Conference Paper

Forming of the Optical Beam with the Rotating Polarization Vector

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Abstract

A method for the optical beam production with the rotating polarization vector based on the interference of two beams with the circular polarizations is proposed. The frequency shift between beams is implemented by means of acousto-optic (AO) diffraction. The method is used for the amplitude light modulation with the frequency *nf* where *f* is acoustic frequency and *n* is integer. AO modulators are fabricated from paratellurite crystal. Modulators allow modulating the optical radiation with wavelength of 0.63 mcm at the quadruple frequency of the acoustic wave. The modulation frequency achieves 180 MHz.

Keywords: acousto-optic diffraction, Bragg regime, frequency shift, rotating polarization vector.

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1. Introduction

One of the important properties of acousto-optic (AO) interaction is the simplicity of obtaining a shift of an optical signal frequency on the sound frequency as a result of the reflection of light from the travelling acoustic grating [1-2]. This phenomenon is widely used for the optical heterodyne detection [3], in laser Doppler anemometry [4-5], etc. In paper [6], the effect of the frequency shift in the AO interaction occurring in the polarization-independent diffraction regime was used to generate optical radiation with rotating linear polarization, while the velocity of rotation was determined by the frequency of the sound wave. Optical radiation at a predetermined linear polarization rotation frequency is promising, for example, in laser interferometry [4], for fibre-optic communication [7], fibre-optic sensors [8], etc. This radiation after passing through a polarizer is registered by a photodetector in the form of an electrical signal with a given frequency related to the frequency of sound.

In our paper we consider the formation of the rotating polarization vector and propose the methods of the multiplication of the rotation frequency.

2. Formation of the rotating polarization vector

The formation of the rotating vector is explained by means of the Figure 1. On the figure the linearly polarized optical radiation with the wave vector **K** and polarization $\mathbf{E}_1$ propagates in the direction z of a gyrotropic crystal. The planes P_1 and P_2 are input and output faces of crystal. Inside of the crystal the radiation splits into two circularly polarized Eigen waves (*1*) and (*2*), whose polarization vectors rotate in opposite directions. Assume that the waves travel at different velocities, so the phase difference between waves is

$$\Delta\phi = \frac{\omega}{c} L\left(n_R - n_L\right), \tag{1}$$

where ω and c are the frequency and velocity of light; L is the length of crystal;n_R and n_L are the refractive indices of Eigen modes. At the output of the crystal the waves are superposed, forming linearly polarized light with the polarization vector $\mathbf{E}_2$. The angle of rotation $\mathbf{E}_2$ relative to $\mathbf{E}_1$ is $\psi = \Delta\phi/2$ [9]. Let's assume that circularly polarized waves propagate within the crystal at the same velocity ($n_R = n_L$), but with different frequencies (ω_1 and ω_2). Then,

$$\Delta\phi = \frac{L}{c}\left(\omega_1 - \omega_2\right) = \frac{L}{c}\Omega = \Omega t, \tag{2}$$

where t is the time. Assuming that $\Omega << \omega_1, \omega_2$, the value of $\Delta\phi$ changes slowly with time. In this case, the angle between the polarization vectors $\mathbf{E}_1$ and $\mathbf{E}_2$ changes with the angular velocity $\psi/t = \Delta\phi/2t = \Omega/2$. In other words, the vector $\mathbf{E}_2$ does not change its modulus and uniformly rotates around the direction of the beam propagation. For elliptical polarization the situation is much more complicated [10]. Here, the total field is represented by an ellipse [11] whose parameters (ellipticity and tilt of the major semi-axis) change slowly with time. Thus, strictly speaking, the major semi-axis rotates un-uniformly. Figure 2 shows the changes in the angle ψ as functions of Ωt for the wave, formed by the superposition of two circularly polarized waves [dashed line (*1*)], and the rotation angle ψ' [solid curve (*2*)] of the major semi-axis upon summation of waves with elliptical polarizations for the ellipticity equal to 0.4. One can see that with the changing of Ωt curve (*2*) varies nonlinearly, although passes close enough to line (*1*). However, with a good approximation, it can be assumed that the rotation angle of the major semi-axis is equal to half the phase difference between the Eigen waves. With the increasing the ellipticity of the Eigen waves, curve (*2*) approaches line (*1*).

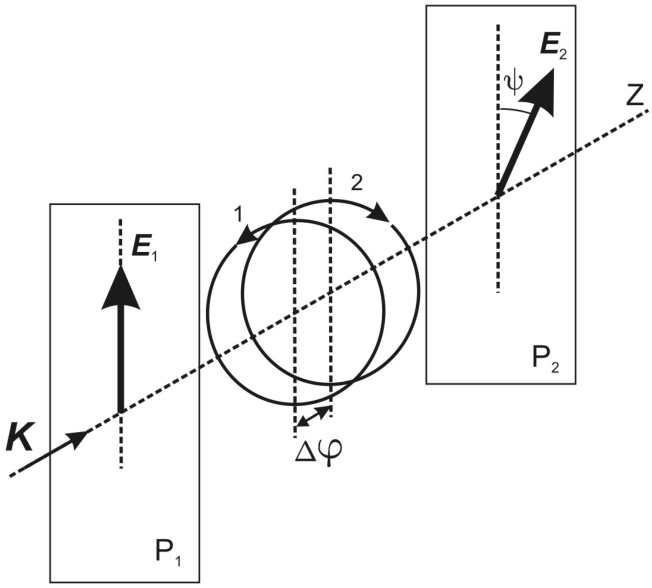

Figure 1: Formation of a linearly polarized wave upon superposition of two circularly polarized waves.

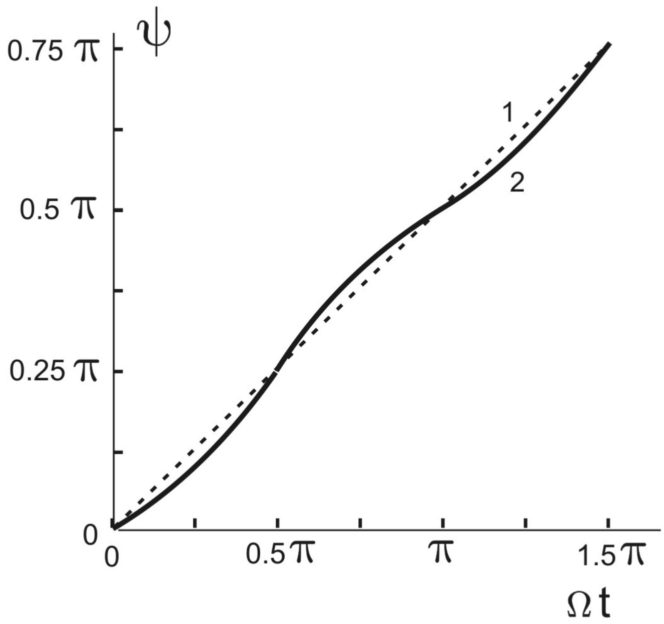

Figure 2: Dependences of angles ψ(*1*) and ψ'(*2*) on Ωt.

For the first time the effect of the polarization vector rotation on the basis of AO interaction in gyro tropic crystal was observed in [6]. A version of the polarization - independent diffraction was used. Figure 3 presents the optical scheme of the method. The linear polarized optical radiation generated by the laser is reflected from the mirror M_1 and directed on the acousto-optical modulator AOM, to the input of which the electric signal with the frequency *f* is applied. The Eigen modes of the AO crystal are circular polarized. Because of the Bragg diffraction, one of Eigen modes is deflected from the initial direction and propagates towards mirror M_2, while the non-diffracted part (other Eigen mode) propagates towards mirror M_3. Mirrors M_2 and M_3 reflect the radiation exactly in the backward direction. After reflection from the mirrors the Eigen modes change the polarization into the orthogonal ones. The reflected beams pass through the AOM again. But the beam that interacted during the first passage through the crystal will not diffract in the second passage, and vice versa, no diffracted beam at the first passage will diffract on the same acoustic wave after the reflection from the mirror. So, two beams form the output beam I_{out}. This beam passes through the polarizer P and the lens, focusing the light onto photo detector PD. If the AO medium is a gyrotropic crystal (e.g., $TeO_2$when all beams propagate near its optical axis), the laser light in the crystal is separated into Eigen waves with elliptic polarizations, close to the right-hand and left-hand circular ones. One can attain the situation when virtually all the laser light is collected in the output beam I_{out}. In fact, the output consists of two beams having the frequencies $\omega + f$ and $\omega - f$, where ω is the frequency of the laser light. The superposition of these beams gives rise to a linearly polarized output beam I_{out} with the polarization vector **E** rotating with the frequency f. The frequency of the electrical signal observed on the oscilloscope is $2f$ because the square-law detector is used.

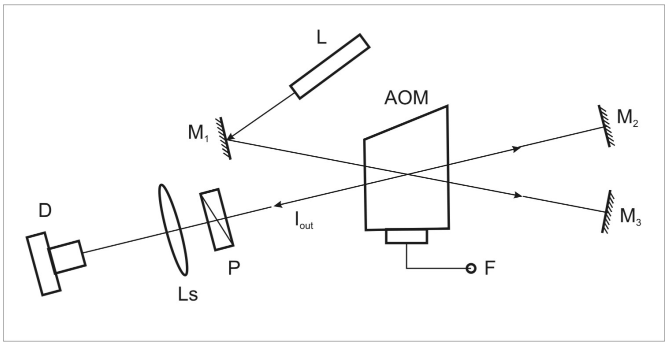

Figure 3: Optical scheme of the AO modulator.

On the Figure 4 it is shown a typical photograph of an alternating signal from the oscilloscope screen. It is seen that the modulation frequency on the screen is ~ 82 MHz, which corresponds to the double acoustic frequency. The time sweep of the oscilloscope in Fig. 4 is 5 ns/division, while the signal sensitivity is 20 mV/division.

3. Formation of the polarization vector rotating with the double frequency

Two versions for the forming the polarization vector rotating with the double acoustic frequency are represented on the figures 5 and 6 [10]. The 1st version is based on

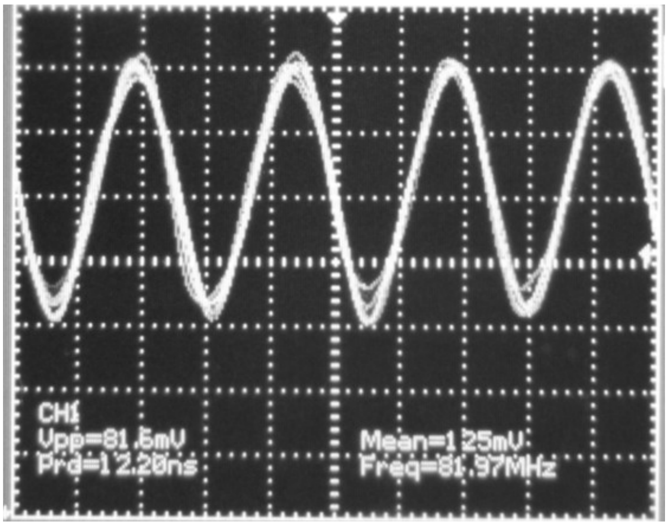

Figure 4: A typical photograph of an electric signal on the oscilloscope screen.

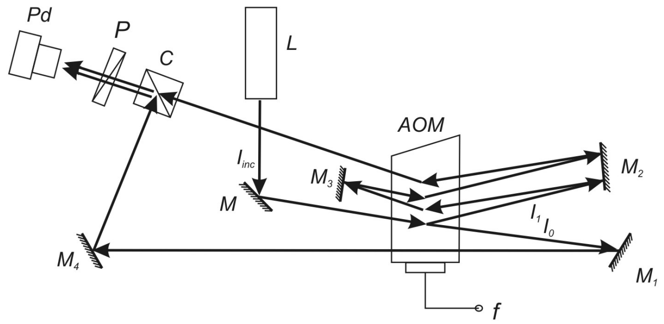

Figure 5: 1st version of the optical scheme.

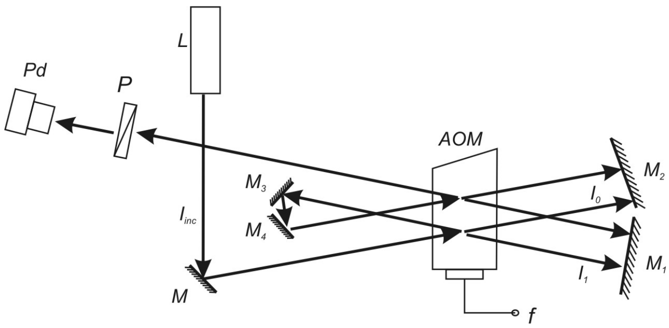

Figure 6: 2nd version of the optical scheme.

the 4 times cascaded AO diffraction of one of the Eigen modes. Second Eigen mode crosses the AO cell without any diffraction. Two modes are superposed by means of the splitter C. The 2nd version involves the 2 times cascaded AO diffraction of both Eigen modes. The frequencies of modes shift in opposite directions on 2*f*. Both cases lead to the forming of the rotation vector with the double frequency. The typical photographs of an electric signal on the oscilloscope screen correspond to 1st and 2nd versions are represented on the figures 7 and 8 correspondently.

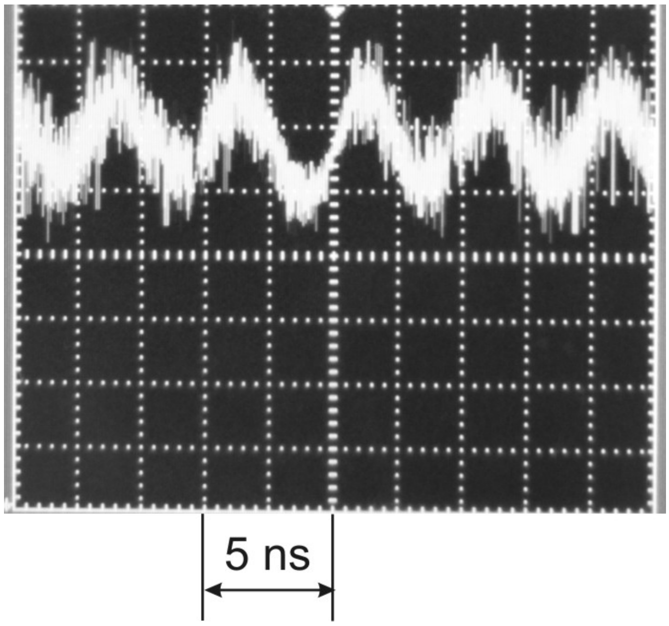

Figure 7: Typical signal of 1st version

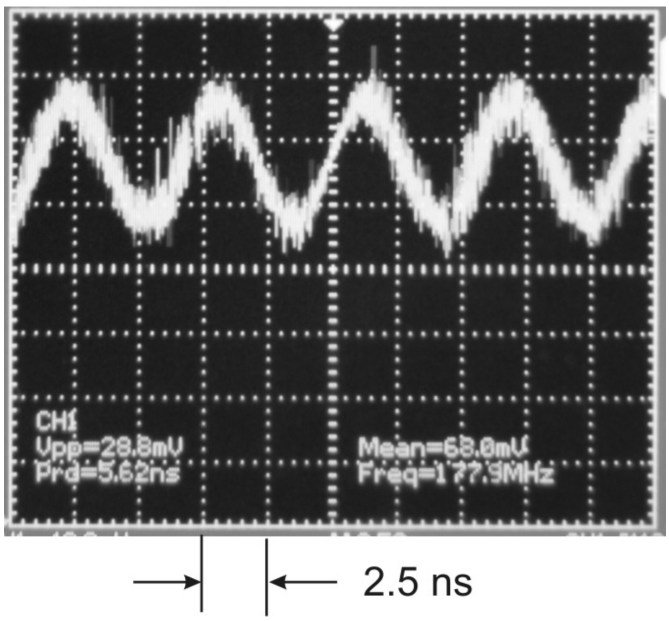

Figure 8: Typical signal of 2nd version.

The acoustic frequency in both cases is 44.5 MHz. The frequency of electrical signal is 4f and equal to ∼ 175.5 MHz. It can be seen that the signal in 2nd version is much better. It can be explain by the strong distortion of the optical wave front after 4 acts of diffraction in 1st case and no so strong distortion of the fronts after 2 acts of diffraction in 2nd case. Besides of this the beams in 2nd case diffract simultaneously and the distortions of beams are equal. So interference pattern in 2nd case is less distorted in comparison with the similar pattern in 1st case.

4. Conclusions

1 We have presented a general approach for the forming of the rotating polarization vector based on the AO diffraction in gyro tropic crystals. The rotation of the polarization arises as a result of the superposition of two waves with elliptical (close to the circular) mutually orthogonal polarizations when the frequencies of beams are different. The superposition of two waves with circular mutually orthogonal polarizations and different frequencies forms the total radiation with linear polarization and the polarization vector rotates with a frequency $f/2$, where f is the difference in the frequencies of the summed waves.

2. We have described schemes, which make it possible to significantly increase the frequency of the polarization vector rotation. The best is a 'hybrid' scheme combining cascade and polarization-independent diffraction schemes.

The results obtained can be used in various devices utilizing the rotation of the polarization vector with a predetermined frequency.

Acknowledgements

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