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Abstract

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HOLOGRAPHY WITHOUT A REFERENCE BEAM IN THE CASE OF THREE-DIMENSIONAL HOLOGRAMS

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In paper (1) the process of interference recording of a wave front without the use of a special reference beam was considered. The image of the object restored in this case as a result of "reading" the hologram from an arbitrary point with coordinate $\vec{\tau}_0$ is described by the Patterson function $P(\vec{\tau})$ and is the complete set of pairs of mutually conjugate (related by a center of inversion) images of the object in accordance with the condition relating the coordinates of the points of the object ($\mathbf{r}_n$) and of its image ($\vec{\tau}$), of the form:

$$\mathbf{r}_n - \mathbf{r}_{n'} = \vec{\tau} - \vec{\tau}_0. \tag{1}$$

This result was obtained for a hologram which by its nature is a two-dimensional periodic structure (for example, the case of a thin-layer photographic emulsion).

Below we consider a method of holography without the use of a selected reference wave in the case of three-dimensional holograms (for example, thick Lippmann emulsions (2,3), colored alkali-halide crystals (4)). We shall show that, when reading a three-dimensional hologram formed without a reference beam, an image coinciding with the original object is restored. Let there be an object consisting of some arbitrary discrete set of coherently luminous points with brightnesses z_n and coordinates $\mathbf{r}_n$. On a three-dimensional photosensitive element, placed in the far field, after exposure the following intensity distribution is recorded:

$$I(\mathbf{g}) \sim \sum_{n,n'} z_n z^*_{n'} \exp\{-i\mathbf{g}(\mathbf{r}_n - \mathbf{r}_{n'})\}, \tag{2}$$

where $\mathbf{g}(\xi, \eta, \zeta)$ is a three-dimensional Fourier vector.

It follows from expression (2) that, in the case under consideration, the hologram is a set of three-dimensional periodic structures, in each of which the alternation of darkenings corresponds to spatial frequencies of the form $\nu \sim a/|\mathbf{r}_n - \mathbf{r}_{n'}|$.

"Reading of a three-dimensional hologram" (restoration of the wave front) will take place only when the Wulff-Bragg condition is satisfied for each of the above-mentioned spatial frequencies. It is easy to show that, taking into account the process of three-dimensional diffraction, the conditions relating the coordinates of the points of the object and its image are modified in comparison with (1) and take the form:

$$\mathbf{r}_n - \mathbf{r}_{n'} = \vec{\tau} - \vec{\tau}_0, \qquad \mathbf{r}_n + \mathbf{r}_{n'} = \vec{\tau} + \vec{\tau}_0, \quad \text{i.e.} \quad \vec{\tau} = \mathbf{r}_n; \tag{3}$$

hence the image of the object restored from the three-dimensional hologram proves to be the following:

$$\Delta P(\vec{\tau}) \sim z^*_{n'} \sum_n z_n \delta(\vec{\tau} - \mathbf{r}_n), \tag{4}$$

where $z_{n'}$ is the brightness of the point source whose coordinates during recording

coincide with the coordinates of the source reading the hologram. For an object characterized by a continuous brightness distribution $u(\mathbf{r})$, we obtain:

$$\Delta P(\vec{\tau}) \sim u^*(\mathbf{r}_i)u(\mathbf{r}), \tag{4'}$$

if $\vec{\tau}_0 = \mathbf{r}_i$.

The results presented above were verified experimentally. Colored alkali-halide crystals KCl and KBr were used as three-dimensional photosensitive elements; in them, recording of the distribution in the interference field was carried out by "bleaching" color centers uniformly distributed throughout the volume (F-centers in the case of KBr, and F- and M-centers, apparently, in the case of KCl). As an example characterizing the image quality, Fig. 1 shows an enlarged reconstruction of the holographic image of a test object (the distance between strokes is 0.1 mm). The source of coherent radiation was a helium-neon laser (wavelength 6328 Å, 10 mW, single-mode operation). Figs. 1, 2, 3 see insert facing p. 1049.

In Fig. 2, images of objects reconstructed from two-dimensional and three-dimensional holograms obtained without a reference beam are compared. From the illustrations presented it is seen that the image of the object reconstructed when a three-dimensional hologram is read by a point source is part of the Patterson function and constitutes an image of the object.

It can be seen that the brightness of the reconstructed image is proportional to the brightness of that point of the object from whose position the hologram is read (in accordance with the condition $\vec{\tau}_0 = \mathbf{r}_i$ and expressions (4) and (4′)). It should be emphasized that the image intensity increases substantially (without loss of quality) if its reconstruction from the hologram is carried out not with a point source, but with a part of the object, i.e., a set of points. In this case, relations (4) and (4′) are transformed into the form

$$\Delta P(\vec{\tau}) \sim \sum_{n'=k}^{m} z^*_{n'} \sum_{n \neq n'} z_n \delta(\vec{\tau} - \mathbf{r}_n), \tag{5}$$

$$\Delta P(\vec{\tau}) \sim \left(\int u^*(\mathbf{r})\, d\mathbf{r} \right) u(\mathbf{r}). \tag{5'}$$

The integration in (5) is carried out over the part of the object used as an extended source reading the hologram. This situation is illustrated by Fig. 3, which presents a photograph of the image of a uniformly luminous triangle reconstructed from a three-dimensional hologram obtained without a singled-out reference wave. The reconstruction was performed with an extended source, namely with a part of the desired object (in Fig. 3a—the bright part of the object).

The consideration given here is useful in holographing complex periodic structures, when reconstruction from a three-dimensional reference-free hologram is carried out by means of a known substructure (Fig. 3b).

In conclusion we note that the results presented above were obtained for the Fourier–Fraunhofer holography scheme; however, they are also valid for the Fresnel scheme.

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Note: Figure translations are in progress. See original paper for figures.