radiation in the same manner as the object itself (for example, a three-dimensional hologram of a convex mirror selects from the white spectrum the radiation that has exposed it, and focuses it in the same manner as the original mirror)[2].

A more perfect image can obviously be provided only by a duplicate of the object, which acts in the same manner as the object itself on any radiation.

As a further development of these concepts, the connection between the space-frequency spectrum of a three-dimensional hologram and the space-frequency spectrum of a phase object was recently investigated. It turned out that the spectrum of a three-dimensional hologram is part of the spectrum of such an object. When the radiation band used to expose the hologram is broadened, the region over which these spectra coincide broadens and the distribution of matter in the three-dimensional hologram approaches the distribution of matter in the original object[3].

Thus, a three-dimensional hologram indeed tends to copy the object. This property of light may be very useful for the development of the theory of an image, and should possibly be taken into account in the elementary acts of interaction between light and matter.

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E. S. Voronin, Nonlinear Transformation of Images and Infrared Holography

The infrared band plays an important part in optical technology. This is connected with the greater transparency of the atmosphere in the IR band, with the lower level of fluctuation noise, and with a number of other specific features. At the same time, reception of radiation in this band is a much more complicated matter than, for example, in the visible, and the problem of reception hinders in many respects the development of IR technology.

The situation is particularly difficult with image receivers, since electron-optical image converters operate only up to 1.2 μ, and thermal systems have definite shortcomings. The use of frequency conversion by methods of nonlinear optics uncover great prospects in this direction. Indeed, using a plane pumping wave of frequency ω_1, then each plane IR wave of frequency ω_2 having a wave vector lying within a certain solid angle will correspond to a plane wave generated in the crystal, with a frequency $\omega_3 = \omega_1 + \omega_2$ and a wave vector whose direction is determined uniquely by the direction of the wave vector of the signal wave. This makes it possible to obtain an image at the summary frequency, if the information is contained in the angle spectrum, i.e., if the field with frequency ω_2 corresponds to radiation from an object located at infinity. This is precisely the possibility employed by Midwinter[1] and by Warner[3] to obtain a visible image of objects illuminated with IR radiation. The image of the object was obtained at infinity with the aid of ordinary lens or mirror systems. Such a procedure, however, yields results that are far from the ultimately attainable ones, and information concerning the longitudinal dimensions of the object is completely lost.

At the Moscow University, M. I. Divlikeev, Yu. A. Il'inskiĭ, V. S. Solomatin, R. V. Khokhlov, and the author have carried out a cycle of investigations in this direction. As a result we developed a new scheme (Fig. 1) for obtaining images at a summary frequency, wherein the object (or its image constructed by means of an ordinary optical system) is located at a finite distance from a nonlinear crystal. This reduces greatly the requirements concerning the divergence of the pump signal, and also concerning the monochromaticity of the radiation, and lifts the limitations on the maximum resolution. The developed procedure yielded, for the first time, diffraction resolution of the image. Inasmuch as in this scheme the information on the object is contained more readily in the spatial structure of the field than in the angular structure, the information on the longitudinal scales of the object is preserved. This makes it possible to transform the three-dimensional image and to obtain holograms of three-dimensional objects illuminated by IR radiation, with subsequent reconstruction in visible light. The reference beam for the recording of the holograms can be obtained either in the same crystal (see Fig. 1) or in another crystal, in which a summary frequency is likewise obtained. The former method has the advantage that the inhomogeneities of the crystal and the distortions of the pump wave front are cancelled out to some degree, since they are the same in the main and in the reference beams. The second method makes it possible to obtain larger angles between the main and the reference beams and to raise them to values determined by the resolution of the available photographic material. When the hologram is reconstructed with the aid of the frequency ω_3, the reconstructed image has the same properties as the image at the frequency ω_2. The angle field of view can be increased by successively photographing the hologram on a single film while varying the refractive indices of the crystals with the aid of an external field or by varying the temperature.

Experiments aimed at converting an image from 1.06 μ to 0.53 μ with a KDP crystal, using two-dimensional interaction of the signal and pump waves, gave the largest resolution. The scheme shown in Fig. 1 yielded, for the first time, ordinary and three-dimensional holograms of objects illuminated with IR. An

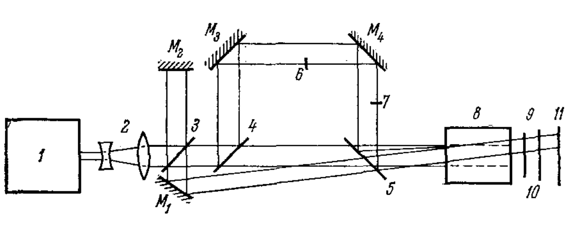

FIG. 1. Experimental setup for the production of holograms. 1) Nd^{3+} glass laser, 2) telescope, 3–5) plates made of K8 glass, M_1–M_4) mirrors, 6, 7) transparencies, 8) nonlinear crystal, 9, 10) filters, 11) film.

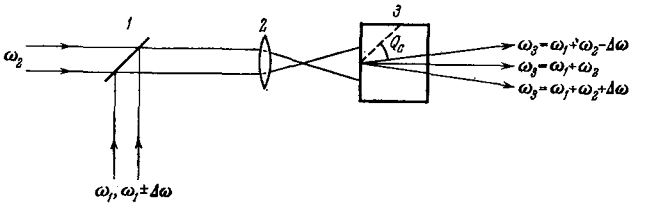

FIG. 2. Diagram of nonlinear spectrograph: 1) plate of glass (silicon), 2) lens, 3) nonlinear crystal.

interesting possibility, pointed out by N. G. Basov, is uncovered by nonlinear frequency conversion in spectroscopic procedures. If the slit of a spectrograph with a spectrum picture in the IR band is transformed into the visible band, then it becomes possible to do this simultaneously for an appreciable section of the spectrum and with high resolution. It is possible to utilize the dispersion characteristics of the crystal in such a way that the resolution in the direction perpendicular to the slit can be greatly increased at the cost of decreasing the resolution along the slit.

The functions of two instruments, the IR spectrograph and the frequency converter, can be combined in a single scheme of a nonlinear spectrograph. Such a scheme (Fig. 2) was proposed at the Moscow University and independently at the State Optical Institute. Nonlinear spectrographs can have a higher resolution and permit spectroscopic investigations of rapid processes.

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K. S. Mustafin and V. A. Seleznev. Methods of Increasing the Sensitivity of Holographic Interferometry.

Holographic interferometry is finding ever expanding and successful applications in various investigations. It is therefore of interest to develop methods of increasing the sensitivity of holographic interferometry. This is the subject of a number of papers[1-4]. The authors consider three methods of increasing the sensitivity of interferometric research on optical inhomogeneities of transparent objects by holography.

1. Three-color holographic interferometry. The method is based on incoherent superposition of two interference patterns with wavelengths λ_1 and λ_2 for the same inhomogeneity, and observing the resultant moire pattern. To this end, a comparison wave front is recorded on the hologram using one wavelength λ_0. This hologram is then illuminated with both an object beam and a reference beam having respective wavelengths λ_1 and λ_2, and the moire pattern is observed on behind the hologram. Two cases are then possible:

a) The finite-width interference patterns have opposite shifts, owing to the presence of the investigated inhomogeneity in the interference patterns with λ_1 and λ_2. In this case the moire pattern is identical with the interference pattern obtained at a wavelength $\lambda_{\text{eff}} = \lambda_1\lambda_2/(\lambda_1 + \lambda_2)$, i.e., at the sensitivity of the method is approximately doubled. If the condition $\lambda_0 = 2\lambda_{\text{eff}}$ is satisfied, then the imperfections of the optical systems do not affect the moire pattern.

b) The fringes in the interference patterns with λ_1 and λ_2 are shifted in the same direction. In this case the moire pattern is identical with the interference pattern observed with a wavelength $\lambda_{\text{eff}} = \lambda_1\lambda_2/(\lambda_1 - \lambda_2)$. This procedure may be useful where an appreciable decrease of the sensitivity of the interferometry is required, with a density jump for the identification of the fringes on both sides of the jump boundary. This method makes it possible to obtain an interference pattern of either increased or decreased sensitivity in a real time scale.

2. Three-beam holographic interferometry. The method is based on obtaining an interference pattern of an object wave with two identical comparison waves. To this end, for example, one registers on the hologram an object wave at a holography angle α_0, and two comparison waves at angles α_1 and α_2, such that $\alpha_1 < \alpha_0 < \alpha_0 < \alpha_2$ or $\alpha_2 < \alpha_0 < \alpha_1$. Under these conditions, the interference pattern obtained with the aid of such a hologram has double the sensitivity. The imperfections of the optical system are eliminated. This method can also be used to obtain interference patterns in a real time scale. To obtain a sharp image of the investigated object it is desirable to use holography of the focused image of the object.

3. Use of nonlinear effects in holography. The method is based on the transformation of the wave front when it is reconstructed from a hologram in a higher order of diffraction. The wave front from the investigated object is registered on the hologram under conditions that are known to be nonlinear. Then the hologram is illuminated with two reference waves so as to obtain an interference between the waves, restored in the n-th and m-th orders of diffraction. This increases the sensitivity by n + m times. The possibility is demonstrated of using nonlinear effects also in the method where the interference patterns are obtained by superposition of two holograms, on which the comparison wave front and the object wave front are registered separately. The influence of the aberrations of the holograms on the obtained interference pattern, using higher orders of diffraction, is considered. It is shown that when weak inhomogeneities are used the aberrations can be neglected if the holography and restoration are effected by plane waves.

By way of illustrations, interference patterns of transparent inhomogeneities, with increased sensitivity, were demonstrated.

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