ON HOLOGRAPHY WITHOUT A REFERENCE BEAM

PHYSICS

1967

SovietRxiv

Abstract

Full Text

UDC 535.4+539.26

PHYSICS

**V. V. ARISTOV, V. L. BROUDE, L. V. KOVALSKII, V. K. POLYANSKII,
V. B. TIMOFEEV, V. Sh. SHEKHTMAN**

ON HOLOGRAPHY WITHOUT A REFERENCE BEAM

(Presented by Academician G. V. Kurdyumov, 21 VI 1967)

It is shown that an image of an object can be predicted when reconstructing, by a plane wave, a hologram recorded without a reference beam. The principle of reciprocity of a point object and a point source is used, successfully applied to the phenomena of holographic recording in work ([1]).

Let us consider an object that is a certain discrete set of N coherently radiating points with coordinates $\mathbf{r}_n$, whose brightnesses are $Z_n = Z(\mathbf{r}_n)$. On a photographic plate located, for example, in the far field, the following intensity distribution (blackening) will be recorded:

$$I(\mathbf{g}) \sim \sum_{n,n'}^{N} Z_n Z_{n'} \exp\{-i\mathbf{g}(\mathbf{r}_n - \mathbf{r}_{n'})\}, \tag{1}$$

where $\mathbf{g}$ is a vector in Fourier space.

The resulting hologram can be "read" with the aid of a plane wave. In this case, in the far field a certain image of the object is formed, i.e., an amplitude distribution described by the relation:

$$P(\mathbf{r}') \sim \sum_{j=0}^{N^2-1} q_j \delta(\mathbf{r}' - \mathbf{r}_j), \tag{2}$$

where $q_j = Z_n Z_{n'}$, $\mathbf{r}_j = \mathbf{r}_n - \mathbf{r}_{n'}$, and $\mathbf{r}'$ is the current coordinate of the image of the object. It is easy to show that the result obtained will not change for the Fresnel scheme either.

Let us note that (2) is analogous to the expression for the function of interatomic vectors (the Patterson function), well known in X-ray crystallography ([2]). Using this analogy, for a known configuration of the object points one can, on the basis

Fig. 1

Figure 1: Fig. 1

of a simple geometrical construction, predict the arrangement and intensities of the points of the object image obtained after "reading" the hologram.

Figure 1a shows a fragment of the periodic structure being analyzed. Figure 1b illustrates the geometrical construction of the object image, whose points correspond to the maxima of the Patterson function. The indices of the points in Fig. 1b indicate the coordinates of the beginning and end of the corresponding vector in Fig. 1a.

Figure 2a is the reconstructed holographic image, in which the arrangement and intensities of the points in each elementary cell, as we see, do indeed agree with the construction in Fig. 1b.

Let us now single out, by brightness, a part of the object points (points of type b, d) in Fig. 1a. Then in the reconstructed photograph (Fig. 2b) the corresponding maxima of increased intensity are clearly visible. This fully corresponds to the situation with so-called "heavy atoms," widely used in structural analysis (see, for example, ([3])).

Without dwelling on other experimental confirmations of the commonality of the properties of the Patterson function and of the image reconstructed by means of a hologram obtained without a reference beam, let us now consider an object characterized by some continuous brightness distribution $U(\mathbf{r})$.

The blackening distribution on the corresponding hologram is the squared modulus of the Fourier transform of the function $U(\mathbf{r})$, which may

Fig. 1. *a*—fragment of the mask of a periodic two-dimensional structure (plane group *pm*); *b*—fragment of the vector system of the structure in Fig. 1*a*

be written in the form of the Fourier transform of its autocorrelation:

$$I(\mathbf{g}) \sim F[U(\mathbf{r}) * U^*(-\mathbf{r})]. \tag{3}$$

After "reading," the image of the object will be determined by the amplitude distribution in the form of the autocorrelation function

$$P(\mathbf{r}') \sim U(\mathbf{r}) * U^*(-\mathbf{r}). \tag{4}$$

It follows from this, as before, that the obtained image of the object is determined by the complete set of vectors between all points of the object (the generalized Patterson function). To better understand the meaning of formulas (3)–(4), let us represent $U(\mathbf{r})$ in the form $U(\mathbf{r}) = U'(\mathbf{r}) + Z_A\delta(\mathbf{r} - \mathbf{r}_A)$, where A

is an arbitrary point of the object. It is easy to show that in this case formula (3), and consequently also (4), can be rewritten so that

$$P(\mathbf{r}) \sim U'(\mathbf{r}') * U'^*(-\mathbf{r}) + Z_A^2\delta(\mathbf{r}') + Z_A^* U'(\mathbf{r}_A + \mathbf{r}') + Z_A U'^*(\mathbf{r}_A - \mathbf{r}'). \quad (5)$$

The last two terms of relation (5) determine two mutually conjugate (related by a center of inversion) images of the object, recorded by means of point A. Since point A has been chosen completely arbitrarily, one may say that expression (4) thus characterizes the complete set of superposed recordings, each point of the object recording the whole object ("recording of itself by the object"). Under the assumption of equal (or close) brightness of all points of the object, none of the images can be isolated within the complete image of the object.

Now let us impart overwhelming brightness to one of the points of the object. Then the last two terms in (5), characterizing the recording of the object by this point, become the principal ones. In this case the second and first terms of expression (5) determine, respectively, the "reading" beam and the halo around it*.

* According to the scheme of image formation (see above), the size of the halo must be of the order of twice the size of the object image. On this basis, in each case a recording geometry can be found in which the image and halo will not overlap.

To the article by V. V. Aristov, V. L. Broude et al., p. 65

Fig. 2. *a*—image of a periodic structure (Fig. 1*a*) reconstructed from a hologram recorded without a reference beam; *b*—image of a periodic structure (Fig. 1*a*) reconstructed from a hologram recorded without a reference beam, points of type *b*, *v* being selected by brightness; *v*—image of a periodic structure (Fig. 1*a*) reconstructed from a hologram recorded without a reference beam; the hologram was reconstructed using a mercury lamp OSL.

Fig. 3. *a*—image of a luminous contour ("circular"); *b*—image of the same contour, on which several points have been selected by brightness.

To the article by Yu. L. Stankevich and V. G. Kalinin, p. 72

Fig. 2. Radiograph of a hole in a lead screen. Obtained using X-radiation from the initial stage of a pulsed spark discharge in air. Voltage 52 kV. Number of pulses 100. Duration of a single flash 1 nsec. Filter—beryllium 0.3 mm, 2.5×.

It is clear that this special case reflects the traditional scheme of recording a hologram with the aid of a reference beam. In this case the two images obtained are mutually inverted in accordance with the centrosymmetry of the Patterson function and may both be either real or imaginary and real ([1]).

As an illustration of the foregoing, one may cite images recorded and reconstructed with the aid of an LG-35 helium-neon laser from the simplest geometrical figure (Fig. 3). It should be noted that the corresponding holograms can be "read" also in "white" light, provided that the special recording geometry is maintained, the conditions for which were considered earlier ([1]).

Institute of Solid State Physics
Academy of Sciences of the USSR

Chernivtsi State
University

Received
15 VI 1967

REFERENCES

[1] L. V. Kovalskii, V. K. Polyanskii, V. B. Timofeev, *Collection: Quantum Electronics*, vol. 2, Kiev, 1967. [2] A. Guinier, *X-ray Diffraction in Crystals*, Moscow, 1961. [3] M. A. Porai-Koshits, *Practical Course in X-ray Structural Analysis*, part II, Moscow, 1960.

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