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Recording of rainbow holograms using As_2Se_3 amorphous layers

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Abstract. The simple method of phase-relief rainbow master-hologram recording using the only laser has been developed. In this method at both recording steps (a normal transmission hologram and phase-relief sunlight-viewable master hologram recording) the same inorganic chalcogenide photoresist and the same postexposure one-stage treatment are used. It results in more simple and cheaper process of master hologram fabrication.

Keywords: rainbow hologram, inorganic photoresist, recording medium, As_2Se_3 amorphous layer.

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1. Introduction

Rainbow holograms (RH) are used in a wide range of applications, including protection of financial and other documents and branded goods, advertising, magazines and other high volume projects. The procedure of producing embossed RH in mass production includes several technological steps (here we consider RH only of classical Benton's type [1]). The first step is origination. The result of this step is a three-dimensional model or several slides for 2D/3D holograms. The second is recording a normal transmission hologram (respective image is visible in coherent laser light). Third step is recording phase-relief sunlight-viewable master hologram using reconstructed image of the transmission hologram as a subject. These steps are followed by manufacturing metallic copies of RH by electroplating and mass production of RH plastic copies by embossing as a final stage.

The intermediate transmission holograms are usually recorded on silver halide photoplates using He-Ne or He-Cd lasers. The second step – recording of master holograms – are carried out by using the photoresist layers and powerful Ar or He-Cd lasers. Such two-step process introduces some aberrations and distortions in recorded image because of shrinking silver halide emulsions and photoresist under postexposure treatment. Utilizing lasers with different wavelengths has the same deficiencies.

In this paper we present the results of investigations related to RH recording (both intermediate and master holograms) using single light-sensitive medium and single laser for both recording steps.

2. Features of recording medium

Medium for recording both transmission and phase-relief RH must posses a unique set of features. In addition to common characteristics of holographic recording media (high resolution, absence of shrinkage during treatment, linear characteristic curve) such medium must be sufficiently lightsensitive, transparent to laser radiation and have high refractive index to ensure sufficient diffraction efficiency of a thin transmission hologram. Our investigations show that the most optimum lightsensitive material for this purpose is such inorganic photoresist as an amorphous As_2Se_3 layer.

In our experiments, lightsensitive As_2Se_3 layers for measurements and hologram recording were deposited onto glass plates (up to 18×18 cm^2 in size) by thermal vacuum evaporation. The thickness of the layers was monitored «in situ» using a quartz-crystal-oscillator monitoring system and measured with microinterferometer after deposition. The holograms were recorded using He-Ne (λ = 632.8 nm) and Ar (λ = 514 nm) lasers. After exposure, the plates were chemically treated in amine-based solution (the same solution both for transmission and rainbow master holograms).

As it was shown earlier [2], As_2Se_3 layers are rather promising medium for recording diffraction optical elements and phase-relief holograms. Vacuum evaporated As_2Se_3 layers are characterized by high resolution (up to nanometer scale), good optical uniformity, absence of shrinkage under postexposure treatment in amine solutions. Fig. 1 shows a spectral dependence of lightsensitivity of As_2Se_3 layers. Maximum sensitivity corresponds to Ar laser wavelength, but these layers also have sufficient sensitivity to He-Cd (441.2 nm) and He-Ne (632.8 nm) irradiation (its respective value at 632.8 nm is not worse than 3 cm^2/J). All these lasers can be used for recording phase-relief holograms on As_2Se_3 layers.

Fig. 2 presents the spectral dependence of optical constants (indexes of refraction and absorption) of vacuum-deposited As_2Se_3 layer. The layer has sufficiently high index of refraction (two times higher than that of organic resist) that results in sufficiently high diffraction efficiency of phase-relief transmission holograms even at small relief depth. These layers have high transparency at He-Ne laser wavelength (a layer of 0.1 μm absorbs only 8% of incident intensity and transmits 73%). At Ar laser wavelength such layer absorbs up to 54% and transmits 25%, and for He-Cd irradiation the absorption increases up to 71% while transmittance drops down to 7%. That is why, for reconstruction of a transmission phase-relief hologram recorded onto As_2Se_3 layers, we may use only He-Ne or Ar lasers. As for He-Cd laser irradiation, we can reconstruct these holograms only as the reflection ones.

3. Recording of holograms

The necessary condition to obtain high-quality holograms is the optimization of the initial lightsensitive layer thickness, exposure, and etching conditions. The optimum exposure value, or irradiation time under constant intensity, is, as a rule, chosen experimentally. The initial layer thickness must be large enough to provide the necessary relief depth after etching treatment. For transmission holograms the necessary relief depth is smaller than for the reflection ones due to large refractive index of chalcogenide. Besides, the thickness of the transmission hologram must be minimum to ensure minimum absorption losses of intensity during the course of reconstruction. That is why, the thickness of evaporated As_2Se_3 layers for transmission hologram recording was 0.3-0.4 μm (after etching an average thickness was reduced to 0.15-0.2 μm), and for reflection holograms – 0.5-0.8 μm.

After optimization of recording conditions the transmission holograms were produced using conventional optical schemes. Diffraction efficiency, η, of such holograms were measured and shown in Table. Efficiency of holograms reconstructed using the Ar laser wavelength is lower than that for He-Ne laser due to higher absorption of As_2Se_3 at shorter wavelengths. But it should be mentioned that diffraction efficiency of an intermediate hologram in the range of 3-10% is sufficient for recording high-effective phase-relief rainbow holograms. For example, for silver halide plates (PFG-03), time of exposure with He-Ne laser irradiation is equal to 5 min under the same conditions, and the diffraction efficiency lies in the range of 5 to 10%.

Table

λ, nm (recording and reconstruction)	Time of exposure, min	η, % (transmission)	η, % (reflection)
514	5	6	23
633	20-30	10	17

High absorption of As_2Se_3 layers at short wavelengths substantially decreases the diffraction efficiency of intermediate transmission phase-relief holograms recorded on these layers, when reconstructing them with Ar (488

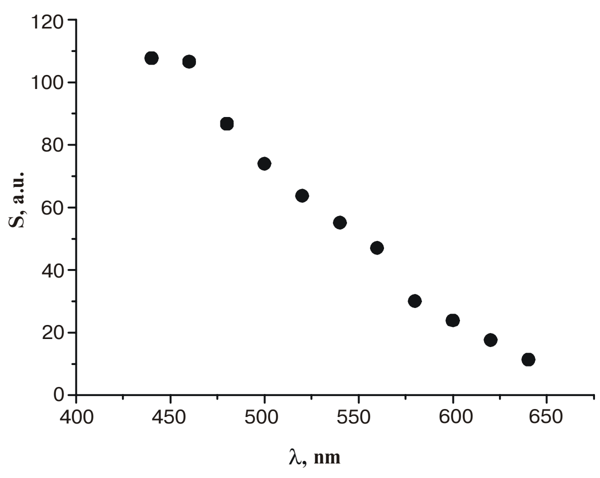

Fig. 1. Lightsensitivity (S) of an As_2Se_3 layer.

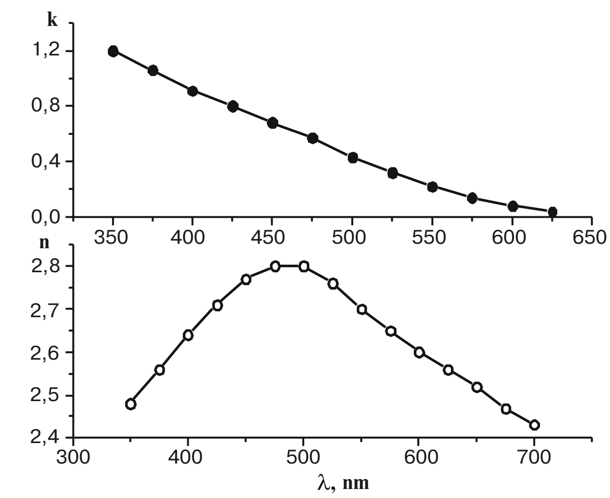

Fig. 2. Optical constants of As_2Se_3 layers: solid dots – index of absorption, *k*; open dots – index of refraction, *n*.

nm) and especially He-Cd lasers. But we can use such holograms as the reflection ones after covering them with reflecting layer. Table shows diffraction efficiencies also for holograms of this type. The advantages of the reflection scheme on the second step of RH recording is in a higher diffraction efficiency and possibility to utilize any laser. Disadvantage is more serious requirements to vibration-proof installation.

Using such intermediate holograms the phase-relief rainbow holograms were recorded onto As_2Se_3 plates both in conventional transmission and reflection schemes. The lasers for this recording step were the same as for intermediate hologram recording, and the time of exposure was almost the same (5-8 min for Ar and 20-30 min for He-Ne lasers).

Chalcogenide layers have higher mechanical and thermal stability in comparison with organic resists, which enables to use the obtained phase-relief holograms for the production of thermopolymer or photopolymer copies using the techniques similar to which are used in replication of diffraction optical elements. The described process is suitable for low-scale production of RH. For mass production the obtained phase-relief master holograms can be used in the course of galvanic nickel deposition followed by the conventional embossing process.

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