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WIDE-ANGLE ACOUSTO-OPTIC DIFFRACTION SPECTRAL SELECTIVITY ENHANCEMENT BY OPTOELECTRONIC FEEDBACK INTRODUCTION

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ABSTRACT

One of the acousto-optic (AO) tunable filters applications is the filtration of divergent optical beams, for example – image spectral filtration. In this case, the so-called wide-angle or tangential AO interaction geometry is used. Unfortunately, such AO devices usually do not have a high spectral resolution, and an increase in the light beam divergence leads to an even greater widening of the AO device transmission function, since the AO phase matching condition for the lateral components of the optical beam spatial spectrum differs from those for the axial components. In this paper we examine the possibility of improving the spectral resolution of a wide-angle AO tunable filter by introducing optoelectronic feedback connecting the optical output of the AO cell and its piezoelectric transducer. The study is carried on the example of collinear AO interaction (a special case of high-frequency wide-angle diffraction). It is shown that the feedback introduction makes it possible to improve the spectral contrast and narrow the AO filter passband up to 20 times, while AO cell transfer function, which determines the value of AO filter angular aperture, remains unchanged.

Keywords: *acousto-optics, feedback, transmission function, optical beam divergence.*

1. INTRODUCTION

Acousto-optic (AO) devices are widely used nowadays as the key or auxiliary elements of various optoelectronic systems designed to solve a variety of technical and scientific tasks [1].

One of their important application areas is the optical radiation spectral filtration including optical image processing. In this case, AO tunable filter (AOTF) should perform spectral filtering of divergent light beams.

The presence of a divergence means that various components of the optical beam spatial spectrum propagate in the AO cell along different directions, and, consequently, the AO phase matching condition will be satisfied only for some of them. Others will diffract in the acoustic field with some mismatch, depending on the propagation direction.

Thus, the angular aperture of the device is determined by the range of light radiation propagation angles for which the AO phase matching condition will be sufficiently satisfied.

Another factor limiting the AOTF angular aperture is the separation angle between the light beams at the output of the AO cell.

The ability of an AOTF to transmit various components of the optical beam spatial spectrum is characterized by the AO diffraction transfer function [2]. Transfer function determination (numerical or experimental) makes it possible to define the angular aperture of the AO device (such a beam divergence when the AO diffraction efficiency decreases in 2 times), to obtain the AO device transmission function and to follow its passband and shape change with an increase of the optical beam the divergence.

An increase of light divergence usually causes the decrease of the maximum possible AO interaction efficiency and spectral resolution reduction.

The variation of optical beam divergence also affects the transmission function shape [3,4].

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The system considered in this paper belongs to the class of AO devices with an optoelectronic feedback [5,6]. Such systems are known for the complexity of their behavior and the variety of operating regimes [7-21].

In this paper, we study the possibility to compensate the optical beam divergence effect on the AO device transmission function by introducing an optoelectronic feedback circuit both experimentally and theoretically.

Feedback connects the optical output of the AO device and its piezoelectric transducer [14-21]. The study was carried out on the example of collinear AO interaction [22]. This geometry is a special case of the high-frequency variant of the wide-angle AO diffraction geometry. The feedback signal is formed due to the specific features of the light polarization transformation accompanying the collinear AO diffraction [23-25].

2. DESCRIPTION OF THE EXAMINED SYSTEM

The scheme of the examined system is shown in Fig. 1. Its main element is a collinear AOTF made of a calcium molybdate crystal ($CaMoO_4$). The AOTF has 4cm AO interaction length [22] and is placed between a pair of polarizers (polarizer on the input and analyzer on the output). The system operation and the possibility of feedback introduction is based on the light polarization transformation that make it possible to obtain output optical radiation amplitude modulation with a frequency of ultrasound excited in the AO cell [23-25].

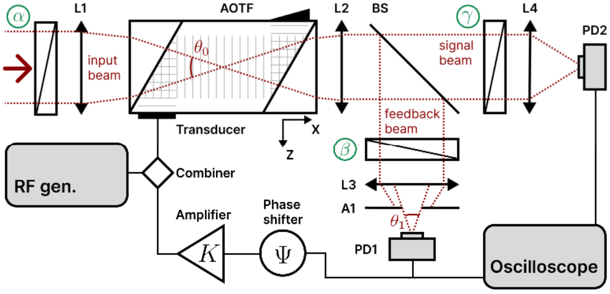

Figure 1. Examined system layout.

It was shown previously that the output optical radiation amplitude modulation has the maximal magnitude for the following mutual orientation of polarizer and analyzer polarization planes: polarizer - along the crystallographic axis Z or Y (α=90° or 0° counting from the Z crystallographic axis), the analyzer polarization plane is at an angle of 45° to the polarization plane of the input polarizer (β=45°). It was also shown that in such case the AOTF is not applicable for spectral filtration.

To implement spectral filtering, the polarization plane of the output polarizer is along the crystallographic Z or Y axis, and orthogonal to the polarization plane of input polarizer (γ=0° or 90°) [19,20].

Thus, to implement spectral filtering in the presence of a feedback circuit, it is required to split the optical beam into two (signal and feedback beams) applying a beam splitter (BS) and to place after it two polarizers with different orientations of the polarization planes (at β and γ angles). The amplitude modulation of the feedback beam intensity is registered by a photodetector (PD1), which forms the input signal for the feedback circuit. The intensity of the signal beam is measured by a photodetector (PD2). The PD2 serves for spectral filtration and is used to determine the spectral characteristics of the system.

Unlike previous investigations [14-20], here we consider the case when the optical beam has a significant divergence. The divergent beam is obtained with a telescope and a convex lens (L1) mounted after the telescope and focusing the light at the center of the AO cell. The divergence can be varied by choosing L1 focal length. The diffracted optical radiation passes through a convex lens (L2) disposed after the AO cell to collimate a diffracted beam. The feedback and signal optical beams are focused on the PD1 and PD2 with convex lens L3 and L4 correspondingly. We may also apply tunable aperture A1 to control the spatial spectrum of the feedback optical beam to examine its influence on the system transmission.

The PD1 signal is fed to the feedback circuit input. Feedback loop includes an amplifier and a phase shifter. The feedback circuit output signal is combined with the RF generator signal and is fed to the piezoelectric transducer of the AOTF.

The He-Ne laser with 633nm optical radiation wavelength is used as the light source.

3. TRANSMISSION FUNCTIONS TRANSFORMATION

Figure 2 shows the oscillograms of the collinear AO filter transmission functions for an optical beam divergence of 1.5° (Fig. 2a), 7.5° (corresponds to the examined AO filter angular aperture) and 10° with feedback (Fig. 2b and 2c correspondingly). The oscillograms presented in Figs.2b and 2c are presented in the same time scale, the oscillogram in Fig. 2a was obtained with twice the sweep time.

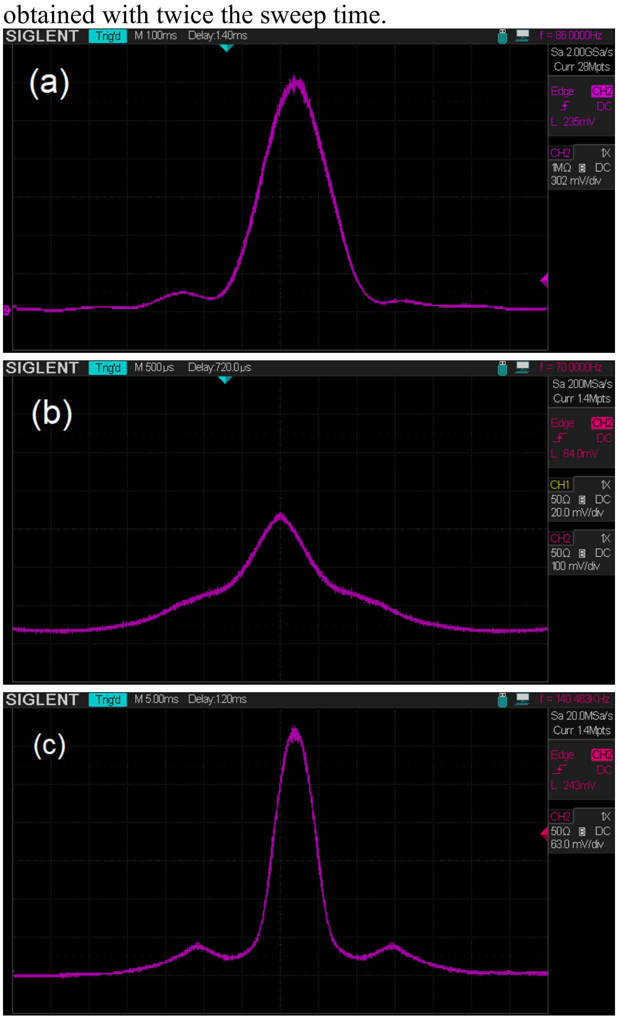

Figure 2. System transmission functions; (a) – without divergence and feedback, (b) - 7.5° optical beam divergence without feedback, (c) - 10.0° divergence with feedback.

The vertical scale differs in three times between Fig.2a and 2b, and in 5 times between Fig.2a and 2c.

Comparing the characteristics shown in Figs. 2a and 2b, we may conclude that an increase in the divergence to 7.5° leads to a decrease in the AO interaction efficiency by about 2 times and a bandwidth increase by 1.5 times (for 10° the diffraction efficiency decreases about 3.2 times in comparison with Fgi.2a, passband increases by 1.9 times).

When feedback is turned on (Fig. 2c), the observed transmission function shape changes significantly. The maximal AO interaction efficiency remains the same to that observed without feedback for the chosen divergence, since it is determined by the AO cell transfer function shape, which is not affected by feedback.

However, the bandwidth of the device narrows significantly, side lobes appear, and the spectral contrast increases. We also note that in the presented case, the introduction of feedback makes it possible to reduce the RF generator signal power by about a factor of 2.5.

The magnitude of the transmission function narrowing at a fixed value of the feedback loop gain that is close to the self-excitation threshold (500 times by amplitude) [20] is determined by the RF generator signal amplitude. The smaller the amplitude, the stronger bandwidth narrowing may be obtained.

4. CONCLUSIONS

The possibility of optical beam divergence influence compensation on the collinear AO diffraction transmission functions applying an optoelectronic feedback circuit has been studied. It was shown that the introduction of feedback makes it possible to narrow the AO device passband, and consequently, its spectral resolution, and to increase the spectral contrast. The lower the power of the signal feeding the AO cell piezoelectric transducer from the RF generator, the higher the narrowing of the bandwidth that can be achieved. In such process passband narrowing is accompanied by the decreasing AO diffraction efficiency, though such system parameters may be chosen when significant transmission function narrowing is observed for almost the same AO diffraction efficiency.

The feedback does not affect the shape of the AO interaction transfer function; therefore, it does not reduce the angular aperture of the AOTF.

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] J. Xu, R. Stroud, *Acousto-Optic Devices*, New York: Wiley, 1992.

[2] V.I. Balakshy, “Acousto-optic cell as a filter of spatial frequencies”, *J. Commun. Technol. Electron.*, vol. 29, pp. 1610-1616, 1984.

[3] V.I. Balakshy, S.N. Mantsevich, "Collinear diffraction of divergent optical beams in acousto-optic crystals", *Applied Optics*, vol. 48, pp. C135-C140, 2009.

[4] V.I. Balakshy, S.N. Mantsevich, "Influence of the divergence of a light beam on the characteristics of collinear diffraction", *Opt. Spectrosc.*, vol. 103, 2007, pp. 804–810.

[5] J. Chrostowski, C. Delisle, "Bistable optical switching based on Bragg diffraction", *Opt. Commun.*, vol. 41, 1982, pp. 71–74.

[6] M.R. Chatterjee, E. Sonmez, "Overview of acousto-optic bistability, chaos, and logical applications", *Proc. SPIE*, vol. 4514, 2001, pp. 41-60.

[7] J. Chrostrowski, R. Vallee, C. Delisle, "Self-pulsing and chaos in acoustooptic bistability", *Can. J. Phys.*, vol. 61, 1983, pp. 1143–1148.

[8] T.-C. Poon, S.K. Cheung, "Performance of a hybrid bistable device using an acoustooptic modulator", *Applied Optics*, vol. 28, 1989, pp. 4787–4791.

[9] V.I. Balakshy, A.V. Kazaryan, V.Y. Molchanov, H. Ming, "Bistable acousto-optic devices for optical information processing systems", *Proc. SPIE*, vol. 1731, 1992, pp. 303–312.

[10] V.I. Balakshy, A.V. Kazaryan, V.Y. Molchanov, "Deflectors with a feedback: new possibilities for image processing", *Proc. SPIE*, vol. 2051, 1994, pp. 672–677.

[11] V.I. Balakshy, A.V. Kazaryan, "Laser beam direction stabilization by means of Bragg diffraction", *Opt. Eng.*, vol. 38, 1999, pp. 1154–1159.

[12] V. Balakshy, Y. Kuznetsov, S. Mantsevich, N. Polikarpova, "Dynamic processes in an acousto-optic laser beam intensity stabilization system", *Opt. Laser Technol.*, vol. 62, 2014, pp. 89–94.

[13] M.R. Chatterjee, M.A. Al-Saedi, "Examination of chaotic signal encryption and recovery for secure communication using hybrid acousto-optic feedback", *Opt. Eng.*, vol. 50, 2011, article 055002.

[14] S.N. Mantsevich, V.I. Balakshy, Yu.I. Kuznetsov, "Effect of feedback loop on the resolution of acousto-optic spectrometer", *Physics of Wave Phenomena*, vol. 24, 2016, pp. 135-141.

[15] S.N. Mantsevich, V.I. Balakshy, Yu.I. Kuznetsov, "Acousto-optic collinear filter with optoelectronic feedback", *Applied Physics B: Lasers and Optics*, vol. 123, 2017, article 101.

[16] S.N. Mantsevich, V.I. Balakshy, "Experimental examination of frequency locking effect in acousto-optic system", *Applied Physics B: Lasers and Optics*, vol. 124, 2018, article 54.

[17] S.N. Mantsevich, V.I. Balakshy, "Examination of optoelectronic feedback effect on collinear acousto-optic filtration", *JOSA B*, vol. 35, 2018, pp. 1030-1039.

[18] S.N. Mantsevich, V.I. Balakshy, "Applications of the frequency locking effect in acousto-optic systems for control of optical radiation composition", *JOSA B*, vol. 36, 2019, pp. 728-735.

[19] S.N. Mantsevich, V.I. Balakshy, "Collinear acousto-optic filtration with electronically adjustable transmission function", *IEEE Photonics Journal*, vol. 11, 2019, article 7800315.

[20] S.N. Mantsevich, A.S. Voloshin, G.D. Slinkov, E.I. Kostyleva, V.I. Balakshy, "Multiple-band frequency locking in an acousto-optic system with optoelectronic feedback", *JOSA B*, vol. 37, 2020, pp. 513-522.

[21] V.I. Balakshy, I.M. Sinev, "Mode competition in an acousto-optic generator", *J. Opt. A*, vol. 6, 2004, pp. 469–474.

[22] S.E. Harris, R.W. Wallace, "Acoustooptic tunable filter", *J. Opt. Soc. Am.*, vol. 59, 1969, pp. 744–747.

[23] V.I. Balakshy, S.N. Mantsevich, "Influence of light polarization on characteristics of a collinear acoustooptic diffraction", *Opt.Spectrosc.* vol. 106, 2009, pp. 441–445.

[24] V.I. Balakshy, S.N. Mantsevich, "Acousto-optic collinear diffraction of arbitrarily polarized light", *Tech. Phys.*, vol. 56, 2011, pp. 1646–1651.

[25] V.I. Balakshy, S.N. Mantsevich, "Polarization effects at collinear acousto-optic interaction", *Opt. Laser Technol.*, vol. 44, 2012, pp. 893–898.

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