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Degenerate Polarization Multiwave Interaction between Light Beams in a Solution of Rhodamine 6G Dye

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Abstract—The characteristics of diffracted waves derived from four- and six-wave mixing in a solution of Rhodamine 6G dye are studied in different combinations of the polarization states that participate in wave interaction.

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INTRODUCTION

One of the main problems in today's optics industry is a search for effective new methods for controlling the energy, spectral, and polarization characteristics of laser radiation [1–4]. Along with using anisotropic nonlinear interferometers [5, 6], of particular importance due to their high potential are holographic methods for transforming light fields based on dynamic holograms in solutions of complex organic compounds upon multiwave interactions (MWI) [7].

The aim of the work was to study the dependence of the efficiency of four- and six-wave mixing (FWM and SWM, respectively) with Gaussian and singular signal waves on the polarization of waves recording a hologram, and to establish features of polarization for a diffracted wave with different combinations of the polarizations that participate in multiwave interaction.

EXPERIMENTAL

Our experimental scheme is depicted in Fig. 1. The radiation source was the second harmonic of a Nd:YAG-laser *1*. The laser operated in the mode of active Q-switching with a pulse length of 20 ns and a repetition frequency of 10 Hz. Using beam splitter *2*, mirrors *3*, *4*, and *5* formed the reading, reference, and signal waves, respectively, which converged in a cuvette with a nonlinear medium (Rhodamine 6G dye solution) *10*, where MWI took place. Delay line *6* was used to equalize the optical paths of the signal and reference waves. To create a singular signal beam, holographic transparency *7* was introduced into the scheme. Mirror *8* directed the resulting optical vortex into the cuvette with the nonlinear medium. FWM was achieved upon propagation of the reading wave directly toward the reference wave. To achieve SWM, the reading wave was deflected by moving mirror *3* into position *3*' to produce the corresponding condition of

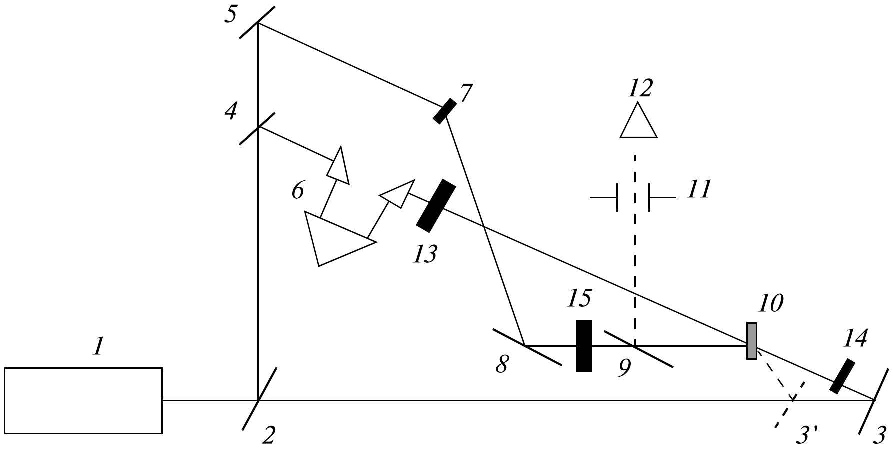

Fig. 1. Scheme of our experimental unit.

phase synchronism. Mirror *9* directed the diffracted beam through diaphragm *11* into registration system *12*. To change the polarization state of the waves, $\lambda/2$ and $\lambda/4$ plates *13–15* were introduced into the system.

RESULTS AND DISCUSSION

The results from investigations on the dependence of the efficiency of MWI with Gaussian and singular signal waves on the angle between the polarization planes of the interacting waves are presented in Fig. 2. It is obvious that the dependences of the intensity of the diffracted wave on the angle between the polarization planes of the signal and reference waves almost coincide for FWM and SWM with the Gaussian signal wave (Fig. 2a). The closer the angle between polarization planes of the signal and reference waves was to 90 degrees, the lower the efficiency of MWI was. Upon orthogonal polarization of the signal and reference waves, the efficiency of MWI was minimal. This is explained by there being no spatial modulation of the intensity; there is only modulation of the light's polarization according to the difference between the wave phases. Light with different polarizations (e.g., linear and circular) excites the dye agent molecules in different ways and induces periodical modulation of a complex refractive index. When this happens, the conditions for polarization holographic recording are attained [8]. The experimental results showed that the efficiency of MWI on polarization holographic gratings was barely one-fiftieth that upon MWI with the same orientation of the interacting waves' polarization planes (Fig. 2a).

When there is MWI with a singular signal wave, the dependence is basically the same. It should be noted, however, that the more complicated effective overlapping of the Gaussian and singular beams is reflected in the greater sensitivity of MWI to changes in the angle between the polarization planes of a single signal and the Gaussian reference waves than for the interaction between all Gaussian light beams (Fig. 2b).

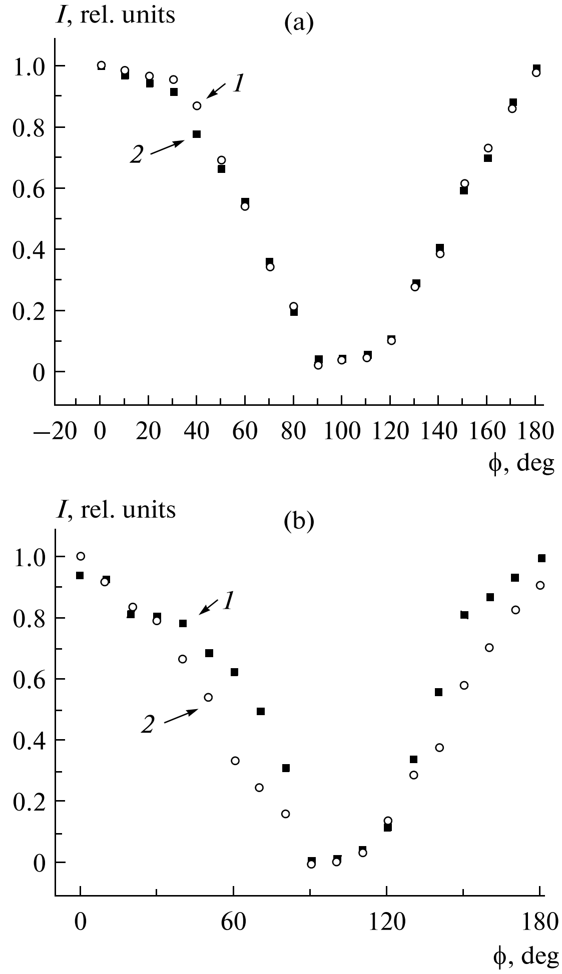

Fig. 2. Dependences of the normalized intensity (*I*) of the diffracted wave on the angle (ϕ) between the polarization planes of waves participating in MWI. (a) (*1*) Upon FWM, (*2*) upon SWM; b: (*1*) FWM with a Gaussian signal wave, (*2*) FWM with a singular signal wave.

Varying the polarization orientations of all the interacting waves allowed us to identify the polarization state of the diffracted wave upon MWI (Tables 1 and 2). It is obvious that during interactions on gratings, recorded with identically polarized waves, the

Table 1. Experimental dependence of the polarization of a diffracted wave upon FWM on the polarization state of the interacting waves

Wave	Polarization							
Reference	→	↑	→	→	↑	→	↑	↑
Signal	→	→	↑	→	↑	↑	→	↑
Reading	→	→	→	↑	→	↑	↑	↑
Diffracted	→	↑	↑	↑	→	→	→	↑

Table 2. Experimental dependence of the polarization of a diffracted wave upon SWM on the polarization state of interacting waves

Wave	Polarization							
Reference	→	↑	→	→	↑	→	↑	↑
Signal	→	→	↑	→	↑	↑	→	↑
Reading	→	→	→	↑	→	↑	↑	↑
Diffracted	→	→	→	↑	→	↑	↑	↑

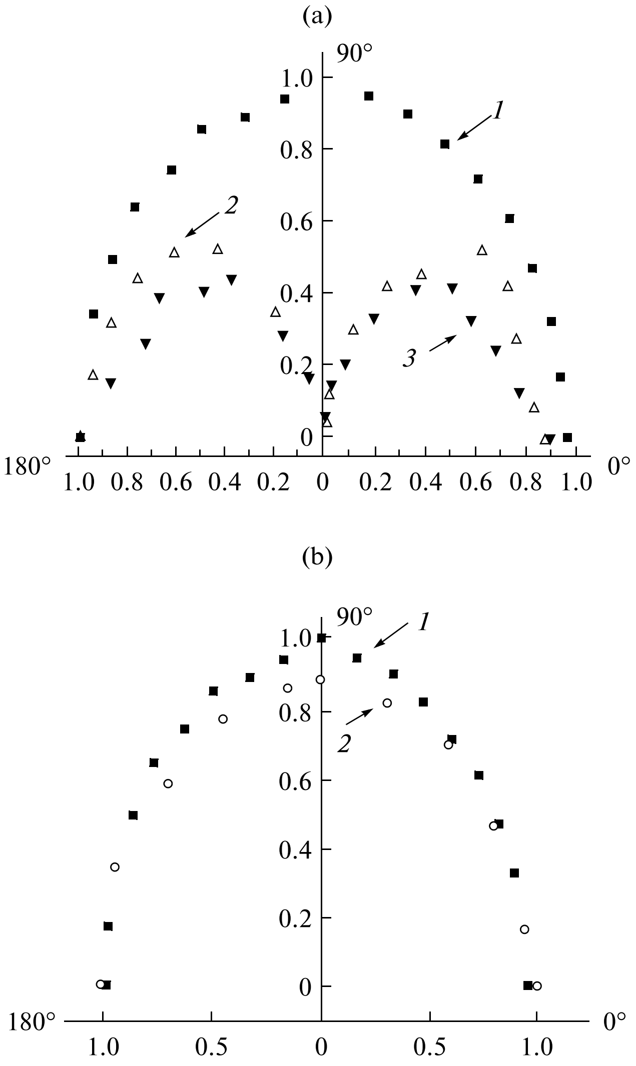

Fig. 3. Indicatrix of the polarization state of a diffracted wave upon FWM. (a) (*1*) Circular polarization state, (*2*) polarization state of a diffracted wave with circular polarization of the signal wave, (*3*) polarization state of a diffracted wave with circular polarization of the reference wave; b: (*1*) circular polarization state, (*2*) polarization state of a diffracted wave at orthogonal circular polarizations of the signal and reference waves.

polarization of the diffracted wave upon both FWM and SWM is determined by the polarization of the reading wave. Another situation observed upon achieving MWI on polarization dynamic gratings: the polarization of the diffracted wave depends not only on the polarization of the reading wave, but on the order of interaction as well. In the course of FWM, the polarization plane of the reading wave turns by 90°, while the polarization of the diffracted wave upon SWM coincides with that of the reading wave. This feature is determined by the specifics of diffraction on the polarization gratings in the first (FWM) and second orders (SWM) and coincides with the data presented in [9] when we consider the interaction between the Gaussian signal, reference, and reading waves. The use of a single beam with screw phase dislocation did not produce any changes and confirmed the independence of features of polarization upon diffraction on polarized dynamic gratings from the type of the signal beam (Gaussian or singular), despite the existence of an orbital moment.

Of particular interest too is considering the MWI of waves with circular polarization. Fig. 3a shows the experimental results from FWM with the circular polarization of one of the interacting waves and the vertical linear polarization of the others. It was shown that upon circular polarization of the reference or signal wave, the polarization of the diffracted wave is elliptical and strongly elongated along the vertical. This can be explained in the following manner: The circular polarization can be presented as the sum of two orthogonal linearly polarized waves with phase displacement between them. The vertical components of the polarization of the waves recording a hologram form a classical dynamic grating, on which diffraction results in conventional multiwave interaction with the formation of a diffracted wave with vertical polarization. The horizontal component of the circular polarization takes part in recording the polarization grating. There is also multiwave interaction that contributes to the horizontal component of polarization of the diffracted wave. As already mentioned, however, the efficiency of such interaction is one to two orders lower, so the horizontal component of the polarization of the diffracted wave is much lower than the vertical component.

The recording of a polarization dynamic grating occurs upon interaction between reference and signal waves with orthogonal circular polarizations, as is reflected in the formation of a diffracted wave with circular polarization upon reading the grating with a wave of linear polarization (Fig. 3b).

CONCLUSIONS

Our results allowed us to investigate the dependence of the efficiency of multiwave interactions with both Gaussian and singular signal waves on the angle between the polarization planes of waves recording a dynamic hologram. The dependences of the polarization state of the diffracted wave upon multiwave interactions between waves with both linear and circular polarization were obtained. The polarization states of diffracted waves with different combinations of the polarizations of all interacting waves were determined. The dependence of polarization on the type of interaction (FWM and SWM) when using a single wave as the signal beam was confirmed experimentally.

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