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Reflection of an optical beam having speckles from a 'thick' acoustic grating

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***Abstract*. A substantial change in the spatial coherence of an optical field with a speckle pattern was experimentally observed during reflection of the field from a 'thick' Bragg grating. This effect is explained within the framework of the Gauss – Sheel model by the difference in the diffraction efficiencies of individual regions of the field represented by Gaussian beams with different angular divergences.**

Keywords: *acoustooptic interaction, Bragg diffraction, speckle pattern of an optical field.*

A change in the spatial coherence of an optical beam having speckles after its reflection from a 'thick' acoustic Bragg grating attracts the attention of many researchers [1 – 5]. Such a Bragg grating is analogous to a multilayer mirror [6] and has many properties of this mirror. Interest in these studies is explained by the fact that, unlike a conventional mirror, which does not change the speckle pattern, a multilayer mirror, which has the angular-selective reflection coefficient, can substantially change the speckle pattern. The speckle pattern also strongly depends on the sound-wave power. These two factors allow one to vary the beam coherence in a broad range.

Acoustooptic diffraction from a 'thick' grating affects the spatial coherence much more efficiently if an acoustic wave is formed by low-power sound. This fact was ignored so far by the researchers, who studied the regimes that were close to overmodulation, i.e., realised at high sound powers. In addition, only theoretical studies have been mainly performed so far.

Our experiments have shown unambiguously that, to affect the speckle pattern most strongly, there is no need to use high-power sound. The typical pattern of acoustooptic diffraction upon three-phonon interaction, when the incident wave diffracts successively to the first, second, and third orders [7, 8] is shown in Fig. 1. We used such a regime because it clearly demonstrates a change in the speckle pattern of the field in diffraction orders that successively appear with increasing acoustic power.

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The experiments were performed using a 0.63-μm He – Ne laser, whose radiation exhibited the speckle pattern after passing through a rough glass plate polished with the M5 powder. Laser radiation was then collimated to a quasi-parallel beam with the divergence $\sim 0.5^\circ$ and directed into a TeO_2 acoustooptic cell, where a transverse acoustic wave propagated along the [110] direction and the anisotropic diffraction of light on the soundwave occurred [7]. The diameter of the light aperture was ~ 0.5 cm, the acoustic interaction length was ~ 0.6 cm, and the acoustic frequency was ~ 28 MHz. In the case of a low acoustic power, only the first diffraction order was observed (left and right spots in Fig. 1a are the zero and first orders, respectively). One can see that the first-order structure has larger grains, while the fine-grain background is absent, although it dominates in the zero order. Our estimates show that the average size of a 'grain' of the optical field in the first order is 4 – 5 times larger than that of a grain in the zero order. As the acoustic power increases, the intensity of the first order increases, the second order appears (Fig. 1b), and then the third order (Fig. 1c). In each case, the largest grains (and, hence, the highest coherence) are observed in the highest diffraction order, while the coherence in lower diffraction orders decreases.

Such behaviour can be qualitatively explained as follows. Let us assume that the speckle pattern is described by the Gauss – Schell model [3, 9], according to which the field is described by a set of randomly distributed Gaussian beams. Mathematically, this can be written in the form

$$I(x_1, x_2) = \frac{2I_0}{\pi\omega^2} \exp\left[-\frac{x_1^2 + x_2^2}{\omega^2}\right] \exp\left[-\frac{(x_1 - x_2)^2}{2\sigma^2}\right]. \quad (1)$$

Here, I and I_0 are the field distribution and its total intensity; x_1 and x_2 are arbitrary points in the fixed plane Z; and ω and σ determine the half-width of the beam (at the e^{-2} intensity level) and the complex degree of spatial coherence (at the $e^{-0.5}$ level).

The diffraction of a Gaussian beam from an acoustic wave in the Bragg regime is described by the expression [10]

$$I_1 = I_0 (2\pi)^{1/2} W^2 \frac{\omega_0}{\lambda} \int_{-\infty}^{\infty} \left| \int_{-\pi/2}^{\pi/2} \frac{\sin\left[(\pi L/\Lambda)\left(W^2 + \alpha^2\right)^{1/2}\right]}{\left(W^2 + \alpha^2\right)^{1/2}} \right.$$

$$\left. \times \exp\left[-\pi^2 \left(\frac{\omega_0}{\lambda}\right)^2 \alpha^2\right] \exp\left[\mathrm{i}2\pi \left(\frac{x}{\lambda}\right)\alpha\right] \mathrm{d}\alpha \right|^2 \mathrm{d}x, \quad (2)$$

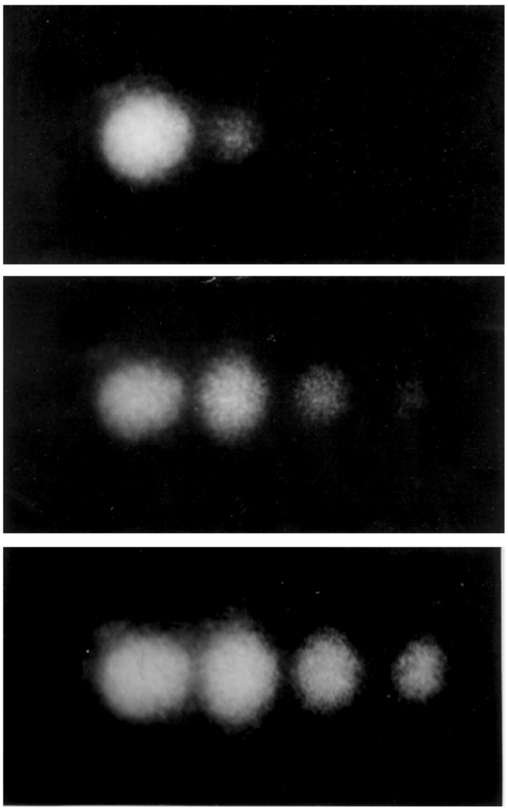

Figure 1. Dependence of the speckle pattern of diffraction orders on the acoustic power.

where I_1 and I_0 are the intensities of the first-order diffracted radiation and incident radiation, respectively; $W = (\Lambda/2\lambda)(\Delta\varepsilon/\varepsilon)$ is the parameter characterising acoustic power; Λ and λ are the sound and light wavelengths, respectively; ε and $\Delta\varepsilon$ are the dielectric constant and its increase caused by the acoustic wave, respectively; ω_0 is the beam-waist diameter; α is the Bragg angle; x is the coordinate along which the acoustic wave propagates; and L is the acoustooptic interaction length along the y axis directed perpendicular to the Z plane.

Note that the main part of light energy scattered to the first order is concentrated within a comparatively small angle because, according to one of the basic properties of the acoustooptic interaction, the divergence of a diffracted field is determined by the lowest of the divergences of the interacting light (incident) and acoustic fields [10]. Thus, the divergence α_0 of the diffracted field will be certainly no higher than that of sound $\varphi_a \approx \Lambda/L$ (typically, $\varphi_a \leqslant 1°$). The region of variation of the coordinate x is restricted in fact by the waist diameter (i.e., its length is less than 4–5 mm). Direct calculations performed assuming that $W \ll 1$, i.e., for low acoustic power, show that the integral in (2), when the light beam divergence is approximately equal to that of the acoustic wave, weakly affects the intensity I_1, which will be mainly determined by the factor $W^2\omega_0/\lambda$. In other words, I_1 increases linearly with increasing ω_0. This is also confirmed by the dependences of the diffraction efficiency on the acoustic power calculated for different relations between the divergences of the incident light beam and the acoustic wave [10].

The initial parts of the dependences calculated in Ref. [10] are linear, their slope depends substantially on the incident beam-waist diameter ω_0 and decreases with decreasing ω_0. This means that regions with a high spatial coherence (i.e., with larger speckles) will diffract much more efficiently than regions with smaller speckles. At high acoustic powers, such a substantial difference is not observed. It was shown [3, 4] that in this case the difference in the diffraction efficiencies for fields with different values of coherence did not exceed $\sim 10\,\%$.

The discovered effect can be used to improve the parameters of an optical image being transmitted, the filtration of optical radiation with respect to its value of spatial coherence, etc.

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