Writing a photorefractive hologram with an external field parallel to the interference fringes

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(Submitted 31 August 1994)
Pis'ma Zh. Eksp. Teor. Fiz. **60**, No. 7, 511–513 (10 October 1994)

A method for writing holograms in photorefractive crystals is proposed. An alternating external field is applied in the direction perpendicular to the wave vector of the interference pattern. The difference between the frequencies of the interfering beams is equal to the frequency of the external field. © *1994 American Institute of Physics.*

In the writing of holograms in photorefractive crystals, various mechanisms are used to separate the space charge. These mechanisms are based on a diffusion of photoelectrons and a drift of these electrons in an external field or the photovoltaic field. A variation of the refractive index arises by virtue of the linear electrooptic effect. The external field applied to the crystal can be either constant or time-varying. In a constant field, the grating can be written by either a fixed or moving interference pattern.[1,2] In the case of an alternating external field, there are two basic writing mechanisms. The first (the so-called Stepanov writing mechanism) is realized when the interference pattern is fixed.[3] In this case the grating of the variation in refractive index and the interference pattern are $\pi/2$ out of phase, so there is an energy exchange between the interfering beams. The second mechanism—lock-in detection—is realized when the hologram is written by rf beams, and the frequency difference between the two beams is equal to the frequency of the alternating external field.[4]

In all these mechanisms, an external field $\mathbf{E}_0$ is applied in the direction parallel to the grating wave vector $\mathbf{q}=\mathbf{k}_1-\mathbf{k}_2$, where $\mathbf{k}_1$ and $\mathbf{k}_2$ are the wave vectors of the writing beams. The reason is that the separation of charges in a certain direction caused by the external field or diffusion occurs when the conductivity is nonuniform in this direction.

In this letter we are reporting an experimental study of the mechanism for writing a photorefractive hologram with the alternating external field $\mathbf{E}_0(t)$ perpendicular to the grating wave vector $\mathbf{q}$. One of the beams is detuned in frequency from the other by an amount Ω, which is equal to the frequency of the external field, i.e., the mechanism of lock-in detection is realized.[4] The interfering beams are focused by a cylindrical lens in the direction of the external field. The photorefractive crystal is at the focus of this lens. The thickness (W) of the illuminated region along the direction of the field $\mathbf{E}_0$ is made comparable to the period of the interference pattern, $\Lambda=2\pi/q$. The process by which the space-charge grating forms can be explained most clearly, at a qualitative level, when the electron drift velocity is small in comparison with Λ and W, when a "meander" field is used instead of a sinusoidal field, and when the travelling interference pattern is replaced by an interference pattern whose phase changes abruptly by an amount π at the instant at which the sign of the external field $E_0(t)$ changes. For $E_0>0$, the photoelectrons gener-

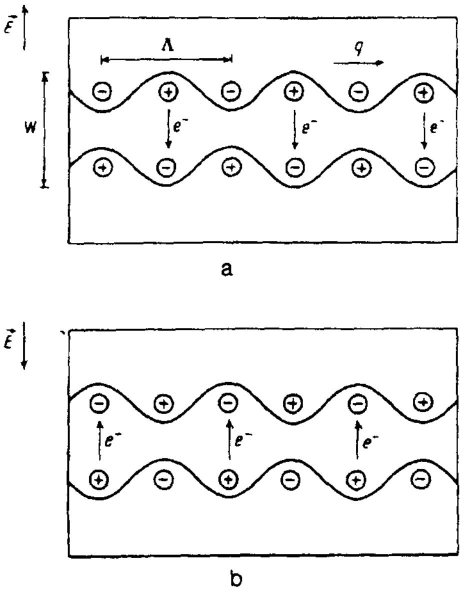

FIG. 1. Qualitative mechanism for the writing of a static hologram in an alternating external field by means of an interference pattern which "jumps" by an amount $\Lambda/2$ in synchronization with the change in the sign of the external field.

ated at the maxima of the interference pattern are retrapped by trapping centers near the lower boundary of the illuminated region, primarily near the maxima of the interference pattern (Fig. 1a). In other words, the screening of the external field occurs more rapidly at the maxima of the interference pattern than at its minima. During the next half-period (with $E_0<0$), the electrons accumulate near the upper boundary of the illuminated region. Since the interference pattern is shifted $\Lambda/2$ from its position during the preceding half-period, however, erasure does not occur during this half-period. Instead, there is an intensification of the grating of the space-charge field E_{sc} (Fig. 1b).

We see in Fig. 1 that the grating of the component of the field $\mathbf{E}_{sc}$, which is parallel to $\mathbf{q}$ in the upper part of the illuminated region, is out of phase with the same grating in the lower part. It is for this reason that the component of the field $\mathbf{E}_{sc}$ parallel to the external field $\mathbf{E}_0$ is used to write the hologram.

The fact that the charges are concentrated near the boundaries of the illuminated region imposes certain limitations on W and Λ. Specifically, since the field of the periodically distributed charge falls off exponentially over a distance equal to the period Λ, efficient writing of a hologram requires that the period of the interference pattern be greater than or comparable to the size of the illuminated region ($\Lambda \geqslant W$).

In this study, the hologram was written in the photorefractive crystal $Bi_{12}TiO_{20}$ (BTO). An alternating voltage with a meander shape and an amplitude of 3 kV was applied to the $1\bar{1}0$ faces. The distance between the electrodes was 5.6 mm, and the thickness of the crystal in the light propagation direction, (110), was 4.5 mm. We used a He–Ne laser ($\lambda = 0.63$ μm). At a resultant power of 0.5 mW of the writing beams, the writing time was 1 s. The frequency of the external field was 33 Hz. A frequency shift of one of the beams was introduced by means of a piezoelectric mirror. The diameter of the beams in the plane of the lens was 4 mm, and the focal length of the lens was 11.5 cm.

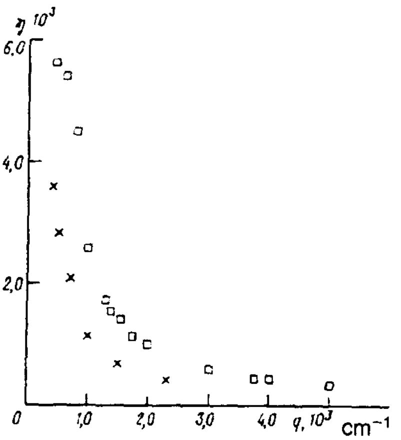

FIG. 2. Diffraction efficiency η versus the spatial frequency of the grating, q. ○—The crystal is at the focus of the cylindrical lens; ×—the crystal is displaced 0.5 cm from this focus. $E_0=5$ kV/cm, $\beta=I_s/I_p=10^{-2}$.

This corresponds to a waist thickness $W\approx35$ μm and a thickness of 50 μm for the illuminated region at the faces of the crystal. The polarization vectors of the beams made an angle of 20° with **q**.

The diffraction efficiency was found as the ratio of the intensity of the diffracted light in the initial stage of the erasure of the hologram, I_d, to the intensity of a reference beam, I_p: $\eta=I_d/I_p$. The intensity ratio of the signal and reference beams was $I_s/I_p=0.01$.

Figure 2 shows the experimental behavior of the diffraction efficiency η as a function of the spatial frequency $q=2\pi/\Lambda$. Also shown here is a plot of $\eta(q)$ for the case in which the crystal was displaced 0.5 cm away from the lens focus, toward the lens. The thicknesses of the illuminated regions on the front and rear surfaces of the crystal were 160 and 230 μm, respectively.

It can be seen from the spatial-frequency characteristic that the hologram has a characteristic frequency (a cutoff frequency), which is half the value of $2\pi/W$.

In conclusion, this study has demonstrated that a hologram can be written by an external field oriented perpendicular to the grating wave vector **q**. The writing mechanism is efficient if the period of the grating is greater than the size of the illuminated region along the direction of the field.

This study was supported by the International Science Foundation under Grant MMM 000.

I wish to thank B. Ya. Zel'dovich for valuable discussions.

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Translated by D. Parsons