Estimate of temperature stability of volume polymer holograms

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Abstract. The results of experiment on the influence of temperature of the environment on the parameters of the volume polymer holograms are presented. The experiments were carried out on specialized holographic setup using digital procedures of recording information and data processing in the range of temperature change (22÷32)°C. It was shown that for hologram-gratings with the thickness about of one millimeter with spatial frequency 350mm⁻¹, the relative change of the angle of diffraction during temperature changing in given range is 1.4·10⁻⁶ K⁻¹.

1. Introduction

The recording media on the polymer base are widely used for recording information, including recording of holograms, holographic optical elements (HOE) and optical elements for systems of archival optical-holographic memory [1]. Volume media with physical thickness of the order of millimeter, intended for these purposes, must ensure the permanence of the registered structure in the process of its production and exploitation. However, the change of medium temperature leads to a change of the geometrical sizes of such structure and its optical constants.

The changes of the sizes of the medium and its average refractive index, as a rule, are of the same order of magnitude, which makes it difficult to estimate them, especially in cases when these changes are differently directed.

In this work the results of experiments that allow us to estimate the impact of temperature changes of the environment on the parameters of volume hologram-gratings are presented. The use of holographic procedures allows to diagnose negligibly small changes of parameters of the samples, which are due to temperature instability that usually unattainable by other methods of research.

2. Object of study

Samples of polymer recording medium "Difphen" developed for recording volume holograms were used as the object of study [1]. Samples of the material "Difphen" represent one of the modifications of polymer light-sensitive medium on the basis of phenanthrenequinone (PQ) and methylmethacrylate (PMMA), in which is used the principle of diffusion increasing of recorded information.

Changes in the samples during the temperature changes can be characterized by the coefficient of linear expansion (dl/dT) and the temperature change of the refractive index (dn/dT) of medium. These coefficients for media based on polymer PMMA are given in table 1.
| Characteristic                              | Polymer, PMMA                        |
|--------------------------------------------|--------------------------------------|
| Linear thermal expansion, $dl/dT$, $K^{-1}$ | $(3.6 \div 6.5) \times 10^{-1}$      |
| Refractive index, $dn/dT$, $K^{-1}$        | $-1.05 \times 10^{-4}$               |

When heating polymer sample increasing of its linear dimensions and the reduction the average refractive index happens, this leads to the change of conditions of reading holograms defined by the Bragg’s ratio:

$$2D\sin\theta_0 = \frac{\lambda}{n_0},$$

(1)

where $D$ – period of hologram, $\lambda$ – wavelength of radiation (in the air), $\theta_0$ – angle of diffraction in the medium; $n_0$ – average refractive index of the medium. The studied holograms were recorded on spatial frequency $\nu = 330 \text{ mm}^{-1}$ ($D = 1/\nu = 3 \mu\text{m}$).

In this work the changes of hologram were diagnosed by changing the angle of diffraction of radiation $\delta\theta$.

3. Procedure of experiments

For estimation of change of the angle of diffraction of radiation during reading holograms in different conditions were used two different procedures. In both procedures the sample with recorded hologram was heated in the temperature range of 20-40°C with the same procedure. The heating was produced by a stream of warm air in order to avoid a sharp rise of temperature of the sample heater was switched on for 30 seconds with an interval of 60 seconds. Measurements of parameters of the hologram were carried out before heating of the sample and in the process of its cooling.

Procedure 1. The studied holograms was illuminated by divergent beam of radiation with the wavelength of $\lambda=633$ nm (He-Ne laser). The intensity distribution in the beam of the diffracted radiation was registered on CMOS - matrix of the camera (fig.1а). This allows obtaining information about contour of angular selectivity of the hologram and change of the angle of diffraction during single measurement act $\delta\theta$ [2]. The angular resolution of the matrix in this scheme is 0,02 mrad.

Procedure 2. The sample with the studied hologram is installed in the scheme in which this hologram was recorded and is illuminated by two coherent beams $I_1$ and $I_2$ which were used for recording holograms (fig.1b). During changing hologram parameters by changing temperature in the space of overlapping beams $I_{1d} + I_{2d}$, $I_{10} + I_{20}$ the low-frequency interference pattern with period $d$ was formed, which could be observed in the air during installing the screen or CMOS-matrix (fig.1с). In accordance with Bragg’s condition and considering that the angle $\phi$ is small the period of interference pattern can be calculated by the formula $d = \lambda/\phi$, in our scheme $\phi \equiv \delta\theta$.

![Figure 1](image-url)

**Figure 1.** a - Procedure 1: distribution of radiation intensity in diffracted beam registered on the CMOS-matrix (left) and after processing (right); b, c - Procedure 2: scheme of the experiment (b); low-frequency interference pattern (c), registered on CMOS-matrix (left) and after processing (right). A-A – the line of scanning the results at digital processing.
4. Results of experiments and their analysis

The results of experimental measurements in the range of temperature change of the sample (22÷32)°C are shown on fig 2. Changing of position of the maximum of circuit of angular selectivity of hologram on CMOS-matrix (procedure 1) is given on fig.2a. It should be noted that measurements by different procedures were carried out by using radiation with different wavelengths (488 nm and 633 nm). Therefore, the comparison of changes of angle of diffraction should not be in absolute units, but in relative units, as it is done in table 2, line 4. Thus, relative change of angle of diffraction of polymer hologram in the visible spectrum during temperature change at one degree presents the value δθ/2θ = (1,39±0,2)10⁻⁶.

![Figure 2](image)

**Figure 2.** The results of experiments on influence of temperature changes on the hologram parameters: a - the shift of the maximum circuit of angular selectivity (procedure 1); b - change of the period of low-frequency interference pattern (procedure 2).

**Table 2.** The change of the angle of diffraction of radiation δθ* during reading volume polymer hologram-grating at change of temperature (T).

| Number of measurement result | Range of temperature changes, ΔT | Procedure 1, λ = 633 nm | Procedure 2, λ = 488 nm |
|-----------------------------|---------------------------------|--------------------------|--------------------------|
| 1                           | (22 ±31)°C                      | (0,30 ± 0,04) mrad       | (0,19 ± 0,02) mrad       |
| 2                           | (23 ±31)°C                      |                          |                          |
| 3                           | 1K                              | (0,033 ± 0,004) mrad     | (0,024 ± 0,002) mrad     |
| 4                           | 1K                              | δθ/2θ = (1,41±0,15)10⁻⁶  | δθ/2θ = (1,37±0,14)10⁻⁶  |
| 5                           | 1K                              | δθ/2θ = (1,39±0,2)10⁻⁶    |                          |

5. Conclusion

Measurements characterizing temperature stability of volume polymer holograms in the range of temperature change (22÷32)°C were carried out. Two different methods revealed the presence of changes of the angle of diffraction of radiation during temperature changes. It was found that the increase of temperature leads to increase of the angle of diffraction of radiation. It was shown that the relative change of the angle of diffraction during temperature change on one degree in the range of measurements error does not depend on the wavelength of the radiation and it is 1.4·10⁻⁶ K⁻¹.

References

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