04

Recording scheme in opposite directed beams for obtaining relief-phase holographic gratings working in transmission

© N.M. Ganzherli[1], S.N. Gulyaev[2], D.A. Ilyushina[2], I.A. Maurer[1]

[1] Ioffe Institute,
St. Petersburg, Russia
[2] Peter the Great Saint-Petersburg Polytechnic University,
St. Petersburg, Russia

e-mail: nina.holo@mail.ioffe.ru, gulyaev@rphf.spbstu.ru, cherrysyrup2033@gmail.com, maureririna@yandex.ru

Received September 17, 2024 Revised September 17, 2024 Accepted September 30, 2024

The article presents the results of experiments on recording thin transmission relief-phase gratings in counter-propagating beams. Holographic gratings with a spatial frequency of up to 800 mm^{-1} were produced on PFG-01 photographic material, the processing technology of which includes tanning bleaching in bleaches containing dichromates, UV irradiation and etching in solutions of glacial acetic acid in isopropyl alcohol. The key point in the processing technology is the destructive effect of short-wave UV radiation with a wavelength less than 270 nm on the gelatin of the photo emulsion. In the course of the experiments, transmission relief-phase holographic gratings were obtained.

Keywords: holographic diffraction gratings, PFG-01 photographic plates, short-wave UV radiation, surface relief, diffraction efficiency, glacial acetic acid, isopropyl alcohol.

DOI: 10.61011/EOS.2024.09.60039.7086-24

Introduction

Earlier we have studied the processes of recording the highly efficient high-frequency relief-phase holographic gratings on the gelatin containing photo-sensitive media in converging beams [1]. An improved technology for treatment of the recording media has also been developed, based on the destructive effect of short-wave UV radiation on gelatin [2] and etching of layers in various etching agents [1]. The samples of phase-relief holographic gratings with spatial frequency of 1200−1600 mm^{-1} and high diffraction efficiency (DE) up to 67% on the dichromated gelatin and up to 42% on silver halide photoemulsion were fabricated (photographic plates PFG-04 and PFG-01 produced by JSC „Slavich") [1].

To obtain the relief holographic gratings, along with a symmetrical optical recording scheme in converging beams, it is interesting to consider optical recording in opposite directed beams (counter-directional scheme). This scheme was proposed by Yu.N. Denisyuk in 1962 as a method of recording the images in three-dimensional media, allowing to store information about the phase, amplitude and spectral composition of the wave coming from the object [3]. This hologram recording scheme is mainly used in artistic holography to obtain a three-dimensional image of a real object. In case of plane object beams and plane reference beams, the hologram structure represents itself a set of parallel layers associated with variations in the refractive index inside the emulsion layer. Therefore, such a hologram is reflective, and the period of the internal structure is approximately equal to half the wavelength of light in optical medium.

Since the layers of the grating come to the surface at an oblique angle, then, when the angle of grooves inclination changes, it becomes possible to record the surface structure in a wide range of spatial frequencies. This possibility was implemented in the study [4], where thin layers of photoresist were used as a photo-sensitive medium. In this case after etching the photoresist and metallizing the surface, a sawtooth relief profile of reflective nature was obtained. The counter-directional scheme is still successfully used to fabricate the holographic gratings with a blaze angle for spectrographs [5].

Silver halide photoemulsion as a photosensitive medium differs significantly from photoresists in terms of its properties. Therefore, it should be expected that optical parameters of holographic structures obtained on silver halide photoemulsion in a counter-directional scheme will be significantly different. This study was aimed at finding a possibility of using counterpropagating beams to record transmission relief gratings on PFG-01 photographic material.

Experiment setting

To register the gratings, an optical scheme was used where the laser beam reflected from the mirror (object beam) is a reverse beam with respect to the reference beam (Fig. 1, a). In this case, the spatial frequency of the grating on the surface of the photographic material can be easily widely adjusted by changing the inclination of the grating layers inside the photographic material. This can be provided by rotating the photographic plate placed in front of the mirror (Fig. 1, b). This scheme is characterized by

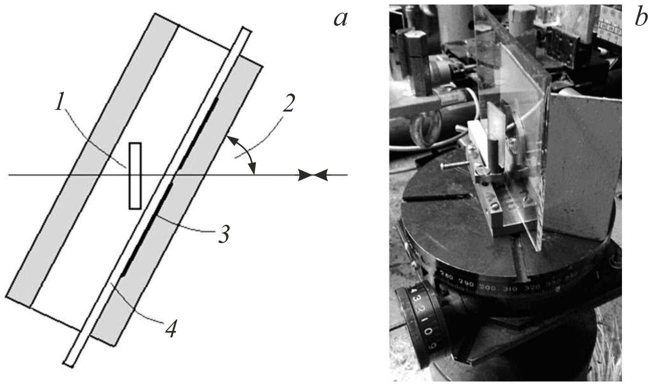

Figure 1. Recording of gratings in counter-propagating beams. (a) Arrangement of mirror and photographic plate relative to the incident beam of light: *1* — mirror, *2* — angle of rotation of the photographic plate, *3* — diaphragm, *4* — photographic plate; (b) photo of the photographic plate rotary device.

simple adjustment and setup of the system, associated with coincidence of incident and reflected beams in space in the plane of photographic emulsion.

In this study, silver halide photographic material PFG-01 for holography with a thickness of emulsion layer $6\,\mu$m was selected as a suitable medium for recording the diffraction gratings. The spatial frequency of the recorded gratings varied from 30 to $800\,\text{mm}^{-1}$. Fabrication of the surface relief structure was carried out by the same methods of treatment that were previously used to record relief gratings in converging beams [1].

Primary amplitude structures were recorded using He-Ne-laser radiation with a wavelength of $0.63\,\mu$m as a silver image (SI) of inclined layers in the photoemulsion developed in the D-19 developer for 4 min and fixed in the acidic fixer. At the second stage of treatment, the photoemulsion was selectively tanned in a bleach R-10 based on dichromate and SI was removed from the emulsion layer by means of second fixation. This operation included a rehalogenating bleaching with simultaneous selective tanning of the photoemulsion layer. At the same time, conditions were created on the layer surface for effective modulation of the destructive effects of short-wave UV radiation, which destroys less hardened areas of gelatin. A DRT-230 high-pressure mercury lamp served as a source of short-wave UV radiation with a wavelength of less than 270 nm. The time of UV lamp irradiation was 25 min. The next step of photochemical treatment was short etching (10 s) of the emulsion layer in solutions of glacial acetic acid (GAA) in isopropyl alcohol (IPA) in the ratio of 1 : 0 or 1 : 1. This was followed by sequential bathing of the samples in two IPA baths (100%) for 30 s each.

The interference patterns of gratings depicting the surface relief were recorded using micro-interferometer MII-4.

Experimental results

The main parameter studied in the experiment was the diffraction efficiency (DE) of holographic gratings. The illustrated graphics shows variation in DE depending on the time t of photographic plates exposure to He-Ne-laser and samples treatment stages (Fig. 2), as well as spatial frequency of the grating ν (Fig. 3). Fig. 2 shows that for the spatial frequency $\nu = 340\,\text{mm}^{-1}$, the addition of UV irradiation and etching operations increases the gratings DE in many times due to a strong increase in the depth of the surface relief and associated DE of the gratings.

Experiments also revealed that at low spatial frequencies $\nu \leq 100\,\text{mm}^{-1}$ the relief is formed mainly by tension forces resulting from dehydration of a wet colloid [6]. UV irradiation and etching operations added to the treatment procedure only slightly increase the height of the surface relief, and the DE may even decrease. When using a silver halide photo-material at low frequencies the reliefs

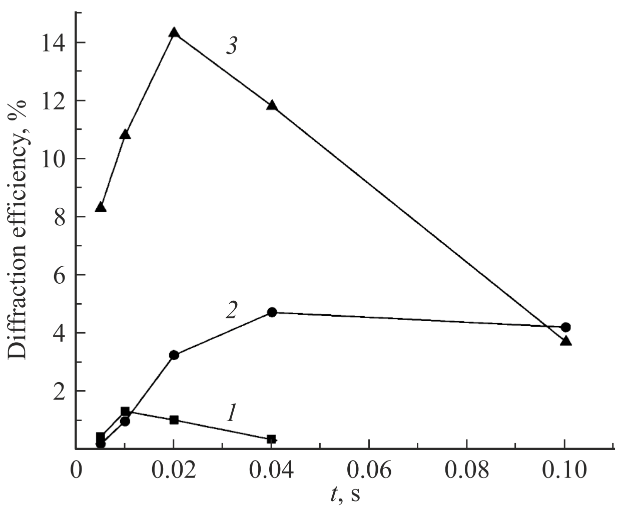

Figure 2. Dependence of DE of the primary amplitude hologram (*1*), relief-phase hologram after selective hardening (*2*), relief-phase hologram after UV irradiation and etching (*3*) on the time of He-Ne- laser coherent radiation exposure for spatial frequency $\nu = 340\,\text{mm}^{-1}$.

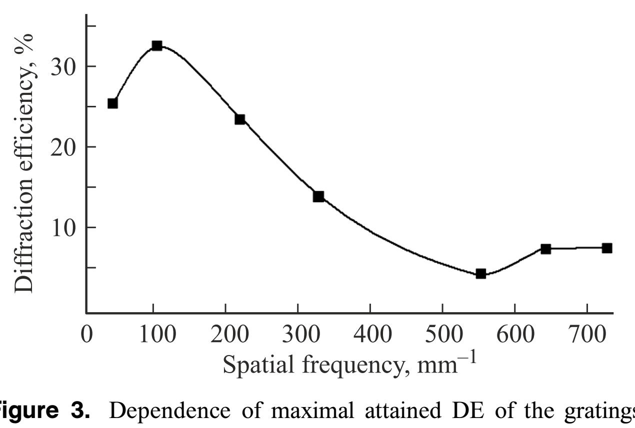

Figure 3. Dependence of maximal attained DE of the gratings on the spatial frequency ν.

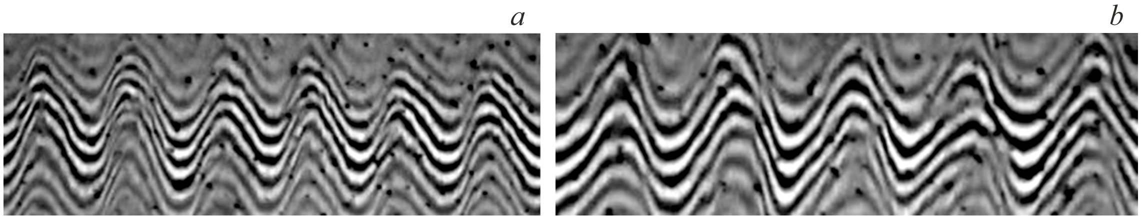

Figure 4. Interference pattern obtained using micro-interferometer MII-4 for symmetric (*a*) and asymmetric shapes of the relief (*b*).

$1-1.6\,\mu$m high may be obtained significantly exceeding the light wavelength. In case of photoresists the height of the sawtooth relief is no higher than $0.2-0.3\,\mu$m [4]. In general, unlike photoresists, the shape of the obtained surface reliefs is symmetrical (Fig. 4, *a*), however, some samples of gratings at low spatial frequencies ($\approx 40\,\text{mm}^{-1}$) demonstrate a clear asymmetry (Fig. 4, *b*).

Conclusion

The results demonstrated that, unlike traditional Denisyuk recording scheme, which is used to record three-dimensional reflective holograms, the counter-directional scheme also makes it possible to obtain thin highly transmissive relief-phase gratings.

It was found that in the case of creating holographic gratings in counter-propagating beams, the best results are obtained by etching the samples after exposure to UV radiation in undiluted glacial acetic acid, in contrast to gratings recording in converging beams, where GAA concentration was half as much [1].

Unlike photoresists, for which the maximum etching depth was about half the wavelength in the recording medium, silver halide photographic materials can produce reliefs with a height of $1-1.6\,\mu$m at low frequencies, which significantly exceeds the wavelength of the hologram recording laser radiation.

Conflict of interest

The authors declare that they have no conflict of interest.

References

[1] A.V. Arkhipov, N.M. Ganzherli, S.N. Gulyaev, I.A. Maurer. J. Opt. Technol, **90** (3), 38 (2023). DOI: 10.17586/1023-5086-2023-90-03-38-47.
[2] S.N. Gulyaev, V.P. Ratushnyi. J. Opt. Technol., **70** (2), 105 (2003). DOI: 10.1364/JOT.70.000105.
[3] Yu.N. Denisyuk. Dokl. Akad. Nauk SSSR, **144** (6), 1275 (1962) (in Russian).
[4] N.K. Sheridon. Appl. Phys. Lett., **12** (9), 316 (1968).
[5] N.K. Pavlycheva. J. Opt. Technol., **89** (3), 142 (2022). DOI: 10.1364/JOT.89.000142.
[6] H.M. Smith. J. Opt. Soc. Am., **58** (4), 533 (1968).

Translated by EgoTranslating