Self-enhancement of $LiNbO_3$ holograms*

T. K. Gaylord
School of Electrical Engineering, Georgia Institute of Technology, Atlanta, Georgia 30332

T. A. Rabson, F. K. Tittel, and C. R. Quick
Electrical Engineering Department, Rice University, Houston, Texas 77001
(Received 23 August 1972; in final form 2 October 1972)

Self-enhancement (an increase in diffraction efficiency upon readout with a single laser beam) is reported for iron-doped $LiNbO_3$ holograms which have not been "fixed" (crystal heated to 100 °C during or after recording). The rate of change for self-enhancement was observed to be equal to and opposite in sign with the rate of erasure observed in the same crystal at the symmetrical Bragg angle.

Volume holographic storage in $LiNbO_3$ crystals has previously been reported.[1,2] These holograms, which potentially have very high information storage capacity, can be produced directly by the interference between light beams intersecting in the crystal.

These holograms are typically written with blue or green light and tend to be insensitive to light of longer wavelengths.[1] Due to the volume (thick) nature of these holograms, the stored data can in general only be read out at the writing wavelength. Thus the lower-frequency light in the insensitive region of the spectrum cannot be used to reconstruct the hologram. Further, if light of the writing wavelength tends to erase the hologram upon uniform illumination during readout, then the hologram will ultimately be erased after a sufficiently large number of readings.

A "fixing" technique for obtaining erasure resistent holograms has been demonstrated by Amodei and Staebler.[3] This method typically involves heating the storage crystal to 100 °C in air during or after exposure. Using this technique, stable nondecaying storage has been achieved—an extremely important effect in producing permanent read-only storage.

The diffraction efficiency of a fixed hologram may be further increased through a self-enhancement process.[3] For the geometry illustrated in Fig. 1, this essentially involves illuminating the hologram with the writing laser beam which has a component of its direction along the $+c$ axis of the crystal. The additional diffraction efficiency produced in this way is not "fixed" and is completely optically erasable. Reversing the direction of the c axis (or equivalently reading out with the other beam) causes the opposite effect, a decrease of diffraction efficiency or erasure. This reversal is consistent with the symmetry expected if the observed induced refractive-index changes are of an electro-optic origin.

In "normal" holograms (holograms which have not been fixed) self-enhancement has not previously been reported. However, the analysis of Staebler and Amodei[4] has indicated that such an effect may occur. Further, they have measured variations in the erasure decay time for the two c-axis orientations given above, with the longer decay time corresponding to the beam with a component in the $+c$-axis direction as shown in Fig. 1. Apparently self-enhancement does occur for this case but an erasure effect is also present and is large enough so that the over-all diffraction efficiency is decreased rather than increased.

The present work reports the existence of self-enhancement in normal holograms written in iron-doped $LiNbO_3$. This is in agreement with the above-mentioned self-enhancement results for a beam orientation of $-\varphi_{Bragg}$ (Fig. 1). Further, erasure is observed for a beam orientation of $+\varphi_{Bragg}$ which is equal in rate, but opposite in sign, to that observed for the self-enhancement. These data are shown in Fig. 2. For self-enhancement (at $-\varphi_{Bragg}$) the rate of change of diffraction efficiency $d\eta/dt$ was 2.97×10^{-8} sec^{-1}. For erasure (at $+\varphi_{Bragg}$) the rate of change $d\eta/dt$ was -3.11×10^{-8} sec^{-1}. Thus the magnitude of the two effects were the same to

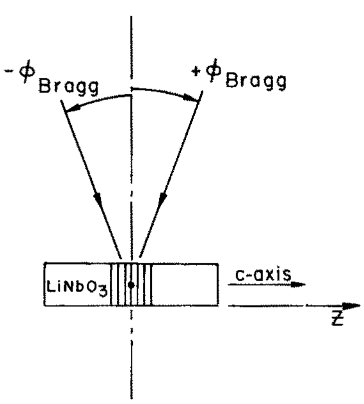

FIG. 1. Configuration of $LiNbO_3$ crystal and writing beams.

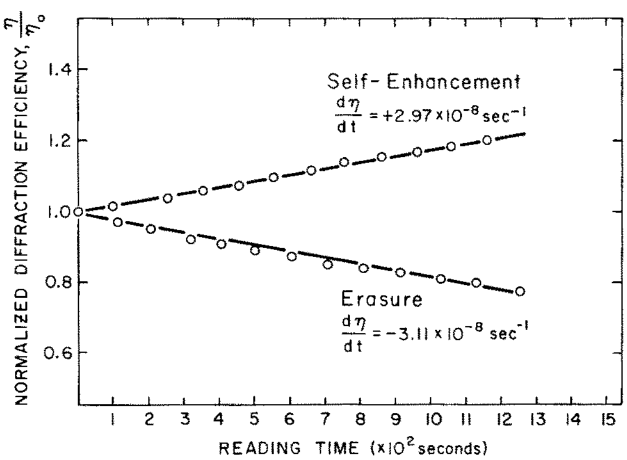

FIG. 2. Diffraction efficiency of a hologram in $LiNbO_3$ for self-enhancement (reading beam at $-\varphi_{Braggs}$), and erasure (reading beam at $+\varphi_{Braggs}$), $\eta_0=1.71\times10^{-4}$.

within 5%. The changes in diffraction efficiency were essentially linear for the time range (0–2000 sec) and power density (10.4 mW/cm^2) used here. A 1-mm-thick poled single-domain $LiNbO_3$ crystal doped with 0.05 mole% iron was used in this work. The crystal was oriented with its *b*-face surface perpendicular to the bisector of the writing beams and with the *c* axis in the plane of the writing beams as shown in Fig. 1. The angle between writing beams was 8.8°. A frequency-doubled Nd:YAG laser (5300 Å) was used with the polarization of the light beams in the plane of incidence. The starting hologram had a diffraction efficiency of 1.71×10^{-4} which was about 20% of the saturation diffraction efficiency.

In summary, self-enhancement in normal holograms (holograms which have not been fixed) is reported here. The observed characteristics of this self-enhancement are consistent with those predicted by the theory of Staebler and Amodei.[4] Self-enhancement in normal holograms may be important in high-capacity data storage applications in that (i) the information may be read out without degrading the hologram so that the memory does not require refreshing and (ii) the crystal need not be "fixed," allowing the data to remain changeable.

*Work supported by the National Aeronautics and Space Administration.

[1]F. S. Chen, J. T. LaMacchia, and D. B. Fraser, Appl. Phys. Lett. **13**, 223 (1968).
[2]J. J. Amodei, W. Phillips, and D. L. Staebler, IEEE J. Quantum Electron. 7, 321 (1971).
[3]J. J. Amodei and D. L. Staebler, Appl. Phys. Lett. **18**, 540 (1971).
[4]D. L. Staebler and J. J. Amodei, J. Appl. Phys. **43**, 1042 (1972).