

# SPECKLE REDUCTION OF OPTICAL FIELDS IN MULTI-MODE FIBERS BY MEANS OF ACOUSTO-OPTIC BRAGG DIFFRACTION

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For reducing the contrast of the speckle structure of optical fields at the output of multi mode fibers, we exploit the benefits of acoustooptic Bragg diffraction. The following operation conditions need to be satisfied: collinear propagation of two beams diffracted into +1 and -1 orders and having different polarization, and being focused on the input facet of the fiber. The proposed diffraction regime yields 90% diffraction efficiency. It is experimentally shown that the diffraction peculiarities in the anisotropic crystal TeO<sub>2</sub> allows the effective control of the contrast in the speckle structure by varying the acoustic frequency.

## I. INTRODUCTION

For each application in optical signal processing<sup>1</sup>, the optical carriers are conditioned to have a required degree of spatial and temporal coherence. However, during the propagation of the carriers through inhomogenous media, and hence their initial characteristics are disturbed. At the position where the optical signal needs to be recorded, means have to be provided to reduce this propagation noise, i.e. to decrease the speckle structure in the propagated signals. One of the possible solutions is to add artificially, dynamically changing fluctuations: e.g. using moving diffusers, exploiting mechanical vibration of optical media, using liquid crystals, etc allows smoothing the phase characteristics of the optical field. It is evident that the speed of the phase change of the separate rays of the optical beam (i.e. the speed of destroying the spatial coherence) has to be much larger than modulation speed of the transmitted signal.

Acoustooptic (AO) interaction is a very convenient alternative to solve this problem as the acoustic wave creates temporal and spatial disturbances of the media and allows modulating the cross section of the optical beam and changing the phase between the separate rays<sup>3</sup>. Typical acoustic frequencies (5-300 MHz) are much greater than the typical frequencies of the mechanical vibration (~1-10 kHz) or the frequencies of the re-orientation of the molecules in liquid crystals<sup>2</sup> (~ 10 kHz).

The approach in the Raman-Nath<sup>3</sup> regime has been widely investigated but in the Bragg regime experimental investigations are still lacking. We propose and investigate a new method to disturb the optical beam coherence using the Bragg diffraction without using considerable acoustic wave power.

In our method the output optical field is composed of two beams: +1<sup>st</sup> and -1<sup>st</sup> diffraction orders. The profiles of these orders can be changed in different ways due to the peculiarities of AO interaction in anisotropic media.

The method is based on the polarization-insensitive AO regime of diffraction<sup>4,5</sup>. In Fig. 1 the optical scheme of the setup is shown. Optical beam generated by laser 1 impinges on the AO cell 2 at the Bragg angle with respect to the acoustic wave. The

beam diffracted into +1<sup>st</sup> order is directed on mirror 3 and after reflection crosses AO cell 2 without additional diffraction. The lens 6 focuses this beam on the input of the multi mode fibre. Other part of the beam propagates through the AO cell without diffraction, reflects from mirror 4 onto opposite direction and diffracts on the same acoustic wave into -1<sup>st</sup> order. This beam propagates collinearly with the first beam and is focused on the same fiber by means of lens 6. The frequency difference between these two beams is  $2f$  where  $f$  is the acoustic frequency. These beams are mixed on the input of the fiber. A screen 7 is placed on the output of the fiber. On this screen the changes in the speckle pattern can be observed.

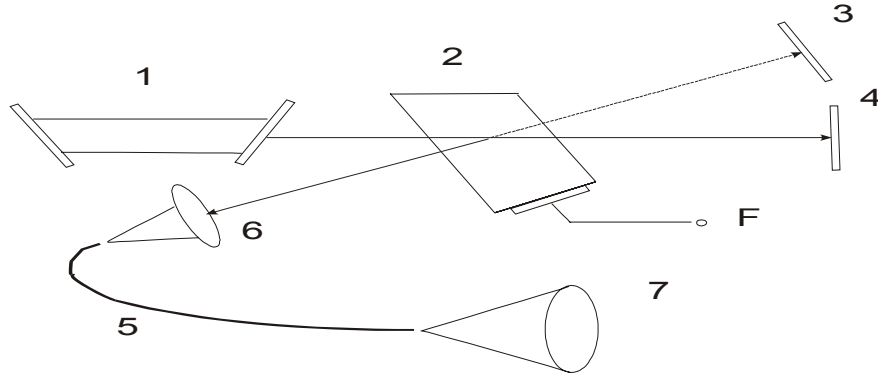


Fig. 1. Experimental setup

## II. THEORY

For the theoretical description we will use the plane wave approach developed in several publications where the AO interaction is considered however the beam profile is described via the introduction of the transfer function<sup>6</sup>.

In the case when only two orders are considered the following set of equations can be derived for the amplitude of the diffracted waves:

$$\frac{dE_0}{d\xi} = -i\frac{\alpha}{2}\exp(-iQ\xi\delta/2)E_1, \quad \frac{dE_1}{d\xi} = -i\frac{\alpha}{2}\exp(iQ\xi\delta/2)E_0, \quad (1)$$

where  $E_{0,1}$  - is the complex amplitude of the plane wave of the 0<sup>th</sup>, 1<sup>st</sup> order, respectively  $\xi = L/z$  - is the normalized distance along the AO cell,  $L$  - is the length of the AO interaction;  $\alpha = CkSL/2$ ,  $C$  is the effective elasto-optic coefficient of the material;  $k$  is the propagation constant of light into the media;  $S$  - is the amplitude of the sound;  $Q = 2\pi L\lambda/\Lambda^2$  - is the Clein-Cook parameter;  $\lambda$  and  $\Lambda$  are the wavelengths of light and sound, respectively, where  $\delta$  - is the angular deviation with respect to the Bragg angle. The solution of this system for the +1 diffraction order is

$$E_1(\xi) = E_{inc} \exp\left(\frac{i\delta Q \xi}{4}\right) \left\{ -i \frac{\alpha}{2} \frac{\sin\left[\left(\frac{\delta Q}{4}\right)^2 + \left(\frac{\alpha}{2}\right)^2\right]^{1/2} \xi}{\sqrt{\left(\frac{\delta Q}{4}\right)^2 + \left(\frac{\alpha}{2}\right)^2}} \right\}. \quad (2)$$

The form of (2) allows introducing the transfer function of the plane wave propagated through the AO cell. This function can be defined as <sup>6</sup>

$$H_1(\delta) = \frac{E_1(\xi)|_{\xi=1}}{E_{inc}}, \quad (3)$$

and the optical field distribution of the +1<sup>st</sup> order can be written as

$$E_1(r) = \int_{-\infty}^{\infty} E_{inc}(\delta) H_1(\delta) \exp\left(i2\pi \frac{\delta}{2\Lambda} r\right) d\left(\frac{\delta}{2\Lambda}\right). \quad (4)$$

The expression (4) allows deducing the profile of the diffracted beam on the basis of the distribution of the incident beam.

If the incident beam is Gaussian, which distribution is described as

$$E_{inc}(\delta) = E_{inc} \exp\left[-\frac{1}{2} \left(\frac{\pi\sigma}{\Lambda}\right)^2 \delta^2\right], \quad (5)$$

where  $\sigma$  - is the half-width of the beam, so (4) with taking into account (2) transforms into

$$E_1(r) = \int_{-\infty}^{\infty} E_{inc} \exp\left[-\frac{1}{2} \left(\frac{\pi\sigma}{\Lambda}\right)^2 \delta^2\right] \left\{ \left(-i \frac{\alpha}{2}\right) \exp\left(\frac{i\delta Q}{4}\right) * \operatorname{sinc}\left[\left(\frac{\delta Q}{4}\right)^2 + \left(\frac{\alpha}{2}\right)^2\right]^{1/2} \right\} * \exp\left(i2\pi \frac{\delta}{2\Lambda} r\right) d\left(\frac{\delta}{2\Lambda}\right) \quad (6)$$

where  $r$  and  $\delta/2\Lambda$  can be considered as the variables of the Fourier transform. The numerical calculations show that diffracted beam profile has very complicated waveform structure depending on both acoustic (frequency, power) and optical (half-width, angle of incidence and so on) parameters.

In our experiments we used the anisotropic AO diffraction, hence the expressions for the  $E_1(r)$  are more complicated. For example the beam profiles diffracted into +1 and -1 orders do not equal each other, the profiles are not symmetric, they depend on the «drift» of optical and acoustical beams. These factors strengthen the efficiency of our method for controlling the speckle structure of the total optical field.

### III. EXPERIMENT

The experiment was made in accordance with the optical scheme of Fig.1. The optical wavelength was 633 nm, AO modulator comprises a TeO<sub>2</sub> mono crystal. The shear acoustic wave was propagating along the [110] axis, optical beam - close to [001] axis.

The acoustic frequency was  $\sim 91$  MHz, velocity of the sound was  $0.617 \cdot 10^5$  cm/s. The used multi mode fiber had a length  $\sim 2$  m and core diameter  $\sim 50$   $\mu$ m. The proposed AO regime was described in details in <sup>4,5</sup>. It was shown that the  $\pm 1$  diffracted orders have different polarization - right-hand and left-hand ones. In other words the beams mixed on the input of the fiber have both different polarization and frequency.



Fig.2 Photographs at the output of the optical fibre. (a) a single beam (b) two interaction beams

In Fig. 2 the speckle structure on the output of the fiber are shown when only one beam propagates (+1<sup>st</sup> order, Fig.2(a)) and two beams (+1 and -1 orders, Fig. 2(b)). It can be clearly seen that the characteristics of the speckle pattern in Fig.2(b) is much more smoothed in comparison with the speckle structure of Fig.2(a).

## CONCLUSION

For the reducing of the contrast of the speckle structure of an optical beam propagated along the multi mode fiber it is proposed the using of two beams with different polarizations and frequencies, which can be obtained by means of acousto-optic Bragg diffraction as +1-st and -1-st orders propagated collinear each other. The anisotropic diffraction based in the proposed method allows enforcing the changes of the field structure and supply the effective reducing of the contrast of the speckle.

The obtained results can be applied to improve the characteristics of optical information, carried by light with speckle structure.

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