Optical systems for research parameters of laser radiation transformed by infrared range diffractive elements

Yu.G. Kurenkova[a], A.V. Mezhenin[a]

[a] *Samara National Research University, 443086, 34 Moskovskoe shosse, Samara, Russia*

Abstract

The optical systems for studying the parameters of laser radiation transformed by diffractive optical elements intended to operate in the infrared range have been created. The systems permit to register the intensity distribution formed by microoptics elements in different sections and give the possibility to measure their power efficiency. The optical systems experimental approvement has been conducted using reflective binary cylindrical lens and focusator to a point.

Keywords: intensity distribution; power efficiency; diffractive optical element; binary cylindrical lens; focusator

1. Introduction

The development of laser technology and its applications brought to the fore the need to develop a variety of radiation control means. One of the common ways to control laser radiation is the use of diffractive optical elements (DOE). Outwardly, this element is a transmissive or reflective plate with a thin phase micro-relief calculated within the diffraction theory. As a result of progress in the field of microelectronics and laser technology, which has led to the emergence of the precision photoplotters and electron beam lithographers in the late 80s, the task of creating a diffractive optical element with a complex profile areas has been solved. The wide-opened field has arisen for physicists, opticians, professionals in the area of applied mathematics and electronics, automation specialists. DOEs with unique characteristics, unachievable within traditional optics, have emerged, for example, laser radiation focusators [1], [2].

One of the most commonly used infrared radiation sources are CO_2-lasers. Nowadays they are widely used in industry for the separation of construction materials and heat treatment [3]–[5], in research at structuring the alloys surface layers [6]–[8], as well as in surgery (including ophthalmology) [9]. Their use in such areas is closely connected with the possibility to realize the required beam intensity distribution on the surface of the biological or technological object. In addition, the radiation control can improve the implemented processes power efficiency.

In terms of radiation control, the main parameters those characterize the DOE are the radiation intensity distribution in the focal plane and power efficiency. Intensity distribution registration is important to check the quality of optical element manufacturing and allows you to compare the size of the focus area and the energy distribution within it with the calculated values. The energy distribution data also supports the measurement of power efficiency e, which is the ratio of the energy caught in the specified area of the focal plane L to the energy of the illuminating beam:

$$e = \int_L I(x) d^2x \Big/ \int_D I_0(u) d^2u, \qquad (1)$$

where $I(x)$ is focal intensity distribution, $I_0(u)$ is intensity distribution of the illuminating beam. Now, the software for the calculation of these quantities is created [10]. The aim of this work is creation and testing the optical systems for studying the parameters of CO_2-laser radiation reformed by diffractive optical elements.

2. The objects of the study

In this paper, a phase reflective binary cylindrical lens (Fig. 1, a) and a focusator to a point with the semitone relief (Fig. 1, b) have been selected as the elements forming the laser radiation to reduce the power losses. The studying objects selection has been conditioned on the one hand by the fact that the reliefs quantized from one to several steps are the most widespread. On the other hand, the DOE gradient surface profile provides a higher energy concentration in a specified area, despite the manufacturing complexity. The analysis of radiation structure formed by them in the focal planes is of interest to determine the impact of fabrication technological errors.

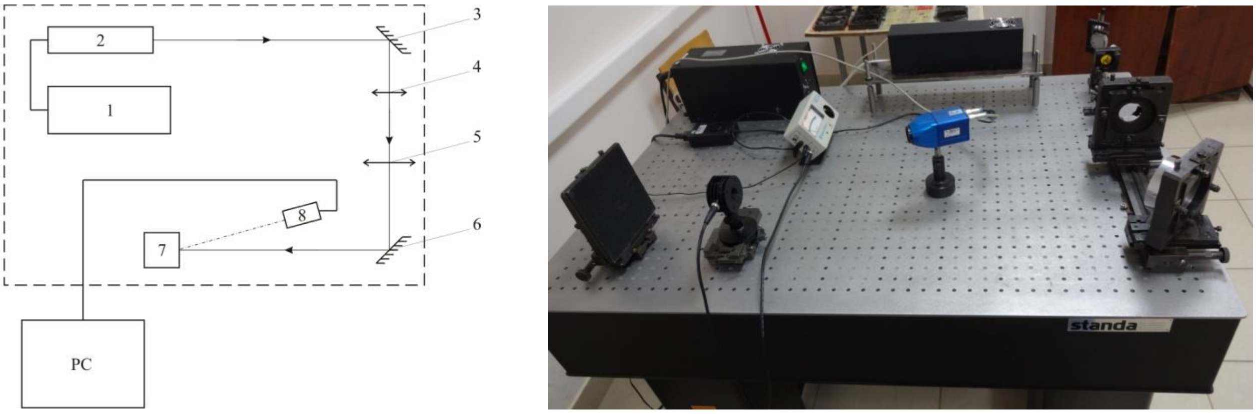
Both the optical elements have been designed so that the axis of the incident beam had formed the angle of 45° with the central normal to their surfaces. The first element consists of two regular patterns etched in the same substrate. It should be noted that the relief of one of them is inverted with respect to the other. The aperture size of the illuminating beam for each binary lens should be 20×20 mm. The beam diameter to illuminate the entire surface of the focusator to a point must be no less than 40 mm. The focal length of binary lenses is f=0.6 m and it is f =0.7 m for the focusator to a point. Calculated maximum relief height of binary elements and the element with halftone relief are 3.75 μm and 7.5 μm, respectively. According to the manufacturer, real stepped profile is created closely to the calculated one (overetching is less than 100 nm), and the gradient profile is characterized by a significant (greater than 1 μm) underetching in the central area and even more at the periphery.

a b

Fig. 1. The test objects: binary lens (a) and focusator to a point (b).

3. Diagnostic stand

The work has been carried out on the stand assembled in accordance with the scheme shown in Fig. 2, a. The stand photo is represented in Fig 2, b.



a b

Fig. 2. The optical scheme (a): 1 – power supply; 2 – laser; 3 – rotary mirror; 4, 5 – collimator; 6 – DOE; 7 – power meter or screen; 8 – IR-camera; PC – personal computer. Photo of stand to explore the characteristics of the radiation formed by the DOE, (b).

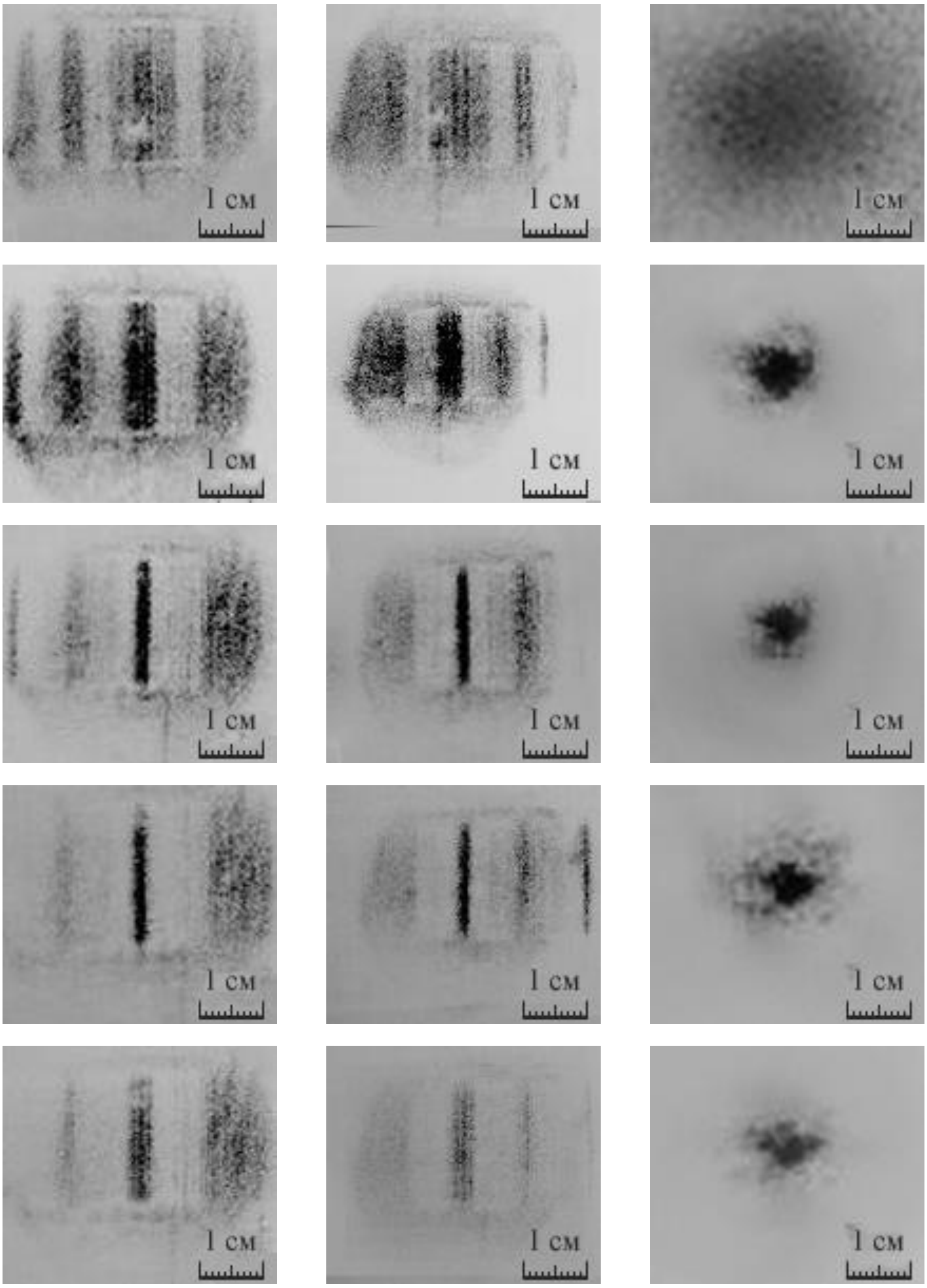
We supposed to carry out the registration of DOE formed radiation intensity distribution in real time using a bolometer infrared camera XPORT-317 operating in the wavelength range of 8–14 μm. The presence of the device of this type in the optical system entails the imposition of restrictions on the laser beam power. For this reason, the CO_2-laser LCD-1A with a nominal output power of 1 W has been chosen as the radiation source. The maximum power of a single-mode beam from the measurements is 3.2 W. To determine the power efficiency we used the «Spectra Physics» model 407A power meter that has an error of ±3% in the wavelength range from 250 nm to 11 μm. The measuring head detector diameter of the device is 1.8 cm.

To register the intensity distribution of the radiation formed by DOE it's necessary that the illuminating beam completely covers its surface, i.e. creates conditions for operating not only central but also peripheral regions of the optical element. Since the output beam diameter of the laser LCD-1A (1.8 mm) is much smaller than the size of the studied DOE aperture (see Section 2) the two-lens collimator is provided in the optical system. In the experiments, we used two collimators. The first consisted of the input diffusing and output collecting lenses and gave the output beam diameter of 24±2 mm. The second was formed by two collecting lenses, the output beam diameter was 40±2 mm. The transverse spot size was controlled on the basis of about 1 m. The stand was assembled on the «Standa» firm's optical table with dimensions of 120×80 cm.

4. Results and Discussion

Fig. 3, a-c shows the intensity distributions (inverted images) obtained on a screen placed at the studying DOEs' focal planes as well as at the several planes coplanar to them to determine the depth and quality of focusing. The data shown in Fig. 3, a corresponds to the results for the binary lens disposed on the substrate (Fig. 1, a) on the left side; Fig. 3, b shows the images received for the right cylindrical lens. Fig. 3, c gives the results for a focusator to a point.

Analysis of the snapshots allows us to conclude that beam is formed at short distances from the DOE and the focusing area has not got sharp boundaries. Starting with a distance of 20 cm in front of the focal plane, the focusing area acquires clear boundaries. We can see vertical segments related to focuses on Fig. 3, a and 3, b, and Fig. 3, c shows a circular area corresponding to the focal spot. The best focusing quality is reached at the distances corresponding to the calculated positions of the focal planes. The clear contours of focal regions persist over long distances. The image begins to blur only at a distance of about 40 cm behind the focal planes. Besides the maxima of higher orders, there is an additional scattering on the snapshots occurred due to defects in the reflective coating and manufacturing technology errors.



a b c

Fig. 3. The intensity distributions for the radiation transformed by the left (a) and by the right (b) binary lenses and by the focusator to a point (c) in the planes located at a distance from the DOE: I line – f-40 cm, II line – f-20 cm, III line – f, IV line – f+20 cm, V line – f+40 cm.

To determine the power efficiency via the formula (1) is necessary to know the focusing area sizes. Since these calculations are not carried out in this work, we use the experimental data. We assume that the binary lens segment width in the focal plane is 2 mm and focal spot diameter is 6 mm for the focusator to a point. To obtain correct measurements with a power meter of this type, the beam size on the collimator output has been regulated. The laser output power reduction allowed us getting 100% radiation capture in the detector reception area. The higher-order peaks impact excluding has been achieved by applying the elements opaque for the radiation on measuring head in the respective regions.

The binary lens power efficiency was 40% at a beam power on the collimator output of 1 W. The focusator to a point power efficiency was determined to be 63% when the beam power on the collimator output was equal 0.8 W. When the detector reception area was fully opened the efficiency did not exceed 84%.

5. Conclusion

The optical systems for studying the radiation intensity distribution formed by DOE and measuring power efficiency have been created. An experimental study of converted beams parameters on the example of the reflecting a binary cylindrical lens and a focusator to a point has been carried out with low power radiation source. Registered radiation intensity distributions allowed us to establish the geometry and assume the dimensions of the focal areas, as well as to determine the DOEs' power efficiency based on these data. The results indicate the high manufacturing quality of binary elements. Low focusator's to a point power efficiency connected with a spot blur in the focal plane which caused mainly by significant microrelief underetching compared to the calculated depth during the fabrication.

Acknowledgements

This work has been carried out within the framework of the strategical academic unit 'Nanophotonics, Perspective Technologies of Earth Remote Probing and Intellectual Geoinformation Systems' (StrAU-3) of the Samara National Research University's competitiveness improving program.

References

[1] Diffractive Computer Optics / edited by V.A. Soifer. – Moscow: "Fizmatlit" Publisher, 2007. – 736 p. – (in Russian).

[2] Methods of Computer Optics: Textbook for High Schools / edited by V.A. Soifer. – Moscow: "Fizmatlit" Publisher, 2003. – 688 p. – (in Russian).

[3] Rykalin, N.N. Laser and Electron Beam Materials Processing: Reference Book / N.N. Rykalin, A.A. Uglov, I.V. Zuyev, A.N. Kokora. – Moscow: "Mashinostroyeniye" Publisher, 1985. – 496 p. – (in Russian).

[4] Grigor'yants, A.G. Fundamentals of Laser Materials Processing / A.G. Grigor'yants. – Moscow: "Mashinostroyeniye" Publisher, 1989. – 304 p. – (in Russian).

[5] Laser Treatment Technological Processes: Textbook for High Schools / edited by A.G. Grigor'yants. – Moscow: Bauman MSTU Publisher, 2006. – 664 p. – (in Russian).

[6] Kazanskiy, N.L. Application of radiation focusers for nanoporous crystalline materials structure formation / N.L. Kazanskiy, S.P. Murzin, V.I. Tregub, A.V. Mezhenin // Computer Optics. – 2007. – Vol. 31(2). – P. 48-51. – (in Russian).

[7] Kazanskiy, N.L. Laser radiation formation for creation nanodimentional porous structures of materials / N.L. Kazanskiy, S.P. Murzin, A.V. Mezhenin, E.L. Osetrov // Computer Optics. – 2008. – Vol. 32(3). – P. 246-248. – (in Russian).

[8] Murzin, S.P. Nanostructuring by movable focusator's application of laser radiation for metal materials / S.P. Murzin, V.I. Tregub, A.V. Mezhenin, E.L. Osetrov // Computer Optics. – 2008. – Vol. 32(4). – P. 353-356. – (in Russian).

[9] Rovinskii, R.Ye. High-power Technological Lasers [Electronic resource] / R.Ye. Rovinskii. – File of pdf format (1,39 Mb), 2005. – 103 p. – (in Russian). — Access mode: http://www.twirpx.com/file/946980/ (04.02.2017).

[10] Pavelyev, V.S. IR range Power Optics on Diamond Films: Tutorial / V.S. Pavelyev, D.L. Golovashkin, V.A. Soifer. – Samara: SSAU Publisher, 2007. – 64 p. – (in Russian).