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Crystal diffraction grating in $LiNbO_3$:Fe derived from interferometric volume holography

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Abstract

A 90° two-beam coupling configuration was used to store an image of an extended object in a 0.032 %wt iron-doped $LiNbO_3$ crystal. A volume hologram was thus generated, via the photorefractive effect, within the microstructure of the crystal. The time evolution of partial spatial erasure of the hologram under illumination was studied by capturing its reconstructed image on a digital camera and performing a two-dimensional inverse Fourier transform. This produced the refractive index grating created through interference of object and reference beams. The nature, intensity distribution and dimensions of the diffraction grating were derived in order to throw light upon the movement and mechanisms of charges, which create the index grating.

Keywords: Photorefractive effect; Volume holography; Two-dimensional fourier transform; Holographic data storage

1. Introduction

The photorefractive effect, where a space-charge field set-up inside $LiNbO_3$ caused variation of refractive index via electro-optic effect, was discovered as long ago as

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1966 by Askin et al. [1]. It was soon discovered that this effect had an important use for holographic data storage [2]. Since that time many new photorefractive crystals and media have been discovered [3], and the possibility of utilising these media for volume holography [4] has been realised.

Holography is the process whereby the light field scattered from an object is reconstructed (in both amplitude and phase) from a set of fringes produced when its scattered light field interferes with that of a coherent reference beam. If the object is simple (such as a flat plate), then the interference fringes would yield the traditional Young's pattern of a cosinusoidal irradiance distribution with an evident spatial period of $\lambda/\sin\theta$ and spatial frequency of $\sin\theta/\lambda$ [5,6]. For an object of complex optical structure, these cosinusoidal fringes lose their symmetry to become considerably more complicated. They are often covered in extraneous swirls and ring-like systems due to diffraction from dust on the optical elements. Once recorded, a construction beam may be shone upon the fringe system (the hologram) and thus the original object light field reconstructed as an image.

Application of these techniques was impossible at these times, since the technology to transfer information from the storage medium to computer for analysis was unavailable until the mid-1990s with the introduction of charge-coupled devices. Even with the widespread interest thus initiated, a serious problem encountered in all media is the erasure of stored data during the readout process. Methods of achieving non-destructive readout of stored data are a primary aim in the field of holographic data storage.

It is not expected that thermal effects are the primary cause of partial spatial erasure of the hologram [7] at the low-light levels used in this experiment. There are three other mechanisms which may cause this effect: (i) Periodic dependence of the diffraction efficiency as described by Kogelnik's equation [8],

$$\eta = \sin^2\left(\frac{\pi\,\Delta n d}{\lambda\cos\theta}\right), \tag{1}$$

where Δn is the magnitude of the refractive index change, d is the crystal thickness and $2\theta = \alpha$, the angle between the object and reference beams. During recording of an extended object, this angle varies depending on the location of the point on the object from which the object light originates. This variation causes a location-dependent change in η according to Eq. (1). (ii) Spatial variation of light intensity of the illuminating laser beam during recording, since the index grating created by the electro-optic effect is linearly proportional to the space-charge field caused by the migration of charge carriers out of bright regions (where electrons from impurity levels can absorb the light and enter the conduction band). Since electrons are preferentially excited in the bright fringes, they diffuse towards the dark fringe regions. This is directly related to how homogeneous the illumination of the crystal is. This charge distribution sets up an internal electric field called a space-charge field. The excitation of electrons from an Fe^{2+} donor to Fe^{3+} acceptor centres through the conduction band [9] can be considered to cause the formation of a capacitor. An important role for the process in the $LiNbO_3$ crystals is played by cationic Li/Nb non-stoichiometry [10]. Such non-stoichiometry may sometimes provide a crucial contribution to the history of the photorefractive process. Such a 'capacitor' will decay