OPTICAL PHASE CONJUGATION IN PURE AND Fe DOPED $LiNbO_3$

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ABSTRACT

Light induced refractive index modulations in photorefractive crystals can be used to advantage to obtain optical phase conjugation (OPC) through Degenerate Four Wave Mixing (DFWM). The applications of OPC in various adaptive optical systems are well known. Among the of photorefractive crystals, $LiNbO_3$ has been chosen for the present studies on account of its greater spontaneous polarization and higher refractive index modulation constant.

In this paper, we report the studies in pure $LiNbO_3$ and Fe (0.02%) doped sample, using 488 nm, which is towards the absorption edge, whereas the earlier reports were with 514.5 nm. The formation and erasure times of the phase grating and the phase conjugate signal are measured using 488 nm wavelength with the pump beams of power 8 mW and probe beam of power 1.2 mW. In the Fe doped crystal, the formation and decay of the phase grating follow a near exponential pattern. The phase conjugate signal also behaves similarly with a formation time of 840 sec and a decay time of 1200 sec. These results are in agreement with the previously predicted values by other workers.

In pure $LiNbO_3$ crystal, though the decay of the phase grating follows the exponential form, with a decay time of 2000 sec, the formation of the phase grating is observed to follow a rather different pattern. After a gradual increase in the diffraction efficiency in the first 600 sec, there is a fall during the next 200 sec and an increase thereafter and subsequent fall. The reasons for this type of behaviour is explained on the basis of a dynamic approach to the volume grating that is formed.

INTRODUCTION

Optical Phase Conjugation (OPC) has got many applications, involving a real time processing of electromagnetic fields. There are applications both in the spatial and frequency domains. For example, aberration correction, autotracking, image processing with submicron resolution, mathematical processing, implementation of parallel optical logic, etc., are among them.

Time reversed wavefronts can be generated by a suitable mixing of waves in appropriate nonlinear material. Photorefractive materials have an advantage in this aspect because of greater nonlinearity to even weak light beams. $LiNbO_3$ is chosen for the present studies because it has greater spontaneous polarization and higher refractive index modulation.

Photorefractive effect occurs in noncentrosymmetric photoconductors and can be summarized as follows:

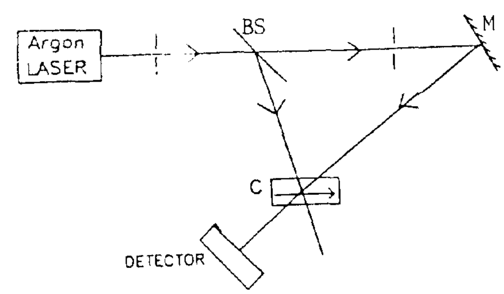
1. Light induced charge migration in crystals,
2. Separation of these charges leading to a static electric field and
3. Electrostatic field induced refractive index change (Pockels effect).

Photorefractive effect is different from other light induced refractive index changes in that the steady state refractive index change is independent of the total intensity of the beams but is dependent on their relative intensity and there is a spatial shift between the intensity pattern and the resulting index variation. Also the speed of this effect is dependent on the total intensity. These peculiarities have led to the extensive studies on these materials and excellent review of these studies can be found in P. Gunther [1] and T.J. Hall et al [2]. Despite these extensive studies, a single photorefractive crystal, with all the desirable qualities for photorefractive effect and free from all the drawbacks is not available today.

Phase grating experiment in $LiNbO_3$ was first reported by F.S. Chen et al [3] and since then few more groups have done experiments using 514.5 nm. Our present studies are with 488 nm which is towards the absorption edge of the crystal.

EXPERIMENTAL ARRANGEMENT

Phase grating formation and erasure studies are done with two beam coupling (figure-1). This setup consists of two beams I_1 and I_2 (where I_2 is approximately 1/8th of I_1), derived from the 488 nm output of a Spectra Physics Ar^+ laser. Both the beams are allowed to illuminate the crystal which is kept with its c axis perpendicular to the intersection of the beams. As the grating is being formed one of the write beams gets diffracted by the grating and its intensity is measured as a function of time. when decay of the phase grating is to be studied, one of the beams is blocked and the decreasing intensity of the diffracted beam is measured.



BS - Beam Splitter
M - Mirror
C - Crystal

FIG.1

OPC is achieved through Degenerate Four Wave Mixing (DFWM). The arrangement consists of two counter-propagating beams I_1 and I_2 (pump beams) and a third weak beam I_3 (probe beam) incident at an angle 2θ to one of the pump beams. By nonlinear interaction inside the crystal a fourth beam is generated counter-propagating to I_3 and is the phase conjugate of it (I_4). The appearance of the fourth beam can be interpreted as a consequence of the diffraction of one of the pump beams on the grating formed by the inter-

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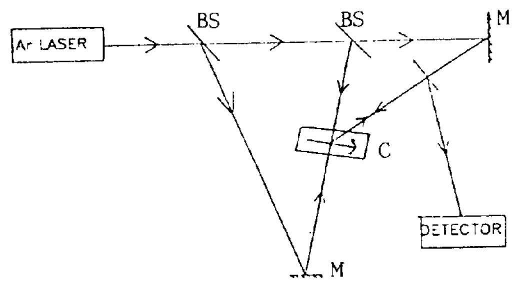
ference of the other pump. The experimental setup used in our present studies is shown in figure-2. Throughout the experiment, the c axis of the crystal is oriented perpendicular to the bisector of the two write beams. The phase matching condition is satisfied automatically with $k_1 = -k_2$ and $k_3 = -k_4$.



BS - Beam Splitter

M - Mirror

C - Crystal

FIG.2

RESULTS AND DISCUSSIONS

The time evolution of phase grating is studied, with the experimental arrangement shown in figure-1. Figure -3 shows the growth and decay of the phase grating in Fe doped $LiNbO_3$. It has been observed that the grating grows completely in 400 sec. The parameter Diffraction Efficiency (η) is the ratio of diffracted beam intensity to the incident beam intensity (I_3/I_1). On blocking one of the beams, it is found that the written grating decays exponentially and is almost erased off within 1000 sec.

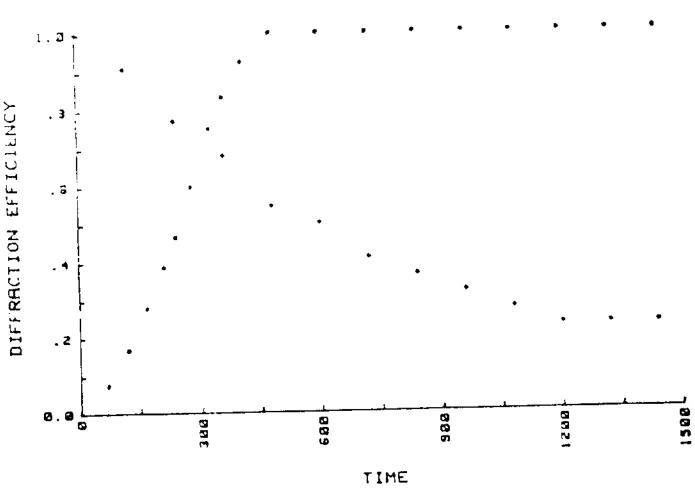


FIG.3

Figure -4 shows the time evolution of phase conjugate reflectivity (R), the ratio of phase conjugate beam to the read beam (I_4/I_3), DFWM geometry shown in figure -2 was used for the purpose. The values are corresponding to the Fe doped samples. The maximum reflectivity is achieved in 950 sec and the signal vanishes in 1200 sec, when the continuous writing of phase grating is prevented by blocking the forward pump beam (I_1).

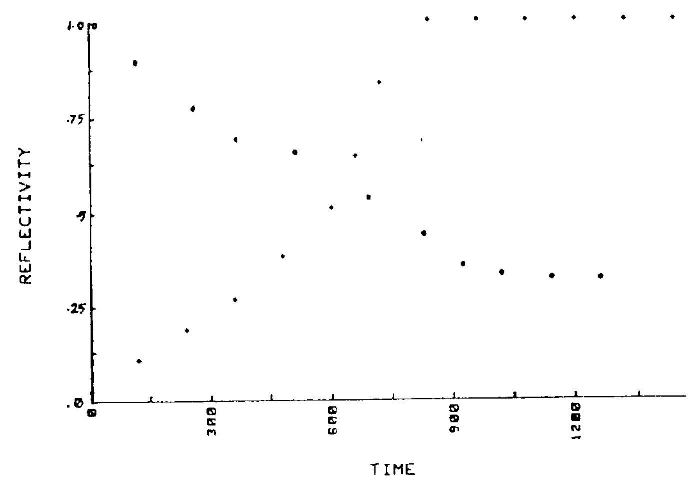


FIG.4

Peculiar grating growth patterns were obtained when phase gratings were written in nominally pure, unpoled as grown samples. There was a continuous growth in the diffracted signal while both the beams were allowed to write the grating. Then after a particular time, there is a reduction in the diffraction efficiency, which continues for a while before the signal starts building up again. Thus, instead of a continuous growth, fluctuations in diffraction efficiency were seen. The results are shown in figure-5. These irregularities were earlier attributed to the experimental limitations, but they are not and in fact genuine and to be expected. Ninomiya [4] developed a dynamic theory for volume hologram recording and R. Magnusson et al[5] applied the above mentioned theory successfully to explain the experimental results in Fe doped $LiNbO_3$ using 514.5 nm writing beams, whereas our results are with pure $LiNbO_3$ and using 488 nm. This dynamic approach predicts an erasure of the phase grating under the influence of the sum of the writing beam intensities ($I_1 + I_2$), while the grating itself grows under the influence of ($I_1 - I_2$). This, in fact, explains even the small scale fluctuations in grating growth.

In our erasure method, only one beam is present and it erases out the phase grating (with its uniform illumination) as it reads the same and a total erasure is complete in 1200 sec. This is a static erasure of the phase grating and no fluctuation is observed, as is expected.

ACKNOWLEDGEMENT

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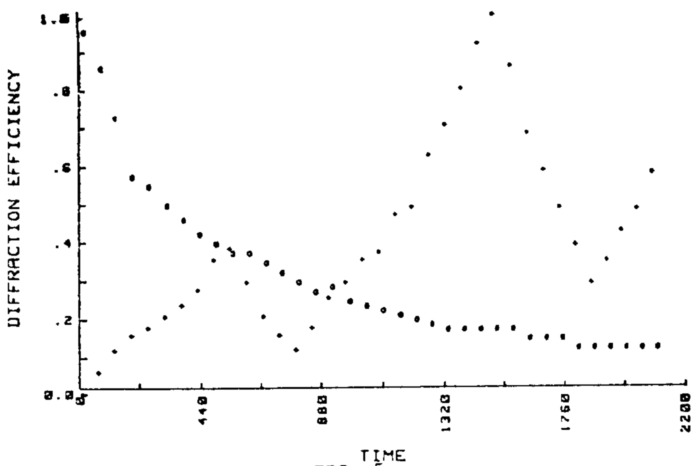

FIG. 5

REFERENCES

1. P.Gunther, "Holography, Coherent Light Amplification and Optical Phase Conjugation with Photorefractive Materials", Phys.Reports, Vol.93, pp 199-299, No.4, 1982.

2. T.J. Hall, R. Jaura, L.M. Connors and P.D. Foote, The Photorefractive Effect- A Review", Prog. Quant. Electr., Vol.10, pp 77-146, 1985.

3. F.S. Chen, J.T. LaMacchia and D.B. Fraser, "Holographic Storage in Lithium Niobate", Appl.Phys. Lett., Vol.13, pp 223-224, 1968.

4. Y. Ninomiya, "Recording Characteristics of Volume Holograms", Jl. Opt.Soc.Am., Vol. 63, pp 1124-1130, Sept. 1973.

5. R. Magnusson and T.K. Gaylord, "Use of Dynamic Theory to Describe Experimental Results from Volume Holography", Jl.Appl.Phys., Vol.47, pp190-199, Jan. 1976.