Quantum Electronics **46** (2) 179–180 (2016) ©2016 Kvantovaya Elektronika and Turpion Ltd

ACOUSTO-OPTICS

DOI: 10.1070/QEL15929

Acousto-optical modulation of light at a doubled sound frequency

V.M. Kotov, S.V. Averin, G.N. Shkerdin

Abstract. **A method of acousto-optical (AO) Bragg diffraction is proposed that provides the amplitude modulation of optical radiation at a doubled acoustic frequency. The method is based on the double transmission of the light through the AO modulator made of a gyrotropic crystal and is experimentally tested by the example of the modulation of light with a wavelength of 0.63 μm, controlled by the paratellurite AO cell.**

Keywords: *acousto-optical diffraction, Bragg regime, rotation of the polarisation vector.*

1. Introduction

Acousto-optical (AO) diffraction is widely used for controlling the parameters of optical radiation (amplitude, phase, frequency, polarisation, etc.) [1, 2].

The present paper describes a method of the amplitude AO modulation, providing a sinusoidal variation of the optical signal with a frequency $2f$, where f is the frequency of the acoustic wave. Here, use is made of the variant of polarisation-independent diffraction [3, 4], in which the optical radiation passes twice through the same AO cell. If the cell is made of a gyrotropic crystal, then, as shown in Refs [3, 4], the method allows the deflection of light in one direction with high efficiency, independent of the incident wave polarisation. Our studies have shown that at the output of the cell the circularly polarised light with the rotating polarisation vector is formed.

Figure 1 presents the optical scheme of the proposed method of AO modulation. The optical radiation generated by the laser is reflected from the mirror M1 and is incident on acousto-optical modulator AOM, to the input of which the electric signal with the frequency f is applied. Because of the Bragg diffraction, part of the light is deflected from the initial direction and propagates towards mirror M2, while the non-diffracted part of the light propagates towards mirror M3. Mirrors M2 and M3 reflect the radiation exactly in the backward direction. The beams reflected from the mirrors pass through the AOM again and interact with the same acoustic wave. Part of the light outcoming from the AOM returns to the laser, while the other part forms the output beam I_{out}. The output beam passes through polariser P and the lens, focusing the laser light onto photodetector PD. If the AO medium is a gyrotropic crystal (e.g., TeO_2 with all beams propagating near its optical axis), then, as shown in Refs [3, 4], the laser light in the crystal is separated into eigenwaves with elliptic polarisations, 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 summation of these beams gives rise to a linearly polarised output beam I_{out} with the polarisation vector $\boldsymbol{E}$ rotating with the frequency $2f$. In our experiments, a sinusoidal electric signal with the frequency $2f$ was observed at the oscilloscope display.

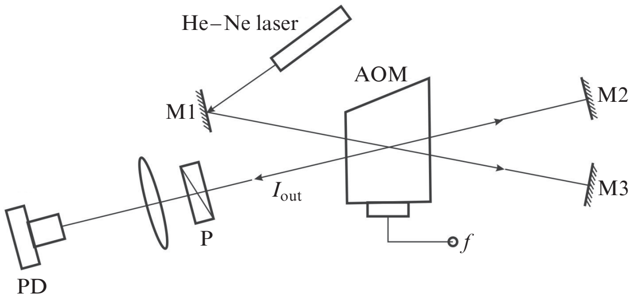

Figure 1. Optical scheme of the AO modulator.

Note that two variants of the polarisation vector rotation $\boldsymbol{E}$ are possible, the left-hand and the right-hand ones. The polarisation is referred to as right-hand, if for the observer looking towards the light beam the electric vector rotates clockwise. For the left-hand polarisation, the vector rotates counter clockwise [5]. The polarisation $\boldsymbol{E}$ will be left-handed, if due to the diffraction the frequency of the left-hand polarised eigenwave increases by f and the frequency of the right-hand polarised one decreases by f. In the opposite case, the polarisation $\boldsymbol{E}$ will be right-handed. One can change from one case to another by reorientation of the AO modulator, e.g., so that the acoustic wave changes its propagation direction to the opposite one (not bottom-up, as in Fig. 1, but top-down). An alternative method consists in slight reorientation of the AO cell providing the exact Bragg matching condition for another eigenwave of the crystal.

In our experiments, the source of the optical radiation was a He–Ne laser emitting the linearly polarised light with the wavelength 0.63 μm. The polarisation vector made an angle

---

V.M. Kotov, S.V. Averin, G.N. Shkerdin V.A. Kotelnikov Institute of Radio Engineering and Electronics, Fryazino Branch, Russian Academy of Sciences, pl. Akad. Vvedenskogo 1, 141120 Fryazino, Moscow region, Russia; e-mail: vmk277@ire216.msk.su

Received 15 September 2015
Kvantovaya Elektronika **46** (2) 179–180 (2016)
Translated by V.L. Derbov

of 45° with the direction of the acoustic wave propagation in the crystal. This provided the equality of intensities for the crystal eigenwaves. The AO cell was made of the TeO_2 single crystal measuring 8 × 8 × 8 mm along the directions [110], [$1\bar{1}0$] and [001], respectively. The travelling transverse acoustic wave with the frequency ~24 MHz and the velocity 0.617×10^5 cm s^{-1} was generated along the [110] direction. The AO interaction length amounted to 6 mm. Figure 2 shows the electric signals from the photodetector, observed (in turn) at the oscilloscope display. One can see that the maximal values of the sinusoidal signal do not coincide with the zero level [curve (*2*)]. This may be due to several factors, namely, the incomplete coincidence of the light beams forming the beam I_{out}, the nonuniform distribution of the field over the beam cross section, etc. Nevertheless, the fact of the amplitude modulation of the light beam at the doubled frequency of the sound is well observed. The presence of modulation and its amplitude is not affected by the rotation of the polariser. This fact means that the rotation of the polarisation vector occurs around the direction of the beam propagation. The present studies are planned to be continued.

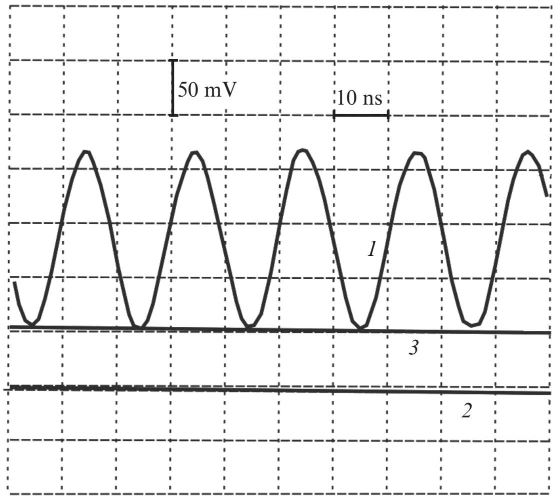

Figure 2. Electric signals from the photodetector, observed at the oscilloscope display:
(*1*) result of the amplitude modulation of the radiation beam with the polarisation vector rotating with the frequency ~48 MHz; (*2*) zero level of the signal; (*3*) signal in the case of one mirror (M2 or M3) removed from the setup.

Using the obtained results, one can draw the following conclusions:

1. The method of the AO amplitude modulation is proposed, based on the double transmission of the light through the AO modulator made of a gyrotropic material and on the property of a mirror surface to alter the polarisation of a circularly polarised radiation in the course of reflection.

2. The method was tested with the TeO_2 single crystal used as the AO medium, and the modulation of the output from a He–Ne laser at the doubled frequency of the sound was demonstrated.

The obtained results may find application in various systems, where the use of linearly polarised light with the polarisation vector, rotating with a prescribed frequency, is necessary.

Acknowledgements. The work was supported by the Russian Foundation for Basic Research (Grant No. 13-07-00138) and the Programme of the State Support of Leading Scientific Schools of the Russian Federation (Grant No. NSh 3317.2010.9).

References

1. Balakshy V.I., Parygin V.N., Chirkov L.E. *Fizicheskie osnovy akustooptiki* (Physical Foundations of Acousto-Optics) (Moscow: Radio i svyaz', 1985).
2. Magdich L.N., Molchanov V.Ya. *Akustoopticheskie ustroystva i ikh primenenie* (Acoustooptical Devices and Their Application) (Moscow: Sov. Radio, 1978).
3. Kotov V.M., Shkerdin G.N. *Pis'ma Zh. Tekh. Fiz.*, **20** (6), 35 (1994) [*Tech. Phys. Lett.*, **20**, 231 (1994)].
4. Kotov V.M. *Kvantovaya Elektron.*, **21** (10), 937 (1994) [*Quantum Electron.*, **24** (10), 874 (1994).
5. Born M., Wolf E. *Principles of Optics* (Oxford: Pergamon Press, 1970; Moscow: Nauka, 1973).