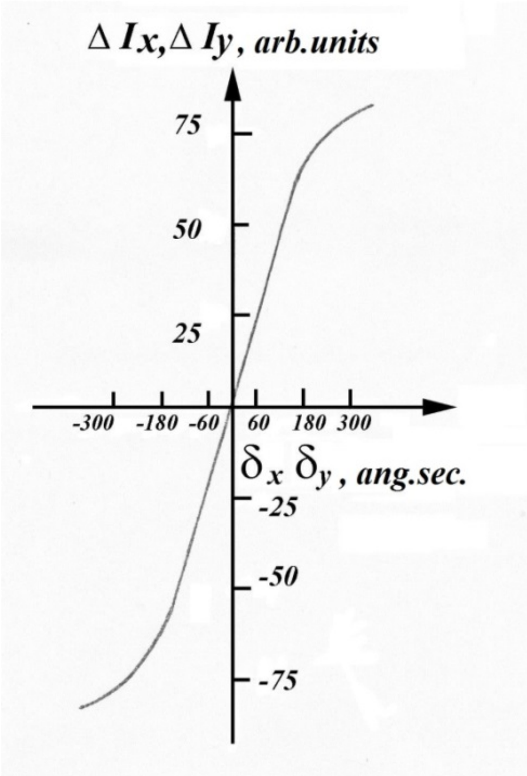

Fig.5. Dependence of the values of the output signals of the differential amplifier ΔI_x and ΔI_y on the angle of rotation of the HOE: δ_x – the angle of rotation of the HOE a around the axis «O*y*»; δ_y – around the axis "O*x*".

The dependence of the sensitivity of the proposed device on the main parameters of the HOE and the photoelectric circuit was considered by us in [16] and for the measurement range of ±150 *arcsec. min* sensitivity was 5 arcsec. s. In sighting mode with a range of 3 *arc. min*. sensitivity increases 50 times and is 0.1 *arcsec. s.*

Optoelectronic devices for sighting in two coordinates

To use the HOE in sighting systems, the device must be equipped with a feedback that provides compensation for the rotation from a given direction caused by any reasons.

The process of sighting according to the proposed method is as follows. The device, with the help of which the sighting is carried out in a given direction, is associated with the HOE. A laser beam of light that determines the direction of sight is applied to the label. Light passing through the HOE forms five beams - four diffracted and one transmitted. The radiation passing through the HOE coincides in the direction of propagation with the laser beam incident on the grating, does not participate in the operation of the device and continues to provide the direction of sighting.

The intensities of the diffracted rays are recorded by sensors and fed to the input of a differential amplifier. The output signal from the amplifier, corresponding to the difference $\Delta I_y = I_2 - I_1$and $\Delta I_x = I_4 - I_3$, is fed to the actuator that rotates the device depending on the polarity of the applied signal (+−or−+) in one direction or another around the axis Oy or Ox. If the object of sight (or the sighting device) has turned, then as a result of the redistribution of energy between the beams $I_1, I_2, I_3$and I_4, signals $\Delta I_x$and ΔI_yappear at the amplifier input, which cause the actuator to rotate the sighting device around the axes Ox or Oy until the beam intensities reach equality, and the signals that turn the device are compensated, and the device returns to its original state ($\Delta I_x = \Delta I_y = 0$).

The sighting process with the help of the proposed HOE can also be carried out according to the laser light scattered from the sighting object. It is relatively simple to do this if the source of light scattered from the object of sight can be considered as a point source. In this case, the HOE is placed at the focus of the converging lens, and the device registers the specified direction of sighting ($\Delta I_x = \Delta I_y = 0$), when the point source of light scattered from the object of sight lies on the main optical axis of the lens. When the point source of scattered light deviates from the main optical axis of the lens as a result of displacement of the object of sight (or the sighting device), signals ΔIx and ΔIy appear at the output of the amplifier, which, through the actuator, return the device to its initial state of registration of the specified direction of sighting on the point source of scattered light.

Summary and conclusions.

Thus, as follows from the results obtained, the use of the angular selective properties of a combination of three-dimensional diffraction gratings registered in the volume of a photosensitive medium makes it possible to create fundamentally new optoelectronic angle measuring devices and sighting systems based on them, which are distinguished by their simplicity of design and high measurement accuracy (due to the use of two parallel channels) and wide functionality. The sensitivity of the proposed device for the measurement range of ±150 *arc. min.* was 5 *arc. s*. In sighting mode with a range of 3 arc. min. the sensitivity was 0.1 *ang. s*.

The measurement does not depend on fluctuations in the power of laser radiation (this is automatically taken into account in the calculations), allows you to unambiguously determine the direction of the angular displacement of the object and allows simple visual observation, which distinguishes it favorably from other currently existing methods.

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