INFLUENCE OF THE ACOUSTOOPTIC BRAGG DIFFRACTION ON THE DEGREE OF THE SPATIAL COHERENCE OF THE OPTICAL BEAM

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ABSTRACT

In this paper we investigate theoretically and experimentally the influence of the degree of spatial coherence of a Gaussian beam on the acousto-optic diffraction efficiency in the Bragg regime. The theoretical procedure is outlined and evaluated by experiments on the basis of AO Bragg diffraction in mono-crystalline TeO_2. Experiments show that domains of high spatial coherence diffract with a substantially higher efficiency than domains with low spatial coherence. Moreover we investigate the distribution of the speckle structure of the optical field of the diffracted beam and it turns out to be practically isotropic.

I. INTRODUCTION

In real-world systems, optical beams carrying information are not immune for noise. To some extent a part of this noise can be modeled by deterministic equations[1], which would mean that experimental methods based on this theoretical descriptions can be developed to partially suppress this propagation noise, e.g. by means of frequency, phase or combined synchronization, and so on (see[2] and references to it).

For processing two-dimensional signals like images, in principal electronic methods are not so effective [3]: by sequentially processing image pixels, the interdependence between any pixel of the image and its neighbors is lost, but this interdependence forms the basis of the image structure. The deterministic information of the noise is lost in that way, such that suppressing noise starts to be complicated. Here optical methods, which treat the image as a whole are much more suitable.

Coherent light is very attractive for transferring images as it allows coding image elements by means of amplitude, phase, frequency or polarization modulation. But the presence of coherence has also disadvantage, the most serious amongst them is the speckle problem, which adds substantial noise.

Acousto-optic (AO) interaction is assumed to be a very effective method for solving this problem [4,5] since the interacting acoustic wave create a three-dimensional disturbance of the medium and allows in principle controlling the phase structure of the optical field. The Bragg regime of diffraction provides on one hand a smaller angular divergence of the diffracted light beam in comparison with the incident one, and on the other hand improves the filtering of "high coherent" domains of the optical beam. This process increases the degree of coherence of the diffracted beam. The former property concerning the divergence changes have been extensively studied in the past, but to the latter property concerning the coherence changes not much attention has been paid. The aim of this paper is the investigation of the influence of the AO Bragg diffraction on the coherence degree of the optical beam dealing with speckle structure.

II. THEORETICAL ANALYSIS.

Theoretical models were already developed where both the intensity and spatial coherence had a Gaussian distribution. For the theoretical analysis we will use the function of the spatial coherence. We consider the hypothetic optical scheme (Fig.1) where the monochromatic optical beam is produced by source S and propagating through the AO cell A. Acoustic wave propagates along the X-axis, optical beam - close to the Z-axis. The input and output planes of the optical field of the AO cell are P and P', correspondingly. The field distributions in P and P' obtained by illuminating dS of the source S are described by $E(x,y)$ and $E(x',y')$.

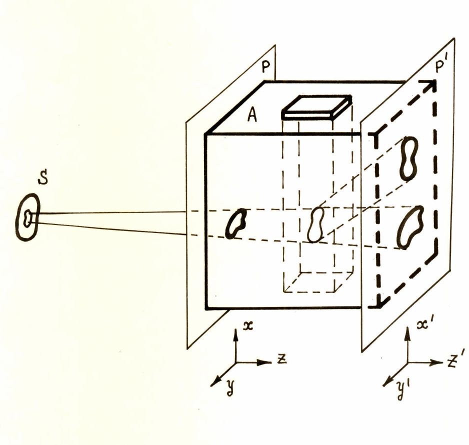

Fig. 1. Hypotetic optical scheme for the definition of the spatial coherence function.

In common cases $E(x,y)$ and $E(x',y')$ are complex. If the acoustic wave is absent the spatial coherence function is described as

$$\Gamma(x,y;x',y') = \iint\limits_S E(x,y)E^*(x',y')dS = \left\langle E(x,y)E^*(x',y')\right\rangle. \qquad (1)$$

This expression does not depend on Z. It is only valid if the optical system is linear and spatially invariant. Here we assume that the distance between P and P' is much smaller than the distance between S and A. When an acoustic wave is launched, the coherence function starts to depend on Z. As a result several diffracted beams appear which correlate with each other. In common case, it is very difficult to solve this problem. We will simplify the approach. We will consider the AO Bragg diffraction when only two beams (0-th and 1-st orders) exist and assume that the coherence degree does not vary along the Y axis, i.e. the AO interaction does not influence the coherence along the Y-axis. We also neglect the frequency change. Finally we consider the case when planes P and P' are coinciding and create the plane Q (P <Q $< P'$). The acoustic wave is restricted by the coordinates z=0 and z=z_0. So the process of the AO interaction can be described by the coupled wave equation system [5]

$$\frac{\partial E_0}{\partial z} = -\frac{i}{2k_0\cos q_b}\left(\frac{\partial^2 E_0}{\partial x^2} + \frac{\partial^2 E_0}{\partial z^2}\right) - tgq_b\frac{\partial E_0}{\partial x} - i\frac{a}{2L}E_{-1};$$

$$\frac{\partial E_{-1}}{\partial z} = -\frac{i}{2k_0\cos q_b}\left(\frac{\partial^2 E_{-1}}{\partial x^2} + \frac{\partial^2 E_{-1}}{\partial z^2}\right) + tgq_b\frac{\partial E_{-1}}{\partial x} - i\frac{a}{2L}E_0, \qquad (2)$$

where $E_0(x,z)$ and $E_{-1}(x,z)$ - are the complex amplitudes of waves diffracted into 0-th and -1-st orders, correspondingly; q_b is the Bragg angle; k_0 is the wave vector of the incident light; a is the phase delay; L is the AO interaction length. In [4] it is shown that the total process is characterized in our case by four coherence functions:

$$\Gamma_{0,0} = \left\langle E_0(x_1,z)E_0^*(x_2,z)\right\rangle; \quad \Gamma_{-1,-1} = \left\langle E_{-1}(x_1,z)E_{-1}^*(x_2,z)\right\rangle; \qquad (3)$$
$$\Gamma_{0,-1} = \left\langle E_0(x_1,z)E_{-1}^*(x_2,z)\right\rangle; \quad \Gamma_{-1,0} = \left\langle E_{-1}(x_1,z)E_0^*(x_2,z)\right\rangle;$$

where x_1 and x_2 are arbitrary points on the plane Q. Here $\langle\ldots\rangle$ related to the integration operation defined in (1). The relation between coherence functions (3) can be deduced from the equations (2). First we assume that $E_0(x,z)$ and $E_{-1}(x,z)$ in (2) depend on x_1, multiply both expressions by $E_0{}^*(x_2,z)$; then we assume that $E_0(x,z)$ and $E_{-1}(x,z)$ depend on x_2 and multiply both of them by $E_0{}^*(x_1,z)$, sum up the obtained expressions, and after integration with the taking into account (1) we will have (4)

$$\frac{\partial\Gamma_{0,0}(x_c,x_d,z)}{\partial z} = -\frac{i}{k_0}\frac{\partial^2\Gamma_{0,0}(x_c,x_d,z)}{\partial x_c \partial x_d} - q_b\frac{\partial\Gamma_{0,0}(x_c,x_d,z)}{\partial x_c}$$
$$-\frac{ia}{2L}\left[\Gamma_{-1,0}(x_c,x_d,z) - \Gamma_{0,-1}(x_c,x_d,z)\right]; \qquad (4)$$

where new variables are introduced $x_d = x_1 - x_2$; $x_c = 0.5(x_1 + x_2)$.

On the basis of this procedure we can derive the equations for $\Gamma_{-1,-1}$, $\Gamma_{0,-1}$ and $\Gamma_{-1,0}$. The obtained expressions describe the relationship between the spatial coherence functions.

In [4] the speckle structure of the incident light was described by the Gaussian Schell-model. In according with this model both envelope and coherence domains of the beam are described by Gaussian functions. It was shown that the spatial coherence degree of the diffracted into -1-st order beam increases on ~ 10% whereas the coherence degree of the 0-th order light decreases on the same value. Physically it means that the domains with the bigger coherence diffract with higher efficiency than the domains with the smaller coherence.

III. EXPERIMENT

We made experiments to check these results by using a real speckle structure obtained by passing of a laser beam through a diffuser. The optical scheme of the experimental setup is shown in Fig.2. The optical radiation generated by He-Ne laser 1(l = 0.63 µm) is scattered by diffuser 2 made from a glass plate, one side of which is polished. The scattered radiation is collimated by lenses 3 and 4 into a convergent beam with beam waist ~0.5 cm. AO cell is placed into the waist. This cell is made from ? ?? $_2$ mono crystal with dimensions 8?8?10 mm along the directions $[110]$, $[001]$ and $[1\bar{1}0]$, respectively. The angle between the incident light and the optical facet is ~45^0.

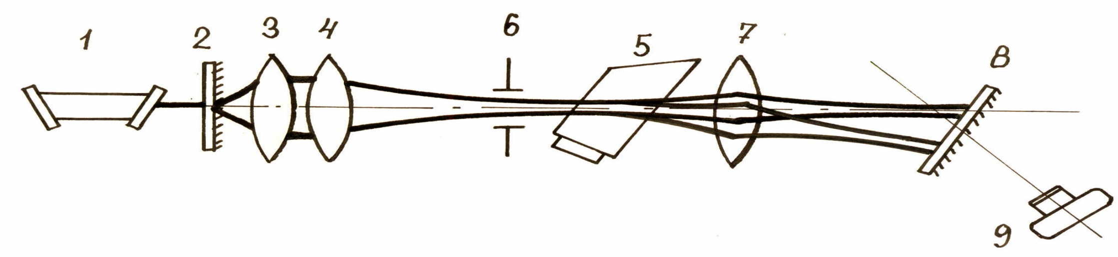

Fig. 2. Experimental setup.

Before the AO cell the diaphragm 6 and after cell the lens 7 are placed. Lens 7 focuses the outgoing beams on the semitransparent screen 8. The beam spots are photographed by means of photo camera 9.

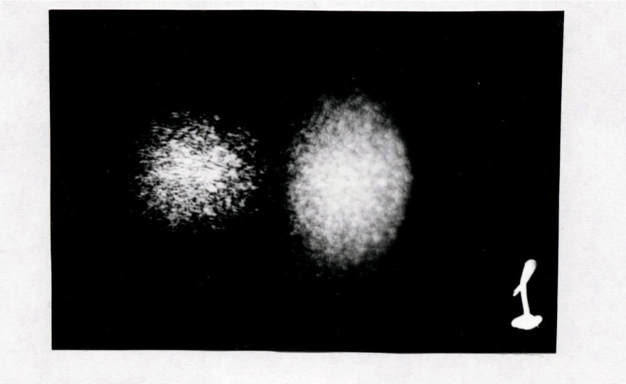

Fig.3. Typical photos of the speckle pattern of 0-th (on right) and –1-st (on left) orders.

In Fig. 3 the typical photograph of the spots of 0-th (on right) and -1-st (on left) orders is represented. The acoustic power was matched to get equal maximum intensities of the spots. On the photograph it is clearly seen that the “grain” sizes of the diffracted beam is bigger than that of the undiffracted one, the speckle structure has more contrast, and the background is suppressed. It indicates that the domains with higher spatial coherence (corresponding to the bigger grains) diffract with sufficiently more efficiency. Other conclusion can be done: the speckle structure is isotropic, i.e. the character of the distribution along X and Y axes are equal each other. In other words neglecting the influence of the AO diffraction on the coherence along Y is not correct. Hence, the theoretical approach of the AO diffraction process needs to take into account the 3-dimensional interaction nature of the optic and acoustic waves.

IV. Conclusions.

A method of deriving the spatial coherence functions during the process of AO interaction is described. t is shown that the higher spatial coherence domains diffract with a higher efficiency than the smaller coherence domains. his behavior was confirmed experimentally on the basis of the real speckle getting by passing the laser beam through a diffuser, which was undergoing the AO diffraction on an acoustic wave propagating in TeO_2 mono crystal.

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