Formation of probing radiation for investigating a uniaxial x-cut crystal with the help of an aperiodic diffractive axicon

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Abstract

The paper presents an experimental study of transformation of a laser beam formed by an aperiodic diffractive axicon (fracxicon) in a lithium niobate x-cut. The beam is shown to undergo astigmatic rhomboidal transformation induced by the crystal birefringence. The output beam intensity distribution is measured at various distances from the crystal. The effects analyzed make it possible to extend the range of measuring thickness or birefringence of solid, liquid or gaseous media with uniaxial optical anisotropy.

Keywords: fracxicon; uniaxial crystal; birefringence

1. Introduction

Besssel laser beams [1-4] possessing non-diffractive properties are an efficient tool in various metrological [5,6], diagnostic [7,8] and testing [9-13] applications. Beams of this kind are also useful for investigating optical anisotropy and birefringence. In [14-22] it is shown that Bessel beam propagation in birefringent crystals of various cuts is accompanied with the transformation of the beam order or kind. In [23-25] the influence of the position and parameters of certain elements of optical scheme (laser wavelength, illuminating beam wavefront curvature, crystal temperature) on the Bessel beam characteristics at the crystal output is analyzed. In [26, 27] the thicknesses of z- and x-cuts of uniaxial crystals are measured by an optical method using the effects mentioned. Similar results can be expected for media with various refractive index distributions: linear, parabolic etc. This makes Bessel beams promising means for remote control of anisotropic films, metamaterials, birefringent crystals and ceramics.

As a rule, conical and diffractive axicons are used to form Besssel beams. The diameter of an axicon (laser beam) amounts to 200-300 mm, while its numerical aperture assumes specified values within a wide range in the long-wave part of the visible spectrum and shortwave infrared. Therefore, Bessel beams can be used for studying both submicron films and air routes many kilometers long.

There are many other axisymmetrical optical elements that form beams with non-diffractive properties, among them a logarithmic axicon [28-30], a generalized axicon [31], an axilens [32], and an aperiodic (fractional) axicon [33]. Linear diffractive axicons [28, 29] are used to produce Bessel laser modes, whereas the analogue of a logarithmic axicon is used to form hypergeometric modes of laser radiation [34, 35] that retain their mode properties longer than Bessel beams. The tandem of a lens and an axicon – a lensacon that makes it possible to form conical axial distributions - also possesses interesting properties. The aperiodic (fractional) axicon also referred to as a fracxicon [33] presented in the paper comprises an axicon and a parabolic lens as special cases.

The theoretical models developed and the experimental results obtained do not limit the use of non-diffractive beams to solids only. It is also possible to measure distributions of optical parameters of liquid and gaseous anisotropic media on their basis. For example, we can analyze the state of disturbed atmosphere, the properties of gas-plasma flows, distribution of ionic solution concentrations. The advantages of special beams including singular and vector ones for the purpose of atmospheric data transmission are described in the review [36]. We should also mention the possibility of producing tunable diffractive elements based on the electro-optic effect for the purpose of fast data transmission and three-dimensional addressing [37, 38].

A relatively small range of measuring due to periodic transformation of the beam order in a crystal [20, 27] is one of the problems of measuring thicknesses of z-cut birefringent crystals. Astigmatic beam transformation in x- and z-cut crystals leads to the splitting of the beam into separate intensity maxima [18, 19]. The angular dimension of the maxima decreases with the increase of the crystal thickness and birefringence [18, 19]. In the case of crystals of considerable thickness it leads to the problem of insufficient spatial resolution of the video camera.

Both problems are solved by using a multizone axicon or a variable-period axicon (fracxicon, lensacon etc.). An element of this kind makes it possible to choose a site of diffractive microrelief the spatial period of which conforms to the optical and dimensional parameters of the tested sample.

The aim of the study was to analyze the transformation of a laser beam formed by an apriodic diffractive axicon (fracxicon) in a uniaxial x-cut crystal.

2. Experimental study

An optical setup was assembled to investigate astigmatic beam transformation. The scheme of the setup is presented in fig. 1. The setup includes a helium-neon laser, a spatial filter – beam expander, a polarizer, a fracxicon, a lithium niobate x-cut crystal, a CCD matrix. The spatial filter consists of a microlens 20x, a pinhole aperture with the diameter of 15 μm, a collimator lens with the focal distance of 200 mm. The setup allowed the formation and investigation of a sufficiently extended fracxicon beam observed at a distance up to 600 mm.

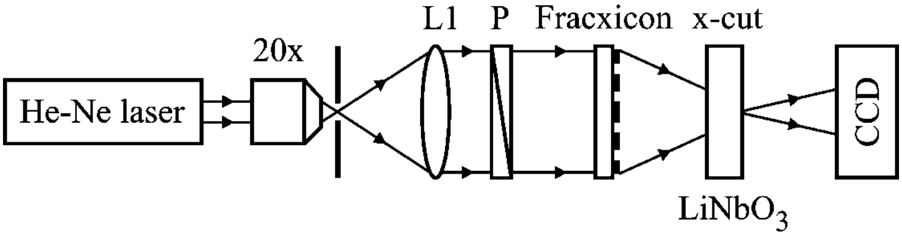
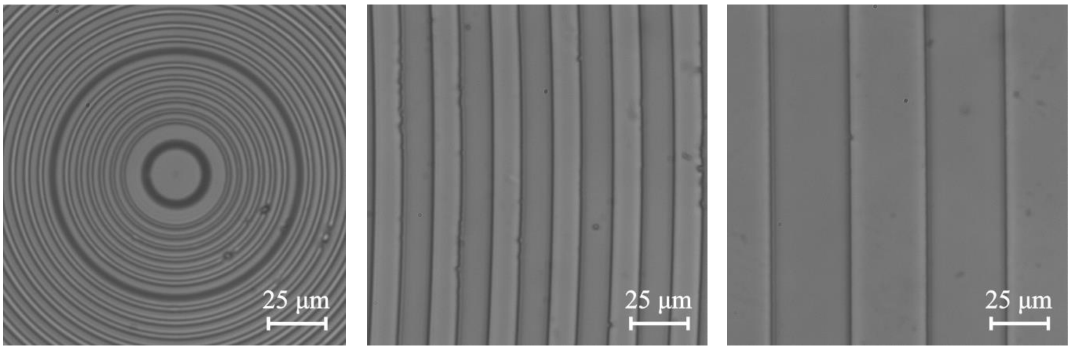


Fig. 1. Scheme of the experimental setup.

A polished uniaxial x-cut crystal of lithium niobate with 842±2 μm thickness was used as the beam converter. The optical axis of the crystal was aligned parallel to one of its sides and its direction was marked. The axis of the polarizer and that of the crystal were parallel in the experiments. A phase diffractive variable-period axicon (fracxicon) shown in fig. 2 was used to form the beam. The fracxicon was made on a fused-silica substrate by plasma-chemical etching. The diameter of the fracxicon was 20 mm, the period of the diffraction microrelief - 7 μm in the central part of the optical element and 70 μm at the edge of the element.



a) b) c)

Fig. 2. Photos of the diffractive fracxicon microrelief: a) central part, b) middle part, c) edge part.

The distance between the crystal and the fracxicon was 75 mm. The image of the output beam was formed directly by the CCD matrix without the use of imaging optics. The images of the beams observed for various distances L between the CCD array and the crystal are presented in fig. 3.

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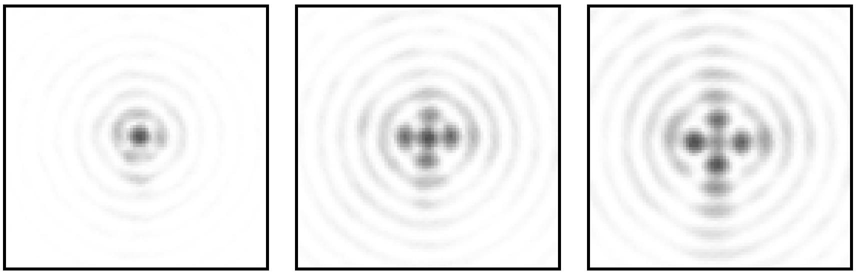
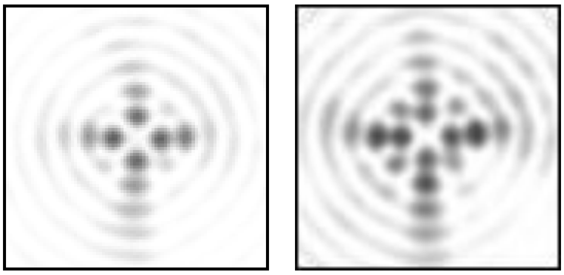


a) b) c)



d) e)

Fig. 3. Output beams for various distances L “crystal – CCD array”: a) L=250 mm, b) L=300 mm, c) L=350 mm, d) L=400 mm, e) L=450 mm.

Increasing the distance between the crystal and the camera makes astigmatic beam transformation more complicated due to the inclusion of fracxicon regions with increased angular aperture. This makes the use of several variable-period diffractive axicons unnecessary. One variable-period diffractive element is sufficient for reliable measurement of the thickness or birefringence of a plane-parallel crystal.

The results obtained in this work are in good agreement with earlier studies [18, 19]. The approach proposed has the advantage of a simpler optical measurement scheme that does not comprise an analyzer. The simplification is made possible due to parallel orientation of the polarizer and the crystal optical axis.

3. Conclusion

The results obtained confirm the validity of using an aperiodic diffractive axicon with specified radial period distribution. It is possible to select the part of the microrelief conforming to the test specimen parameters and the characteristics of the optical measurement system on the basis of this element. Measurement with the use of several parts of fracxicon improves the accuracy of determining the thickness or birefringence of the crystal.

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