Assessment of transformations of nanoporous volume holograms

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Abstract. The work presents the experimental results on assessment of the impact of the ambient humidity variation on parameters of silver-containing volume holograms in nanoporous silicate matrices 1 mm thick. The experiments were conducted on a dedicated holographic stand with the use of digital methods of data recording and processing. The diffraction angle of 633 nm radiation was found to change by 0.8 mrad at humidity variation in the interval (40÷90%) which is suggested to be related to a change of the average refractive index of a hologram by as much as 6·10⁻³ and be due to the absorption of water vapors by the light-sensitive composition, distributed in the free pore volume.

1. Introduction
Silicate-glass-based nanoporous matrices are a kind of a special tool for studying physico-chemical processes in a limited volume of a nanosized scale: limited space and effective contact with pore walls determine essential features of filling material state as distinct from the case of its being in a space without any significant restraints.

Porous-matrix-based recording media exhibit a number of useful properties: they are practically shrink-proof and have low coefficient of thermal expansion. Yet, the issues related to changes in the optical parameters of such media have been studied insufficiently.

2. Object of study
The object of study was a transmission volume hologram, recorded in the silver-halide recording medium on the base of a nanoporous silicate matrix about 1 mm thick. The medium exhibits the physico-mechanical properties of silicate glass [1].

The composition of the medium, where the hologram was produced, includes (see Figure 1a): silica skeleton, occupying ~50% of the sample volume; free pore volume ~40% of the sample; gelatin with developed silver particles ~10% of the sample (silver volume concentration ~10⁻³).

Silica skeleton is known to retain its geometrical and optical properties at variations of the ambient humidity [2]. However, humidity variation can affect the parameters of a hologram, recorded in a silver-halide composition inside the free pore volume. The present work aims to assess the potential changes.
Figure 1. Schematic view of developed silver-halide medium (a): 1 – silica skeleton, 2 – developed silver particle, 3 – immersion, filling free pore volume; (b) - optical schematic of measurements: 1 – radiation source (He-Ne laser, \(\lambda = 633\) nm); 2 – hologram; 3 – CMOS matrix of a photocamera.

3. Experimental procedure
The optical schematic of the experimental setup is given in Figure 1b. The hologram under study was illuminated with a divergent laser radiation beam, and the photocamera matrix recorded the radiation intensity distribution in the diffracted beam (see Figure 2a). Then, the acquired data was digitally processed and the angular selectivity contour of the hologram was constructed (Figure 2b).

Observation and assessment of transformations of the angular selectivity contour of the hologram at variation of the ambient humidity proceeded as follows: formation of the diffracted beam and selection of the frame recording mode (exposure and repetition rate); photocamera recording of necessary number of frames in the automatic mode, computer processing of the acquired data; construction and analysis of angular selectivity contours.

The view of information, recorded in a typical frame, is given in Figure 2a. The angular selectivity contour, derived by processing the frame (by scanning along line A-A) is given in Figure 2c. The transformations were analyzed by comparing the shapes of angular selectivity contours and estimating the change in their positions in the photocamera matrix (see Figure 2c).

The investigation of the impact of humidity variation comprised several stages (see Figure 3): Stage 1 – installing a sample in the stable state into an optical layout and taking the working frames during several tens of minutes; Stage 2 – creating an enclosure around the sample (with the help of a protective housing), where humidity \(~90\%\) was maintained for 20 hours; Stage 3 – taking the working frames at relaxation of a hologram upon the protective housing removal; Stage 4 – exposing the sample under stable conditions in the workroom for 70 hours; Stage 5 – taking the working frames in the stable state of the sample.
4. Experimental results and their analysis

Figure 3 gives the outcomes of processing of experimental results: the position of the principal maximum of the angular selectivity contour of a hologram under study on photocamera matrix is shown for all necessary investigation stages. The quoted data show the recording the frames in the automatic mode with high accuracy to demonstrate the invariability of the position of the angular selectivity contour maximum of a hologram in a stable state (Stages 1 and 5, the second half of Stage 3). Clearly seen is the region of the hologram parameter instability upon a sharp change of humidity – the initial period of Stage 3 of duration about 50 minutes. Attention is drawn to the change in the position of the angular selectivity contour maximum at Stage 5 (stable state of the sample upon exposure in the high humidity atmosphere) against Stage 1 (stable state of the sample before exposure in the high humidity atmosphere). The position of the maximum is clearly seen to have shifted by 40 pixels. The angular resolution of the matrix (the angle between two neighboring pixels) in given layout is 0.02 mrad. Thus, allowing for the experiment geometry, the said shift is an evidence of diffraction angle reduction by 0.8 mrad.

![Figure 3. Position of the angular selectivity contour maximum of a hologram on the CMOS matrix in the course of the experiment.](image)

The reconstructing radiation wavelength (laser) and hologram period (due to the silica skeleton) can be considered unchanged during the experiment. Therefore, in conformity with the Bragg condition, the change in the diffraction angle can be attributed to variation of the average refractive index \( n_0 \) of the sample. Under condition of the present experiment, the diffraction angle reduction by 0.8 mrad corresponds to an increase of the average refractive index \( n_0 \) by as much as \( 5.8 \times 10^{-3} \). The detected growth of the average refractive index of the sample upon exposure in the higher humidity atmosphere can be suggested to be attributable to absorption of water vapors in the free pore volume.

5. Conclusion

As a result of the present work, the impact of humidity variation on parameters of hologram gratings in nanoporous silicate matrices was assessed. The variation of ambient humidity has been shown to be capable of causing a change in the average refractive index of such a hologram. The analysis of the experimental data allows suggesting the changes in the average refractive index of an air-dry hologram at variation of humidity to be due to absorption of water vapors by the light-sensitive composition in the free pore volume.

References

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