LASERS

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Laser system emitting 100 mJ in Laguerre – Gaussian modes

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***Abstract*. The optical scheme and radiation parameters of a neodymium glass laser system emitting high-power 40-ns pulses in the first – third-order Laguerre – Gaussian modes of energy up to 100 mJ are described.**

Keywords: *neodymium laser, high-power laser radiation, Hermite – Gaussian modes, Laguerre – Gaussian modes, astigmatic mode converter.*

1. Introduction

The interaction of laser radiation with matter has been studied for many years either by using multimode radiation [as a rule, an uncontrollable superposition of Hermite – Gaussian (HG) modes] or Gaussian laser beams (TEM_{00} mode). In recent years, interest is increasing in the use of laser beams with the circular intensity distribution for this purpose. For example, the use of high-power Bessel beams (especially, for the laser breakdown of gases) has shown that the parameters of the produced plasma can be efficiently controlled by varying not only the laser pulse duration but also its spatial structure [1]. Another example is the prediction of interesting phenomena observed upon stimulated Brillouin scattering (SBS) of vortex Laguerre – Gaussian (LG) beams, which are denoted LG_{pl} (where p, l are mode indices) [2].

Note that the use of circular beams for producing a high-temperature plasma was first proposed as early as 1964 [3]. However, the method of screening the axial region of a laser beam proposed in [3] cannot give in principle the circular intensity distribution in a lens focus [4]. After the first reports about the possibility of obtaining LG beams [5, 6], it was proposed to use them for studying the interaction of super-power radiation with plasmas [7]. Most of the studies of the interaction of LG beams with matter were performed so far at relatively low power levels because the radiation was obtained by diffraction methods [8 – 11], which are restricted by the damage level of elements used in them (as a rule, made of plastic). The experimental studies of the SBS of an LG_{01} beam [12, 13], which confirmed conclusions made in [2], the radiation power exceeded the SBS threshold. The LG_{01} mode was produced by using high-quality fused silica phase plates with a high damage level [14, 15]. Note, however, that the generation of higher-order LG_{pl} beams for $p + l > 1$ with the help of spiral phase plates is rather problematic.

In this paper, we describe the scheme and parameters of a pulsed laser system emitting more than 2 MW at 1.05 μm, in which LG beams are obtained for the first time by the conversion of HG beams in a tunable astigmatic $\pi/2$ converter [16].

2. Optical scheme of the laser system

The laser system consists of a laser emitter itself and an astigmatic converter.

2.1 Laser emitter

A laser emitter (Fig. 1) consists of a master oscillator (MO) and a two-pass laser amplifier. Both MO and amplifier use active elements in the form of GLS-23 neodymium phosphate glass rods. The diameter and length of the active element in the MO are 5 and 100 mm, and these parameters for the amplifier are 8 and 150 mm, respectively.

The optical scheme of the MO is similar to that described in [17] except a system of masks used to select transverse radiation modes. The replacement of one of the linear masks by a cross lines allowed a more reliable locking of the HG mode zeroes up to the TEM_{12} mode inclusive.

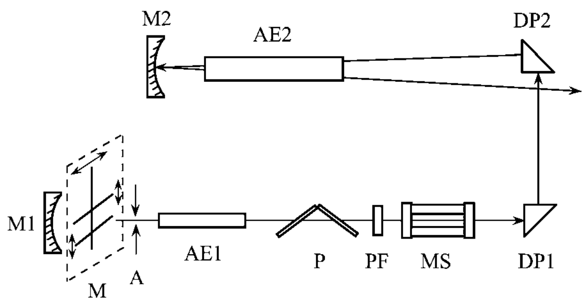

Figure 1. Optical scheme of the emitter: (M1) spherical mirror of the MO ($R = 2$ m); (M) masks; (A) iris aperture; (AE1) MO active element; (P) polariser; (PF) passive Q switch; (MS) longitudinal mode selector; (DP1, DP2) deflecting prisms; (AE2) amplifier active element; (M2) retroreflecting spherical mirror of a two-pass amplifier ($R = 2$ m).

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The transport of the beam between the MO and amplifier is performed with the help of two prisms, and a highly reflecting spherical mirror of radius 2 m is used to provide two transits of radiation in the amplifier and ensure a plane wavefront at the converter input (see below). The use of this mirror in the optical scheme in Fig. 1 eliminates the need in additional optic elements for matching the laser beam diameter with converter parameters and reduces the size of the system.

The active element of the MO was pumped by using a pump cavity with a reflecting monoblock, which, as shown in [17], is important for obtaining stable lasing at HG modes. A similar monoblock was used in a pump cavity of the active element of the amplifier.

In the flashlamp power supply of the MO and amplifier, we used PS 701AT units with storage capacitors with capacitances 100 and 200 μF, respectively.

2.2 Astigmatic converter

Unlike a $\pi/2$ converter without compensation for the saddle-shaped wave front of LG modes [18] used in previous paper [17], we employed here an astigmatic converter constructed according to a scheme described in detail in [16]. It consists of two identical optomechanical blocks OB1 and OB2, each of them containing positive and negative cylindrical lenses with the same focal distance $|F| \sim 80$ cm and a positive spherical lens ($f = 80$ cm). The cylindrical lenses in each of the blocks can be synchronously rotated in the opposite directions around the optical axis of the converter, providing its tuning. The powers of cylindrical lenses in the initial position completely compensate each other and their axes coincide with the principal axes of the intensity distribution of a mode of the emitter. The distance between blocks is fixed so that spherical lenses are separated by a distance f and form an optical Fourier transformer.

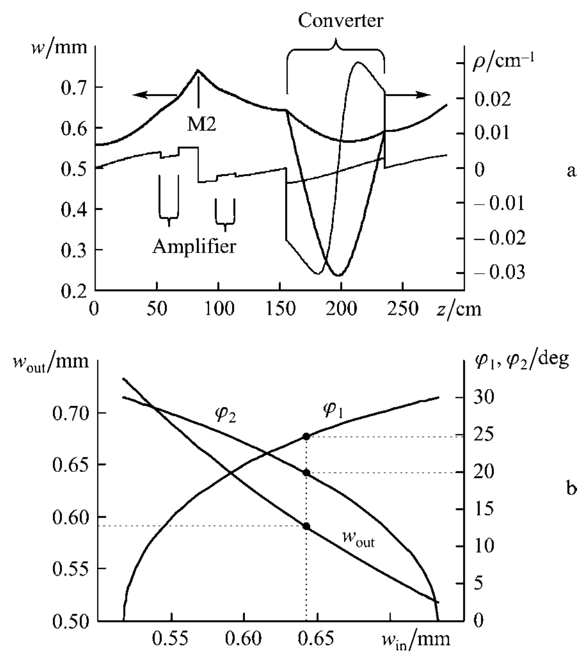

Figure 2. Calculated radii of the laser beam w (solid curve) and of its wave-front curvature ρ (thin curve) at different distances from the output element of the MO (a) and the tuning diagram of the converter (b).

In the case of the plane wave front of the HG mode, which is formed at the converter input by mirror M2, the rotation of cylindrical lenses in OB1 provides the matching of the converter with the laser beam parameters. The curvature of wave fronts at the converter output is compensated by rotating cylindrical lenses in OB2. In this case, the laser beam propagates behind the converter without distortions of the intensity distribution of LG modes. The calculated dependences of the laser beam radius $w(z)$ and its wave-front curvature $\rho(z)$ at different distances from the output element of the MO are presented in Fig. 2a. The kinks of the curves and discontinuity points $\rho(z)$ correspond to the boundaries of optical elements. The changes of $w(z)$ and $\rho(z)$ between the lens blocks of the converter in panes $x = y$ and $-x = y$ are shown, respectively, by two curves. The radii w of the laser beam at the input and output of the converter and the orientation angles $\varphi_{1,2}$ of cylindrical lenses in OB1 and OB2 are indicated by points in the tuning diagram of the converter (Fig. 2b). For parameters of the converter lenses presented above, the beam radius at the converter input lies in the range $w_{\text{in}} = 0.52 - 0.73$ mm.

3. Radiation parameters

As pointed out above, masks placed in the MO resonator provide fixing the zeroes of all the modes up to the TEM_{12} mode. The higher-order TEM_{13} and TEM_{14} modes were also obtained in experiments, but already without fixation of all the zeroes of the field, resulting in the spontaneous variation in their structure during operation (for example, the passage from the TEM_{13} mode to the TEM_{14} mode).

The radiation energy at the MO output was 18 – 30 mJ, depending on the HG mode type, for the pump threshold 50 – 75 J. The laser pulse duration was 40 ± 1 ns. The radiation energy at the converter output for the generation of the TEM_{12} mode and its conversion to the corresponding LG mode at different pump levels of the amplifier is presented in Fig. 3.

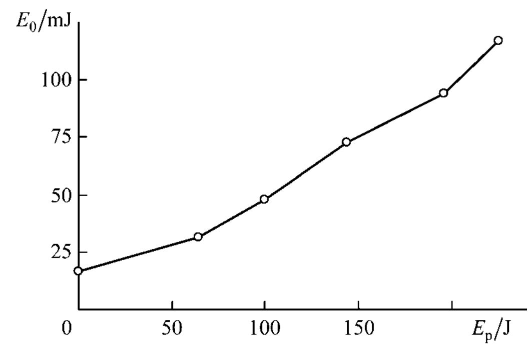

Figure 3. Dependence of the output energy E_0 of the laser system on the pump energy E_p at the output of the mode converter for the TEM_{12} mode.

Some of the field distributions for LG modes obtained at a distance of 75 cm from the converter OB2 are presented in Fig. 4 (the experimental cures are obtained by averaging the data for cross sections in planes $x = 0$, $y = 0$, $x = y$, and $-x = y$). The beam radius $w = 0.68 \pm 0.04$ mm measured in experiments corresponds to the calculated value in Fig. 2a. The field distribution for the LG_{01} mode is obtained with a con-siderable saturation of an array photodetector and

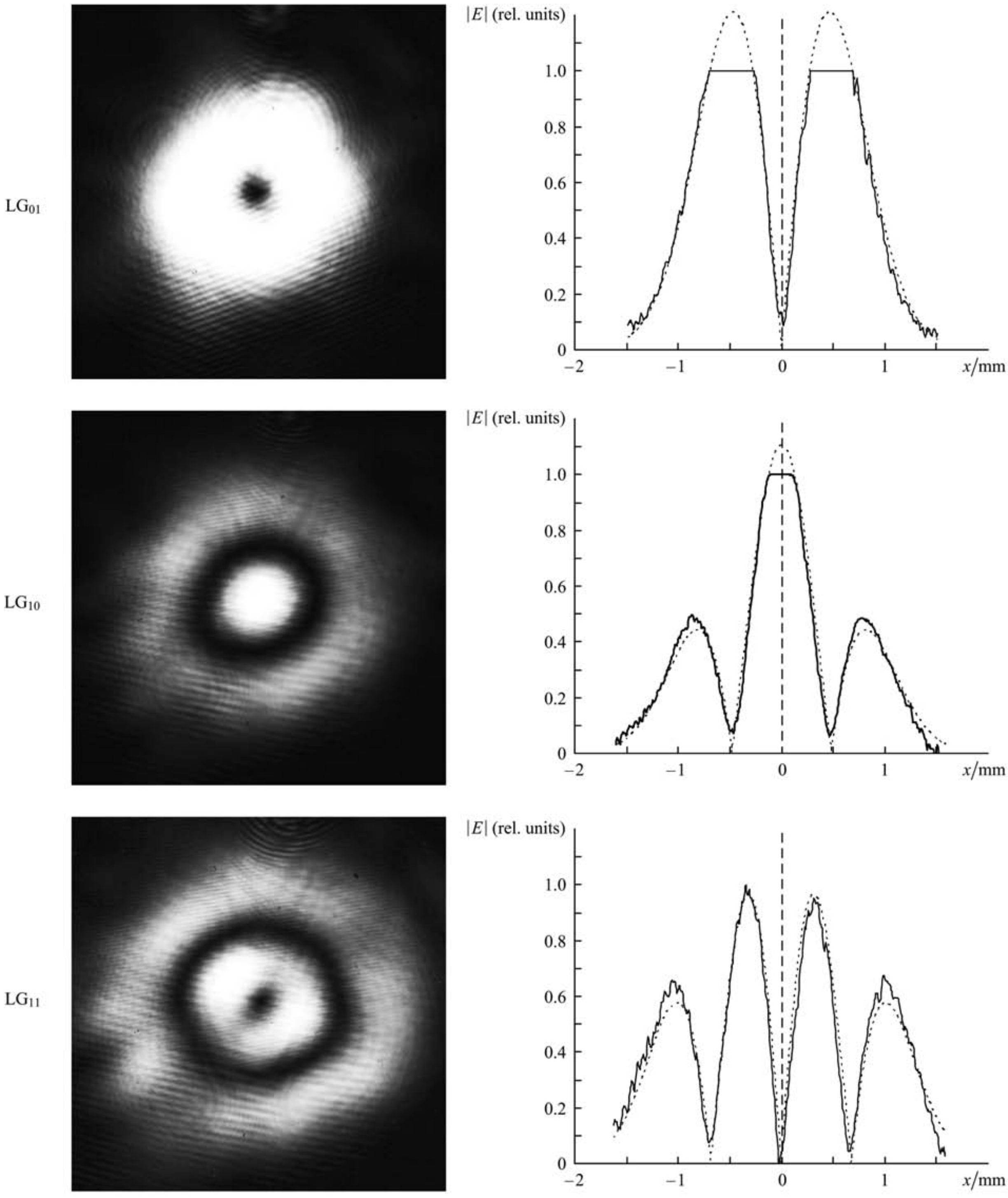

Figure 4. Distributions of the field amplitude for LG modes at a distance of 75 cm from the converter (photographs) and the results of their processing: experimental (solid curves) and theoretical (dashed curves) distributions.

demonstrates a rather low level of the field zero $|E(0)|$. The estimate of the ratio $|E(0)/E_{\max}|$ gives the value $\sim$0.03 for the LG_{01} mode, i.e. less than 10^{-3} for the intensity, which suggests that the contribution of the even-order modes is rater small. The radiation quality for the LG_{10} and LG_{11} modes is somewhat worse: the ratio of the circular minimum intensity to the maximum intensity is estimated as $\sim 2 \times 10^{-3}$ and $\sim 4 \times 10^{-3}$, respectively.

4. Conclusions

The laser system described in the paper allows the controllable generation of Laguerre-Gaussian modes up to the third order inclusive with the output energy up to 100 mJ, which corresponds to the peak power for 40-ns pulses exceeding 2 MW. This power level and quality of radiation obtained in experiments are sufficient for performing various experiments on the interaction of laser radiation with matter.

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