FANNING NOISE SUPPRESSION IN DUAL-WAVELENGTH HOLOGRAPHIC STORAGE*

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Abstract It was shown how the fanning noise is reduced by the dual-wavelength method in the photorefractive crystals. The non-destructive readout can be realized. The experiments were first done with lithium niobate doped with iron to find the optimal reading out configuration. Afterwards lithium niobate doped with iron and magnesium was used to record the high signal-to-noise-ratio holograms. In order to retrieve the hologram with filed losses a cylindrical lens was added into the reference path.

Key words dual-wavelength, fanning noise, non-destructive.

双波长全息存储中的扇形噪音抑制*

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摘要 分析了普通配置下双波长存储中，不同波长偏离对扇形噪音读出的影响，并从实验上研究了掺铁铌酸锂晶体的最佳读出配置。为能使所存图像完整再现，使用了一个柱面镜来调整读出光的波前，在双掺铌酸锂晶体中实现了整幅图像高信噪比再现，达到了预期效果。

关键词 双波长，扇形噪音，非破坏。

Introduction

Since the last decade holographic methods[1] have become very popular in material research. Many materials ranging from crystals to polymers to liquids have been examined in order to use them for optical data storage, waveguides[2], phase conjugation[3], image amplification, frequency doubling, and so on. Especially data storage applications seem to be very attractive. With a theoretically predicted storage density of 10^{18} bit/m^3 and with a tremendous reading speed, in future, such materials will replace common devices like magnetic hard discs. Lithium niobate, which is one of the most widely used electro-optical materials, has been treated in many ways, e. g. by doping with various elements, thermal treatments, applying electric voltages, and examining it at wavelengths

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from ultraviolet to infrared. But problems still exist, which have to be solved first, such as avoiding the effect of the beam fanning and the nondestructive reading out of the stored information.

Beam fanning, the amplified light-induced scattering from the defects on the surface of or in the crystal, can deplete the energy of the pump beam as well as the signal beam and make the reconstructed image noisy. Many techniques have been proposed to suppress the beam fanning, by doping with damage-resistant dopants (In^{3+}, Mg^{2+}, Zn^{2+}), the properties of the photorefractive crystals could be optimized. So we used the double-doped lithium niobate as our storage medium, but the experiments were first done with the iron-doped lithium niobate to choose the proper readout configuration.

Several methods, including thermal fixing[4], electrical fixing[5] and two-step recording,[6] have been developed to realize nonvolatile readout. Another effective method was the dual-wavelength method, the shortage of this technique was the partial retrieval of the stored information because the signal beam wasn't plane wave. Petrov[7] and Psaltis[8] improved this method, but the recording processes involved in these techniques are complicated and time-consuming, therefore, it is difficult to design a practical storage system based on these methods. Our group proposed a convenient and effective way by adding one cylindrical lens in the reference path, the problem of the image field losses can be solved simply. Furthermore, the Bragg mismatch in dual-wavelength method reduced the retrieval of the fanning noise.

In this paper first the structures are investigated with the fanning noise in lithium niobate doped with iron to search for the right readout configuration. And then an effective way is reported in lithium niobate doped with iron and magnesium to solve the problem of image field losses.

1 Resistance of the beam fanning

During the production of a grating, undesired structures occur due to the fact that the incident reference and signal waves are scattered by inhomogeneity in and on the surface of the crystal under consideration. As this phenomenon can also be examined by using only one beam hitting the lithium niobate crystal the results in the following were got only from holographic scattering experiments using the experimental set-up in Fig. 1. The laser used is an argon-ion laser, which provides the wavelengths 514, 501, 496, 488, 476, and 458nm. The investigated sample is a $LiNbO_3$ crystal doped with 0.05Wt% Fe_2O_3 in the melt with the dimensions $a \times b \times c = 22 \times 13 \times 12mm^3$.

The transmitted intensity is determined by the number of parasitic gratings. This number depends on how many scattered waves interfere with the incident beam. The total possible scattered intensity remains constant for a given structure of parasitic gratings inside the sample. The total scattered intensity, which appears during the reading process depends on the angle, the reading wavelength, the rotation axis of the sample, and the polarization. According to this model[9] every material, where light-induced structures appear, can be characterized in detail. Our experiments were perfomed on different rotation axis and the reading wavelength. For reading a light-induced structure with different rotation axis two cases have to be distinguished.

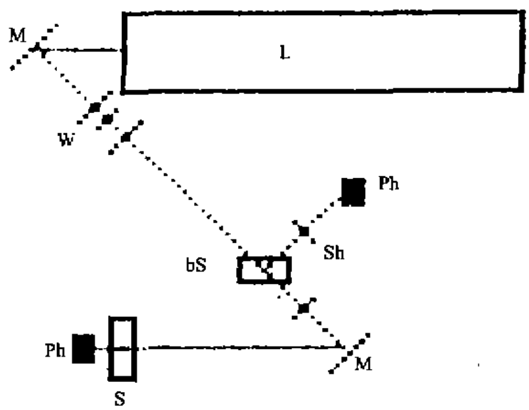

Fig. 1 Experimental setup for holographic scattering experiments: L—laser, W—expansion system, bs—beam splitter, M—mirror, sh—shutter, ph—photodiode, s—sample holder
图1 全息光散射实验装置:L—激光器, W—扩束系统,bs—分束器,M—反射镜, sh—开关,ph—光二极管,s—样品夹持器

The rotation about an axis parallel to the c-axis is referred to as ω-rotation, and the rotation perpendicular to the c-axis as φ-rotation. The different wavelengths were provided by the argon-ion laser.

The light-induced structures were examined which were produced with the wavelength 514nm with an exposure of $120Ws/mm^2$ and read by the wavelengths 514, 501, 496, 488, 476, and 458nm with an intensity of $1.5mW/mm^2$. The results for the ω-rotation can be seen from Fig. 2, where the stated angels refer to that in the medium. The results for the φ-rotation are given in Fig. 3. But due to the fact that the rotation table used in the experiments had only one rotation axis, the light-induced structures were produced again before they were used for the φ-rotation case.

When the rotation angle was equal to zero and the readout wavelength was equal to that of the recording light, the transmitted light intensity was the smallest in both rotation case, because the Bragg condition was fulfilled for any parasitic gratings and all of the noise gratings could be retrieved. While the crystal was rotated deviating the original angle, because each parasitic grating requires a distinct Bragg-matching condition, the readout wave at different angle could read out only some of the gratings, the transmitted light intensity became higher than that of the zero-angle case. The main difference between both rotations is that their FWHM differs by a factor of seven. Therefore, the φ-rotation, which can provide a large storage capacity, is chosen instead of the ω-rotation in the angular-multi-storage system.

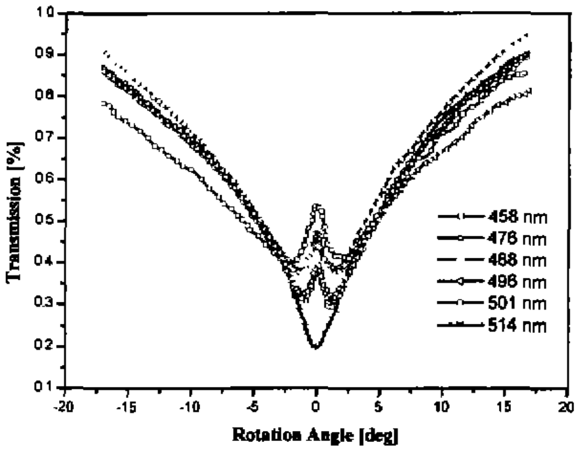

Fig. 2 Transmission as a function of the rotation angle; reading with different wavelengths at ω-rotation with an intensity of $1.5\ mW/mm^2$; recording with the wavelength $\lambda = 514\ nm$ with an exposure of $120Ws/mm^2$

图 2 透射率和转角的关系(用514nm激光记录噪声栅，曝光量为 $120\ Ws/mm^2$，以 ω 方向转动晶体，用 $1.5mW/mm^2$ 不同波长的激光读出噪声栅)

When we changed the readout wavelength, the circumstance was similar, only part of the parasitic gratings could match the Bragg condition. Therefore, the transmitted light intensity was stronger than that readout with the 514nm. As a result, the bigger the readout wavelength deviation, the smaller the fanning noise which could be read out. Furthermore, if the wavelength of the readout beam is longer than that of the recording beams, for example 670nm, we could realize non-destructive readout, this method is called the dual-wavelength technique.

2 Reduction of the field losses

Assuming the signal and the reference beams are plane waves, a hologram consisting of a single grating can be recorded. The hologram can be reconstructed by a plane readout wave with Bragg

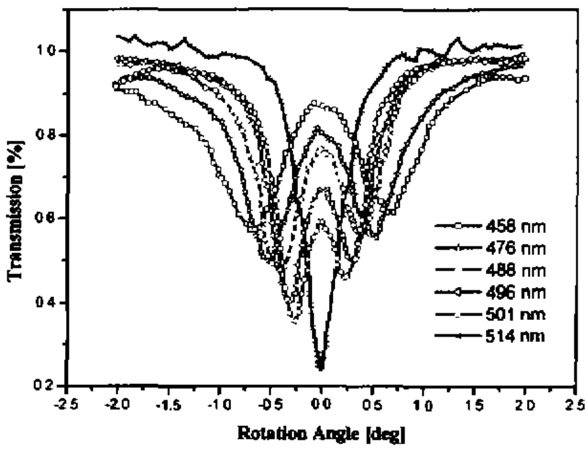

Fig. 3 Transmission versus rotation angle for different reading wavelengths; φ-rotation; recording withthe wavelength $\lambda = 514nm$ with an exposure of $100\ Ws/mm^2$; reading with an intensity of $1.5\ mW/mm^2$

图 3 透射率和转角的关系(用514nm激光记录噪声栅，曝光量为 $100\ Ws/mm^2$，以 φ 方向转动晶体，用 $1.5mW/mm^2$ 不同波长的激光读出噪声栅)

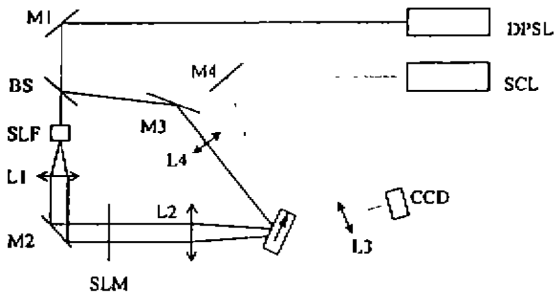

Fig. 4 Experimental setup for holographic storage: DPSL — diode pumped solid laser, SCL—semiconductor laser, M's—mirrors, SLF—spatial light filter, L1,L2 and L3— spherical lenses, L4—cylindrical lens, BS—beam splitter

图 4 全息存储实验装置(DPSL—半导体二极管泵浦固体激光器,SCL—半导体激光器,M′s—反射镜,SLF—空间光滤波器,L1、L2 和 L3—球面镜,L4—柱面镜,BS—分束器)

matched at any wavelength $\lambda' < 2\Lambda$, where Λ is the grating fringe spacing, and λ' represents a readout wavelength. When the hologram is reconstructed at different wavelength, the incident angle of the readout beam θ' should be adapted to the corresponding Bragg angle.

However, it should be poined out that in the traditional storage setup, as shown in Fig. 4, the output from one point on the spatial light modulator (SLM) is not collimated owing to diffraction. After the spherical lenses (L2 and L3) they will be focused on a point on the image plane. These wave vectors include one ground spatial frequency component and many high spatial frequency components. The ground spatial frequency components from all points on SLM play the key role in the image field losses of dual-wavelength method. Therefore, the signal beam can be considered as a spherical beam only composed of the ground spatial frequency components. As a result, the recorded holograms will consist of multiple gratings with different grating vectors. Because each grating requires a distinct Bragg-matching condition, the plane readout wave with a wavelength differnet from that of the writing beam could only read out part of the gratings, the stored information could be partly retrieved.

Here we find that the image retrieval with plane readout wave without image field losses could also be realized by using a cylindrical recording reference beam according to the storage geometry and the wavelengths of the writing beam and the readout beam. By shaping the reference wave front, we can get the grating vectors which could be reconstructed by the red plane readout wave.

The experimental setup is shown in Fig. 4, two extraordinarily polarized beams from a diode pumped solid laser (wavelength: 532nm) record holograms. The crossing angle between the two recording beams is 45° in air. The signal beam, which is expanded and collimated, passes through a computer-addressed SLM. Further a cylindrical lens (L4) is put into the reference beam to change the reference wave front. A $LiNbO_3$ crystal[10], $a \times b \times c = 12 \times 14 \times 4.5mm^3$, co-doped with iron (0.05Wt%) and magnesium (0.8mol%), is used in the experiment as the storage medium. The c-axis lies in the incident plane. For retrieval, a plane wave at 670nm from a semiconductor laser reads out the recorded holograms. An imaging lens (L3) and a CCD camera are arranged to detect the

(a) (b)

Fig. 5 The reconstructed image by plane readout beam (a) the reference wave is a cylindrical wave, (b) the reference wave is a plane wave

图 5 用平面波再现的图像:(a)参考光为柱面波前、(b)参考光为平面波前

retrieved image. In the experiment the distance equal to the focal length, $f=300$nm, of the lens (L2) lies between the SLM and L2, which brings the signal beam to a focal point of 15mm behind the sample. In order to adapt the reference wave front, the cylindrical lens with $f=200$mm is added to the reference light path to focus the reference beam to a point of 106.5mm behind the sample. The stored image is read out by using a plane wave at 670nm. This is shown in Fig. 5 (a). For a comparison, we also record holograms without the additional lens L4 in the reference arm. The reconstructed image, again with a plane wave at 670nm, is shown in Fig. 5(b). Now only one fifth of the stored image is retrieved. From this it can be seen that retrieval of holograms without image field losses with dual-wavelength nonvolatile holographic method could be effectively realized by adding a cylindrical lens into the reference arm.

3 Conclusion

In conclusion it is shown how the light-induced structures in $LiNbO_3$ doped with different elements can be characterized and by doping with the right elements undesired retrieval of the noise grating can be reduced. Furthermore, a new method for a free image field loss reconstruction of holograms is provided. Therefore the dual-wavelength technique is effective to resist the fanning noise and to realize the non-destructive readout.

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