Strengthening of the photorefractive response in a ferroelectric $Ba_2NaNb_5O_{15}$ crystal in an alternating external field

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The writing of a static photorefractive grating in the ferroelectric $Ba_2NaNb_5O_{15}$ with a traveling interference pattern and an applied alternating field has been studied experimentally. Two- and four-wave arrangements were studied by a synchronous-detection method.

Various mechanisms for writing in a photorefractive crystal have been studied in detail: a diffusion mechanism,[1] a mechanism of drift in a static field,[2] and a mechanism of drift in an alternating field.[3] A new mechanism for writing a static photorefractive grating was recently proposed: a "synchronous-detection" method.[4,5] This mechanism is based on a synchronization of the frequency of an alternating external field with a frequency shift between the writing beams. In contrast with the mechanism mentioned above for writing a static pattern in an alternating field, this method is capable of writing gratings in crystals with a small drift length. A study of the writing of a grating by the synchronous-detection method in an SBN crystal[6] has revealed that a strong alternating field can disrupt the single-domain structure of the crystal. In the present study, the synchronous-detection mechanism has been implemented experimentally for the first time in the ferroelectric $Ba_2NaNb_5O_{15}$ crystal, of symmetry group $2mm$.

The experimental layout is shown in Fig. 1. A crystal of thickness $l=4$ mm, with electrodes separated by distance $d=3$ mm, was illuminated by either two beams (for the two-wave mixing) or three beams (for the four-wave mixing), from a 10-mW He–Cd laser ($\lambda=440$ nm). All beams were polarized in the plane of incidence. Also in the plane of incidence was the optic axis of the crystal. The direction of this axis was reversed in the course of an experiment (Fig. 1). The frequency of the pump wave was

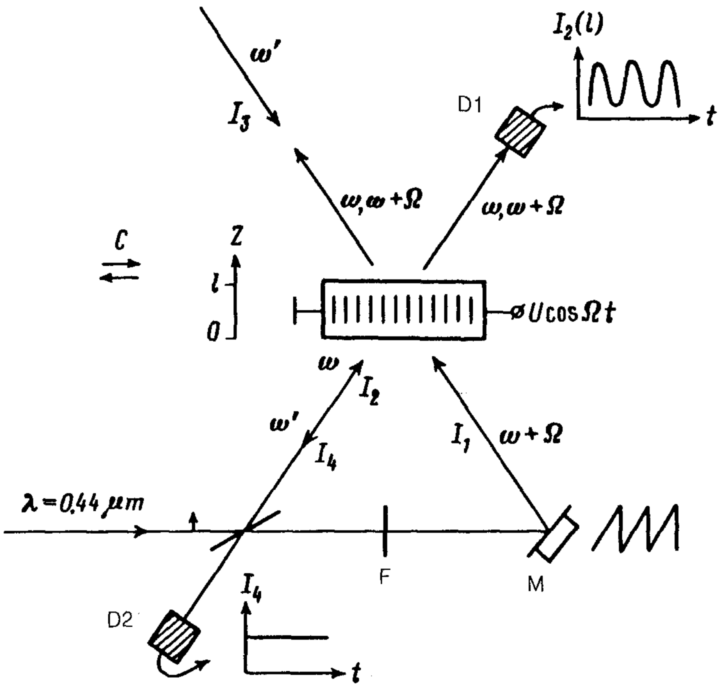

FIG. 1. Experimental layout.

shifted by applying a sawtooth voltage to a mirror (M) attached to a piezoelectric transducer. The sawtooth voltage was synchronized with the voltage applied to the crystal from the power line (at the frequency $\Omega = 50$ Hz) through a transformer. The ratio of the signal and pump intensities, $\beta^2 = I_2(0)/I_1(0)$, was varied with the help of optical filters (F). The intensity of the signal beam at the output, $I_2(1)$, was measured by photodetector D1. The intensity of the conjugate wave, $I_4(0)$, was monitored by a second photodetector, D2.

In two-wave mixing, the diffraction efficiency was measured as $\eta = I_p^d/I_p^p$, where I_p^d is the intensity of the pump wave diffracted in the direction of the signal beam in the absence of the latter at the beginning of the erasure, and I_p^p is the intensity of the pump behind the crystal in the absence of the written grating. When no external field was applied to the crystal, and no voltage applied to the transducer, the diffracted wave was detected for a spatial period $\Lambda < 2$ μm, because there was only a weak diffusion response. When an alternating field was applied to the crystal, no response of the crystal was observed. This result is attributed to the short electron drift length. When a sawtooth voltage was applied to the transducer and an alternating voltage was applied simultaneously to the crystal, the diffraction efficiency of the grating increased substantially for all spatial frequencies studied.

Figure 2 shows the normalized diffraction efficiency η/β^2 (β^2 is the ratio of the intensities of the writing beams) as a function of the applied field. As has been shown previously,[4,5] self-diffraction has a significant effect on the overall diffraction efficiency.

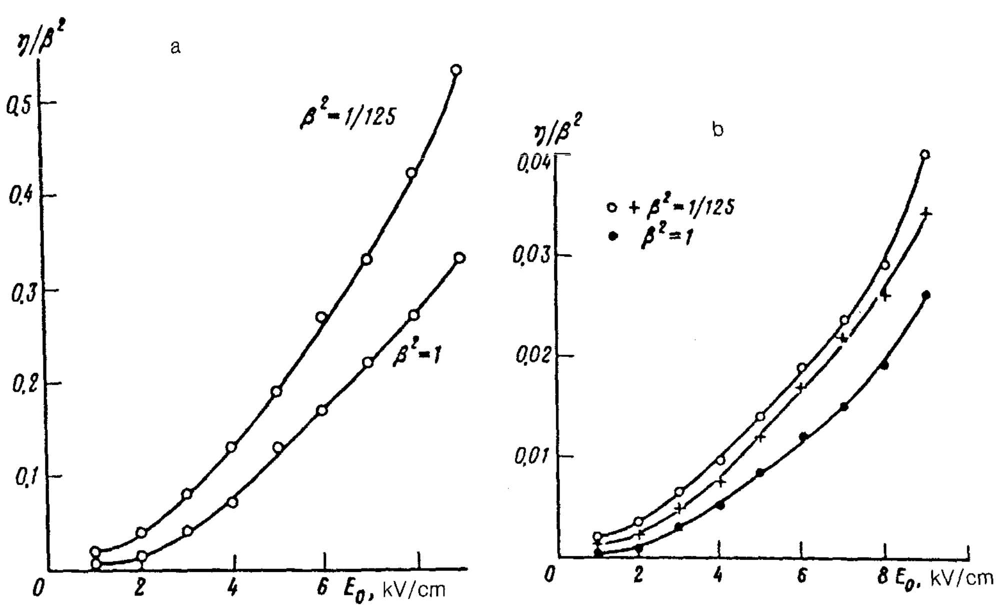

FIG. 2. The diffraction efficiency η, divided by the ratio of the signal and pump intensities, β^2, versus the amplitude of the alternating external field, E_0. ○—The optic axis is directed to the right (Fig. 1); +—to the left. a) Spatial period $\Lambda \sim 100$ μm; b) $\Lambda \sim 2$ μm.

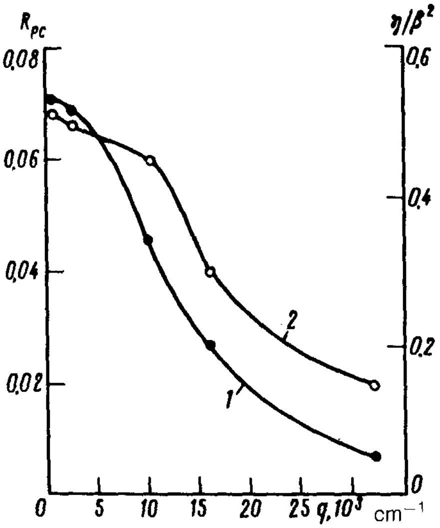

FIG. 3. *1*—Normalized diffraction efficiency η/β^2 versus the spatial frequency q for $E_0 = 9$ kV/cm and $\beta^2 = 1/125$; *2*—reflection coefficient in the four-wave mixing versus the spatial frequency q for $E_0 = 8$ kV/cm, $I_1/I_3 = 1$, and $I_2/I_1 + I_3 = 1/250$.

In the present experiments, the sign of the electrooptic coefficient depended on the direction of the optic axis of the ferroelectric crystal. By rotating the crystal through 180° we reversed the effect of the secondary gratings which were written, reducing or increasing the total diffraction efficiency. The effect of self-diffraction was noticeable only at spatial frequencies $\Lambda < 2\ \mu\text{m}$ (Fig. 2). We see from Fig. 2 that for a unit ratio of the intensities of the writing beams the self-diffraction does not have a significant effect, since the secondary gratings, of identical amplitude, are out of phase.[4,5] The functional dependence of the diffraction efficiency on the external field agrees with the theoretical prediction[4] $\eta(E_0) \propto E_0^2$. On the other hand, the absolute value is smaller than the theoretical value calculated[1] with the electrooptic coefficient $r_{33} = 45$ pm/V. Apparently the actual value of r_{33} is smaller.

Figure 3 shows the diffraction efficiency versus the spatial frequency $q = 2\pi/A$. The functional dependence $\eta(q)$ agrees qualitatively with theoretical predictions.[4] The decrease in diffraction efficiency at high spatial frequencies is a consequence of diffusion and a saturation of trapping centers. In addition, when the angle between the writing beams is large the polarizations of these waves are not strictly collinear. The result is a decrease in the effective contrast of the traveling interference pattern which does the writing. For the nondegenerate four-wave mixing, there are also differences from the degenerate case, because of self-diffraction effects.[5] In these experiments, the negative feedback was eliminated in the case of the nondegenerate four-wave mixing because the writing by the diffusion mechanism was weak.

The reflection coefficient in the case of four-wave mixing is defined as $R_{pc} = I_4(0)/I_2(0)$. The Fresnel losses and the absorption are thus taken into account automatically in this definition of the efficiency R_{pc}. A conjugate signal is not observed when the piezoelectric transducer is turned off ($\Omega = 0$). Figure 3 shows the reflection coefficient for the case of four-wave mixing as a function of the spatial frequency for the nondegenerate interaction. This behavior is similar to that of the diffraction efficiency. The smaller absolute value of R_{pc} is explained on the basis that the contrast of the resultant interference pattern is lower. We should also point out that Fresnel losses and absorption are incorporated in the definition of R_{pc}. The writing mechanism which we studied here is a broad-band mechanism in terms of the spatial frequency q. The time taken to write the holograms in these experiments was 1–10 s.

In summary, we have studied the writing of a static hologram by a rapidly traveling interference pattern in an alternating external field. We studied the effect of diffusion on the writing of a grating. We studied the cases of two- and four-wave mixing. The experimental results agree reasonably well with previous theoretical predictions.[4]

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