Phase-Conjugate Imaging Properties in High-Efficiency KNSBN:Cu Double Phase-Conjugate Mirror

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In this study, we investigate the performance of a high-efficiency KNSBN:Cu double phase-conjugate mirror (DPCM). A phase-conjugate transmissivity as high as 58% and a phase-conjugate reflectivity as high as fivefold are observed. Experimental results also show that the DPCM has a good fidelity of phase-conjugate image. Also, amplified phase-conjugate images are observed.

Key words: double phase-conjugate mirror, KNSBN:Cu crystal, phase-conjugate image, image fidelity, phase-conjugate transmissivity, phase-conjugate reflectivity

1. Introduction

In recent years, double phase-conjugate mirrors (DCPMs) draw great attention for their wide applications in the optical computing, image processing, threshold device, interferometer, oscillator, adaptive interconnection and laser injection locking. In some photorefractive crystals, such as BaTiO3 and SBN, DCPMs were formed with different incident geometry. However, the efficiency of these DCPMs was low. In general, the phase-conjugate transmissivity of these DCPMs did not exceed 35%. Recent research shows that the fidelity of DPCM is a function of the efficiency of DPCM. Also, transverse light distribution of phase-conjugate light has a large shift when compared to incident light. It is necessary to form a high-efficiency and high-fidelity DPCM so that a stable high-efficiency DPCM with a modified-bridge geometry in a KNSBN:Cu [Cu-doped (0.04–0.06 wt% Cu) (K0.5Na0.5)0.96Sr0.04Ba0.06Nb2O6] crystal was investigated. In this study, we investigated the efficiency and fidelity of the KNSBN:Cu modified-bridge DPCM. A high phase-conjugate transmissivity and a high phase-conjugate reflectivity are achieved in the DPCM. The experimental results show that the DPCM has a good fidelity of phase-conjugate image. In addition, the amplified phase-conjugate images were observed.

2. Experimental

The experimental schematic of the DPCM is shown in Fig. 1, which is called a modified-bridge geometry. The two extraordinary polarized light beams (diameters of 1.6 mm) of Ar+ laser (wavelength of 514 nm) are incident onto a cubic KNSBN:Cu crystal of 6 x 6 x 6 mm3, as shown in Fig. 1. The two light beams are mutually incoherent, because the difference of the two optical paths is about 80 cm which is much longer than the coherent length (5 cm) of the laser. The incident positions x1 and x2 are symmetrically equal, and the incident angles Φ1 and Φ2 are also symmetrically equal, that is, x1=x2=x and Φ1=Φ2=Φ. Using this experimental schematic, we observed the phase-conjugate transmissivity TPC (TPC=Ic*/Ic) as a function of Ic/Ic as shown in Fig. 2(a). When Ic/Ic is 1, the phase-conjugate transmissivity is 58%, which is close to our knowledge is the highest efficiency value in DCPMs. A great phase-conjugate transmissivity is strongly required in applications. According to Ref. 11, when the incident conditions of the two beams are symmetrically identical, the two phase-conjugate transmissivities of the two incident directions are equal, that is, TPC=Ic*/Ic=Ic*/Ic. In the same incident conditions of Fig. 2(a), the corresponding phase-conjugate reflectivity (RPC=Ic*/Ic) is a function of Ic/Ic, as shown in Fig. 2(b). When Ic/Ic=25, a phase-conjugate reflectivity as high as fivefold is observed. This high value means that the high-efficiency KNSBN:Cu DPCM can be used as a phase-conjugate amplifier. In a self-pumped phase-conjugate mirror (SPPCM), the phase-conjugate reflectivity is always smaller than 100%. The phase-conjugate reflectivity of the KNSBN:Cu DPCM is much higher than that of SPPCM. Therefore, the high-efficiency DPCM can be used in some aspects, where the phase-conjugate light is required to be amplified. Moreover, the KNSBN:Cu DPCM is suitable for working in the lower incident laser power. When Ic=Ic=2 mW, the phase-conjugate transmissivity reached 58% and the gain of the DPCM entered the saturate state. This high efficiency arose from the great coupling constant, low light loss because of the short light path, and a great interaction region in the KNSBN:Cu modified bridge DPCM.

In following experiments of the phase-conjugate image, the experimental arrangement shown in Fig. 3 was used. The beam diameter was expanded to 8 mm, and the two incident beams were focused on the crystal surfaces by two lenses (f=9.5 cm).

In the bridge SBN DPCM, there is a great transverse peak-shift of the phase-conjugate light distribution in comparison with the incident light distribution. This result will affect the fidelity of the DPCM. The bridge SBN DPCM suffers from this defect in applications. For the high-efficiency KNSBN:Cu modified-bridge DPCM, we used a one-dimensional image sensor (1,024 units) to observe the transverse distribution of the phase-conjugate light beam and incident light beam. The apparent trans-
Fig. 1. Experimental schematic of the modified-bridge double phase-conjugate mirror, where the KNSBN:Cu crystal is a cube of $6 \times 6 \times 6$ mm$^3$.

Fig. 2. (a) Phase-conjugate transmissivity $T_{pc}$ vs $I_1/I_2$, (b) Phase-conjugate reflectivity $R_{pc}$ vs $I_1/I_2$, where the symmetrically incident angles are $\Phi_1 = \Phi_2 = 66^\circ$, the symmetrically incident positions are $x = x_1 = x_2 = 2.3$ mm, and in order to produce a large ratio of $I_1/I_2$, a large incident power $I_1$ (10 mW) is used. Here, the abscissa is the log scale.

Fig. 3. Experimental arrangement of phase-conjugate image using KNSBN:Cu DPCM. $A_1$ is the plane of incident image. $A_2$ is the plane of phase-conjugate image.

Fig. 4. Comparison between the transverse intensity distribution of the phase-conjugate light beam (curve 1) and the incident light beam (curve 2). The vertical scale for curves 1 and 2 is different. $d$ is the beam diameter.

verse peak-shift in the phase-conjugate light intensity distribution did not take place, as shown in Fig. 4. Thus, this behavior is beneficial to applications of the DPCM. Based on above experimental results, we consider that the gain of four-wave mixing, by which the DPCM is formed, is identical across the incident beam diameter. The gain of four-wave mixing is in the saturate state anywhere inside the incident beam diameter. Therefore, the apparent transverse peak-shift is not generated in phase-conjugate light transverse distribution. In optical image processing and laser locking, the peak shift must be avoided.

In phase-conjugate mirrors, the spatial resolution of the phase-conjugate image is used to examine the spatial fidelity of the DPCM. In one light pass, we inserted a standard USAF resolution test card to investigate the resolution of the phase-conjugate image. The experimental result is shown in Fig. 5, from which the resolution of the phase-conjugate image is considered to be 32 line pairs/
mm. This shows that the high-performance KNSBN:Cu DPCM has a good spatial fidelity of the phase-conjugation. We recognize that, if the film could be located accurately at the equivalent position of the incident pattern, the resolution may be increased.

When the incident light beams were plane wave, we observed a phase-conjugate reflectivity as high as fivefold, as shown in Fig. 2. In a phase-conjugate imaging experiment, the image-carrying incident beam is a spherical wave. And, inside the image-carrying incident beam, the light distribution is uncontinuous. Thus, the interaction region in the DPCM also is uncontinuous. These two reasons lead to a decrease in the efficiency. The phase-conjugate reflectivity of the image-carrying beam can not reach fivefold. Under spherical incident wave of continuous light distribution, we observed threefold in phase-conjugate reflectivity. Under the spherical incident wave of uncontinuous light distribution in the imaging experiment, the phase-conjugate reflectivity does not exceed twofold. Figures 6(a) and (b) are the comparison between phase-conjugate images with different phase-conjugate reflectivity. In Fig. 6(a) and (b), the intensities of the phase-conjugate images are respectively 1.4 and 0.5 times as large as that of the incident image. These experimental results show that even in a real image experiment, the DPCM has amplifying ability, which is useful in many applications such as compensating light-path loss. In Fig. 6(b), the fidelity of the phase-conjugate image is decreased. This is due to the ratio change between the two incident light beam intensities. For this phenomenon, in Ref. 8, an explanation has been described by Orlov et al.

3. Conclusions

The modified-bridge KNSBN:Cu DPCM has a very high efficiency. A phase-conjugate transmissivity as high as 58%, and a fivefold phase-conjugate reflectivity were observed. The apparent transverse peak-shift of phase-conjugate light distribution in comparison with the incident light did not take place. The high-efficiency DPCM has a high fidelity in phase-conjugate image. The experimental results show that the modified-bridge KNSBN:Cu DPCM can be used as a phase-conjugate amplifier.

References