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Radial distribution of a single-pass amplified radiation in the active elements of CuBr lasers

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Abstract. The paper presents the results of study of single-pass amplified radiation distribution of copper bromide vapor laser active elements used in high-speed laser monitors. The possibility of modifying the profile of a single-pass amplified light beam by changing the copper bromide vapor concentration is demonstrated. This means of influence on the radiation profile seems to be easiest due to implementation by varying only one parameter of operation. Gaussian, ring-shaped or flat profiles can be achieved depending on the temperature of the containers with copper bromide. The diameter of the beam becomes narrower when increasing the concentration of copper bromide vapor. This feature is characteristic of the discharge tubes as small (diameter 2.5, length 5 cm) and large (diameter 5 cm, length 90 cm) active volume.

1. Introduction

Laser monitor based on active media of copper vapor laser or copper bromide vapor laser is one of the effective instruments for the diagnostics of processes accompanied by intensive shielding background light [1–12]. Laser monitors allow observing processes such as surface modification for operational characteristics improvement, production of novel materials including nanostructures, processes of thermonuclear synthesis, plasma-induced processes, etc. There are a number of papers devoted to the application of such active media for imaging various objects but researching towards the development of practical laser monitors is carried out insufficiently.

In the work [13] it is reported about CuBr vapor lasers for different applications. In the work [12] one of these lasers was applied for objects visualization under conditions of intensive background lighting. In the paper [11] a construction of laser monitor based on an active medium of CuBr laser is represented and visualization results obtained by the laser monitor for some objects are also given. An optical part of the laser monitor construction is shown in figure 1. The main element of the laser monitor scheme is an active element of brightness amplifier.

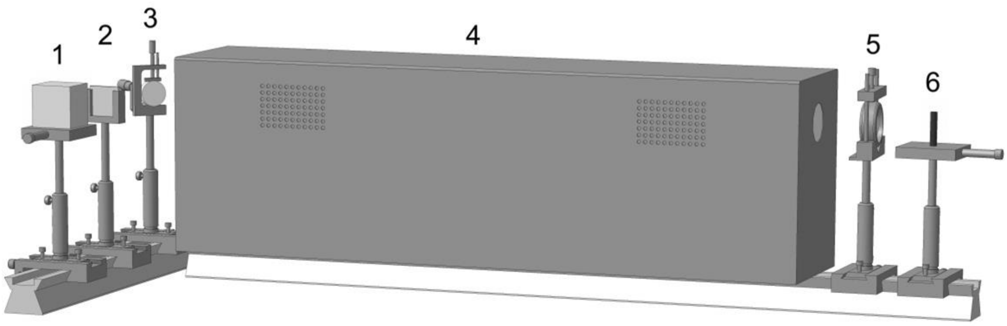

Figure 1. Laser monitor: 1 – CCD-camera, 2 – optical filters, 3 – deflecting mirror, 4 – brightness amplifier, 5 – lens, 6 – object under observation.

The applied laser monitor scheme implies that an active medium of CuBr laser generates light illuminating an object of visualization and simultaneously amplifies light reflected from the object. However, the presence of radial inhomogeneity of population inversion in the active medium accordingly leads firstly to non-uniform illuminating the visualization object and then to non-uniform amplifying light reflected from the visualization object. As a result the visualization object image is obtained with distortions. It should be noted that such distortions are only connected with incorrect brightness transfer of some parts of obtained picture but not with the picture shape deformations. Image shape deformations depend mainly on quality of passive optical part of the laser monitor scheme.

The radial inhomogeneity of population inversion in the active medium can be estimated from corresponding inhomogeneity of the gain profile. The gain profile as well as gain coefficient depend on the pumping condition of the active medium in general and on CuBr vapor concentration in the working volume of an active element [14] in particular. The aim of the current research was study the influence of CuBr vapor concentration on the radial distribution of radiation in CuBr vapor brightness amplifiers.

2. Experimental technique

Figure 2 shows the constructions of active elements used in the present work and applied earlier as brightness amplifier for laser monitors in the works [11, 12]. The active element of the brightness amplifier [11] that is shown in figure 2*a* consists of a gas-discharge tube (GDT) made of a fused quartz with a length of 50 cm and inner diameter of 2.5 cm. The maximum average lasing power of this active element enclosed in a parallel-mirror cavity was equal to 3.2 W at a pulse repetition frequency of 20 kHz and a pumping power of 600 W (the power consumed by a high-voltage power supply from the mains). The active element of the brightness amplifier [12] that is shown in figure 2*b* consists of GDT made of a fused quartz with a length of 90 cm and inner diameter of 5 cm. The maximum average lasing power of this active element was equal to 5 W at a pumping power of 1450 W. Performance of this GDT was studied in details in papers [15, 16]. Pumping of the active medium is realized by a circuit of pulse charging storage capacitor and then it direct discharging on the GDT by a thyratron [17]. Active admixture of HBr that is often used for lasing power increasing of CuBr laser [2] was not used in the current research.

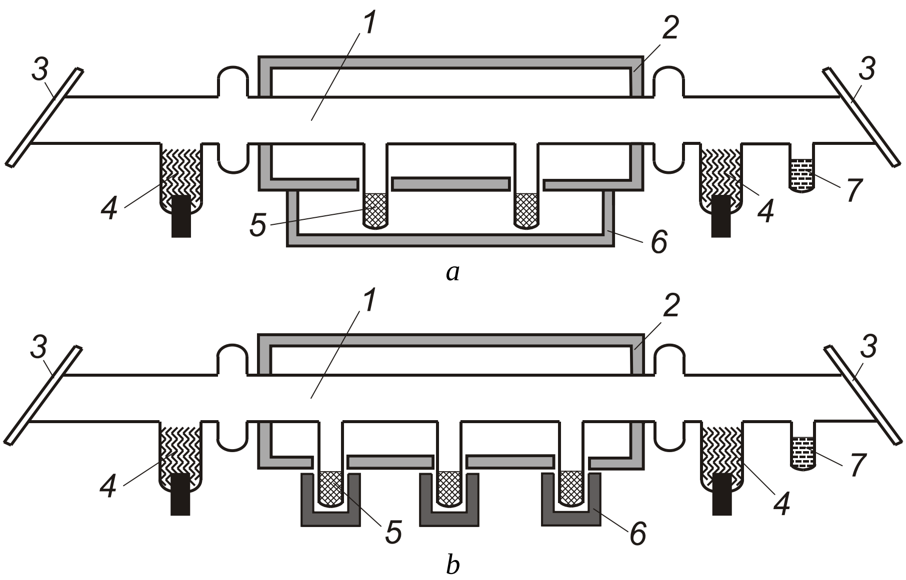

Figure 2. Active elements: 1 – quartz gas-discharge tube, 2 – main heater (heater of working area of GDT), 3 – output windows, 4 – copper electrodes, 5 – container with CuBr powder, 6 – auxiliary heater for containers with CuBr powder, 7 – container with adsorbent.

The both constructions of active elements have separated main heater for working area of GDT and auxiliary heater for containers with CuBr powder. That allows to influence on the amplifying characteristics of active element by varying CuBr vapor concentration. A feature of the first construction (figure 2*a*) is a common heater for all containers with CuBr powder. The second construction of the active element (figure 2*b*) has an individual heater for each container with CuBr powder. The advantages of the first configuration over the second are ease of design, manufacturing, simplicity of assembly, and less of electrical connections and wires. The disadvantage of this construction is the higher influence of the main heater and the energy dissipated by the discharge on the heating temperature of CuBr powder. As a result the heating temperature of CuBr powder is slightly changes every time when pumping conditions are varied. The second construction of the active element with individual heaters is characterized by minimal influence on the heating temperature of CuBr powder and accordingly on CuBr vapor concentration in the active medium.

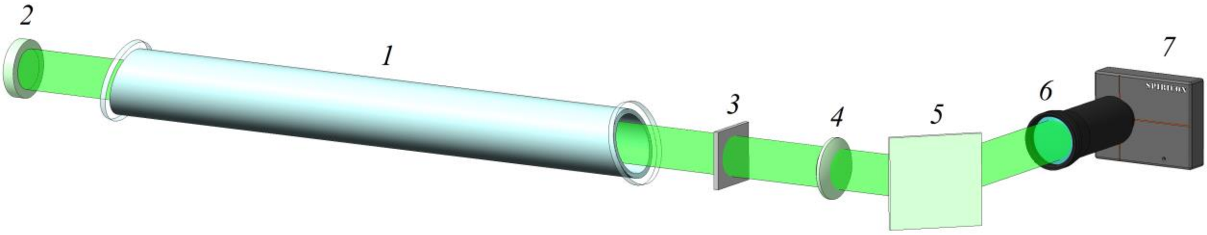

Figure 3. Experimental setup scheme: 1 – brightness amplifier, 2 – plane mirror, 3 – optical filters, 4 and 6 – lenses, 5 – beam-splitting plate with 20% reflectance, 7 – CCD-camera.

Study of single-pass amplification profiles of the active element is carried out by an experimental setup scheme shown in figure 3. Pumping active medium leads to population inversion of working laser levels in the active element and causes generating an amplified spontaneous emission (ASE). ASE reflected from the mirror is returned to the active medium again where it amplifies by intensity. The plane mirror simulates a visualization object with uniform reflectance that allows eliminating influence of reflected properties of the object on the analysis of amplifying characteristics of the active element. When beam profiles of ASE were studied the mirror was took away.

As a light analyzer a CCD-camera (beam profiler) Spiricon SP503U with BeamGage Standard 5.4 software was used. The size of the CCD-camera matrix is 6.4×4.8 mm^2. To match a cross section of the laser tube output beam with the matrix of the CCD-camera a fourfold zoom lens SPZ17024 mounted on the CCD-camera and Industar-51 lens were used. To eliminate the overexposure of the CCD-camera the output light was pre-attenuated by gray optical filters. To define an average radiation power a measuring head of power meter (L30C-SH from Ophir Optronics Solutions Ltd.) was set at the output of the laser tube.

3. Results and discussion

Figure 4 shows the profiles of single-pass amplified light beam corresponding to different average radiation power for the GDT of 2.5 cm bore. For this series of experiments the pumping power was 600 W and the CuBr heater temperature range was varied from 315 to 410 °C. These temperature values are comparatively low owing to closely spaced main heater of GDT with heater of containers with CuBr powder. The geometry of the optical scheme remained unchanged for all represented regimes. As one can see in figure 4 Gaussian, ring-shaped or flat profiles are achieved depending on the temperature of the containers with CuBr powder. Hence, increasing average radiation power that is caused by growing CuBr vapor concentration leads to significant contraction of light beam profiles. When average single-pass amplified radiation power is 0.2 W the light beam diameter is close to GDT diameter and reaches ~2 cm. When average single-pass amplified radiation power growths to 2.4 W the light beam diameter decreases twice and equals to ~1 cm. At reduction of CuBr vapor concentration in the active medium a contraction of lasing profile for the same active element was observed in the work [18].

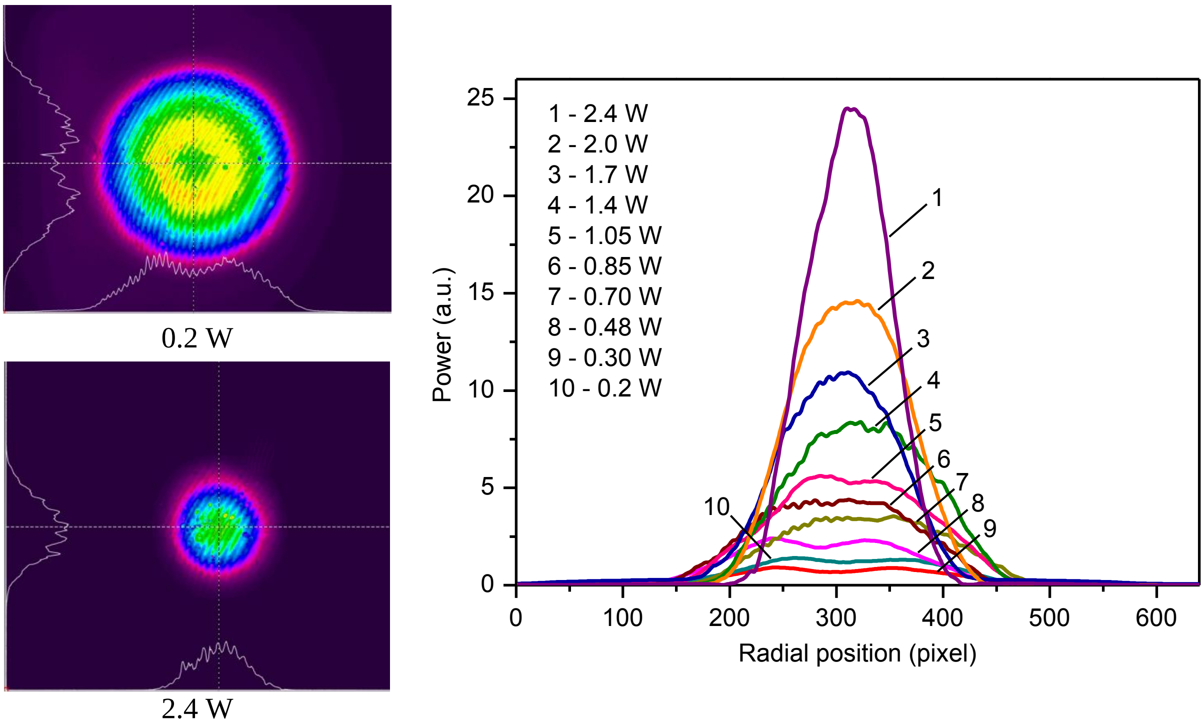

Figure 4. The profiles of a single-pass amplified light beam at various average radiation powers for the GDT of 2.5 cm bore.

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A considerable contraction of profile light beam occurs also in the active element of big diameter. Moreover, in the GDT with diameter of 5 cm it is observed a regime when radiation virtually disappears on the axis (figure 5). These measurements were carried out at unchanged pumping power value of 1350 W. The temperature of the containers with CuBr powder was varied in the range from 440 to 570 °C. The considerable intensity dip on the beam axis for the GDT with diameter of 5 cm comparing to the GDT with diameter of 2.5 cm is probably caused by overheating on the axis of the gas-discharge tube owing to high pumping power.

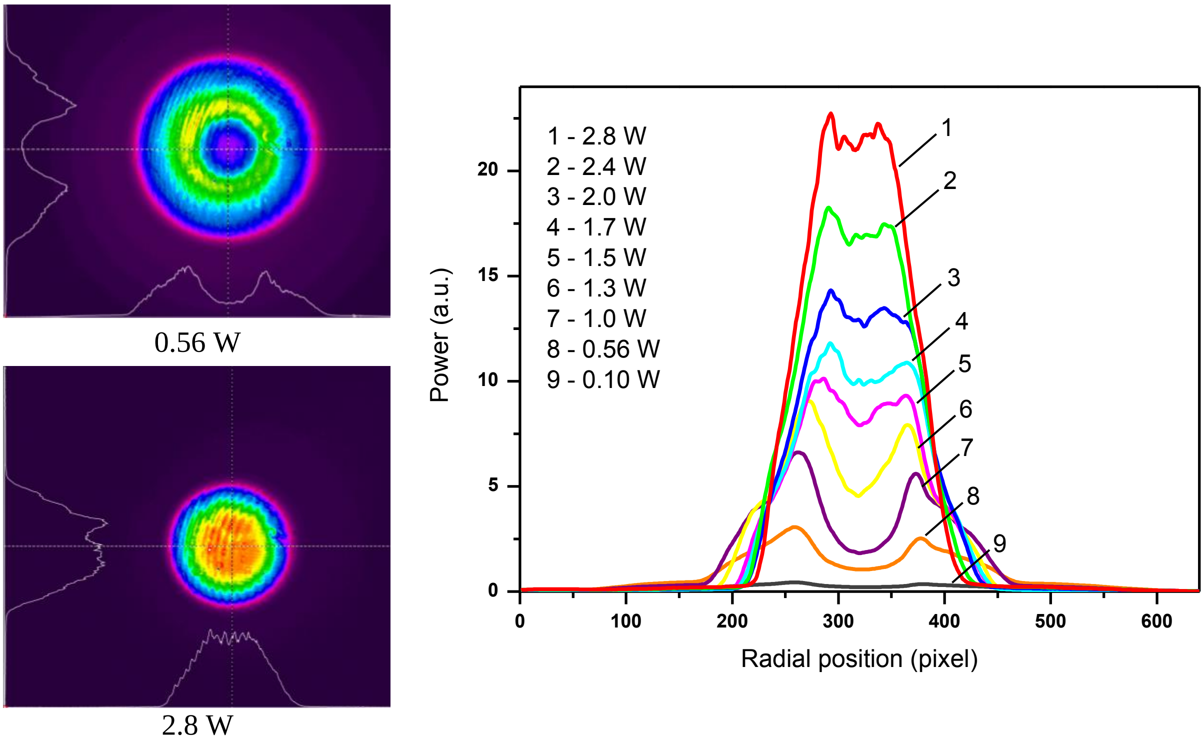

Figure 5. The profiles of a single-pass amplified light beam at various average radiation powers for the GDT of 5 cm bore.

The contraction of light beam profile that is caused by increasing CuBr vapor concentration was noted earlier in [14] where an active element of CuBr-laser with a length of 90 cm and diameter of 8 cm was used. The all containers with CuBr powder were heated by a common heater. In the work [14] the measurement of light beam profile was carried out by a master-oscillator power-amplifier scheme with a master-oscillator laser beam of 1.5 mm in diameter.

In laser projection microscopes and laser monitors the illumination of a visualization object and amplification of reflected light occur during the same pulse of radiation. To obtain an image with correct brightness a uniform illumination of a visualization object is preferable. Figure 6 shows beam profiles of ASE at various average radiation powers. Accordingly to presented data more uniform illuminating a visualization object occurs at a smaller amount of CuBr vapor concentration. More uniform illumination of a visualization object in combination with more uniform amplification profile subsequently provides higher quality of obtained images. This fact was noted in [19] which states that the working conditions of CuBr vapor laser active elements in the brightness amplification mode for obtaining high-contrast images differ from the conditions providing maximum average output power in the lasing mode. The difference of working conditions is in less optimal CuBr concentration.

Not only increasing CuBr vapor concentration leads to contraction of light beam profile. Such conditions as pulse repetition frequency and pumping power should be taken into consideration at optimizing performance of laser monitor. Significant contraction of light beam profile at increasing pulse repetition frequency was observed in [20].

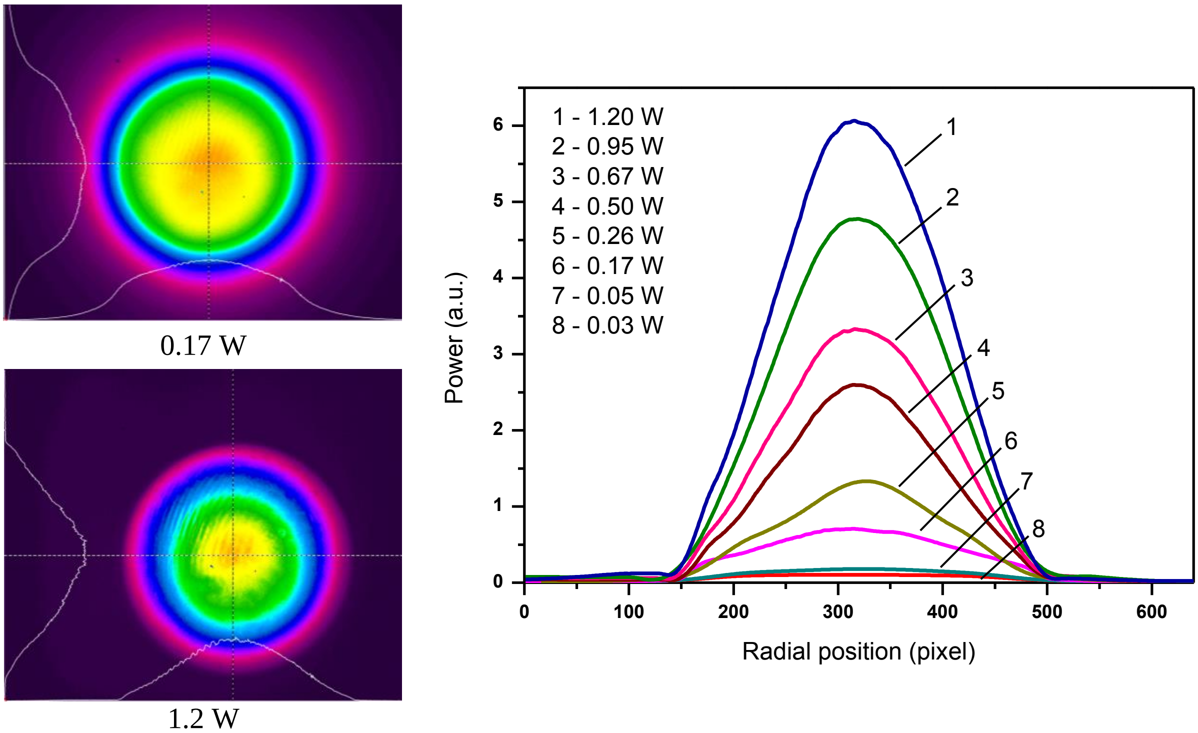

Figure 6. The beam profiles of ASE at various average radiation powers for the GDT of 5 cm bore.

4. Conclusions

The study showed that increasing temperature of containers with CuBr powder, i.e. growing CuBr concentration in the active medium, leads to considerable contraction of the output beam profile of CuBr brightness amplifiers. The profile contraction occurs for ASE, for a single-pass amplified light beam and even for a laser beam. It is observed for both gas-discharge tube with diameters of 2.5 and 5 cm and is accompanied by increasing output lasing power.

The uniform (flat top) of beam profile of ASE and gain defines image quality obtained with laser monitor. The most flat top of a single-pass amplified light beam profile for the GDT of 2.5 cm bore is observed within average output powers from 480 to 850 mW that is considerably less than maximum average output power (2.4 W) of a single-pass amplified radiation for this GDT. The optimal mode for the GDT of 5 cm bore lies within average output powers of a single-pass amplified radiation from 1 to 1.8 W that is also less than maximum value. The mentioned modes correspond to 10-15% temperature reduction of the containers with CuBr powder.

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References

[1] Petrash G G 1991 *Optical Systems with Brightness Amplifiers* (Moscow: Nauka)
[2] Evtushenko G S, Shiyanov D V and Gubarev F A 2010 *Metal Vapor Lasers with High Pulse*

Repetition Rates (Tomsk: Tomsk Polytechnic University)
[3] Zemskov K I, Kazaryan M A, Matveev V M, Petrash G G, Samsonova M P and Skripnichenko A S 1984 *Sov. J. Quantum Electron.* **14** 288
[4] Batenin V M, Klimovsky I I and Selezneva L A 1988 *Soviet Phys. Dokl.* **33** 949
[5] Abrosimov G V, Pol'skii M M and Saenko V B 1988 *Sov. J. Quantum Electron.* **18** 544
[6] Abramov D V, Arakelyan S M, Galkin A F, Klimovskii I I, Kucherik A O and Prokoshev V G 2006 *J. Quantum Electron.* **36** 569
[7] Buzhinsky R O, Savransky V V, Zemskov K I, Isaev A A and Buzhinsky O I 2010 *Plasma Phys. Rep.* **36** 1269
[8] Yermachenko V M, Kuznetsov A P, Petrovskiy V N, Prokopova N M, Streltsov A P and Uspenskiy S A 2011 *Laser Phys.* **21** 1530
[9] Dashinimaeva E Z and Trigub M V 2014 *Proc. Int. Conf. of Young Specialists on Micro/Nanotechnologies and Electron Devices (EDM)* pp 257–261
[10] Evtushenko G S, Trigub M V, Gubarev F A and Torgaev S N 2011 *Bul. Tomsk Polytechnic Univ.* **319** 154
[11] Evtushenko G S, Trigub M V, Gubarev F A, Torgaev S N and Shiyanov D V 2013 *Testing. Diagnostics* **13** 42
[12] Evtushenko G S, Trigub M V, Gubarev F A, Evtushenko T G, Torgaev S N and Shiyanov D V 2014 *Rev. Sci. Instrum.* **85** 033111
[13] Andrienko O S, Gubarev F A, Dimaki V A, Ivanov A I, Levitsky M E, Sukhanov V B, Troitskii V O, Fedorov V F, Filonov A G and Shiyanov D V 2009 *Atmos. Ocean. Opt.* **22** 999
[14] Gubarev F A, Troitskiy V O, Trigub M V and Sukhanov V B 2011 *Opt. Commun.* **284** 2565
[15] Gubarev F A, Trigub M V and Fedorov K V 2014 *Proc. Int. Conf. of Young Specialists on Micro/Nanotechnologies and Electron Devices (EDM)* pp 309–313.
[16] Gubarev F A, Evtushenko G S, Vuchkov N K, Sukhanov V B and Shiyanov D V 2012 *Rev. Sci. Instrum.* **83** 055111
[17] Dimaki V A, Sukhanov V B, Troitskii V O and Filonov A G 2012 *Instrum. Exp. Techniq.* **55** 696
[18] Gubarev F A, Evtushenko G S and Li Lin 2014 *Testing. Diagnostics* **13** 160
[19] Trigub M V 2013 Laser monitor for non-destructive testing of goods and visualization of fast processes shielded by background lighting *Dissertation for a PhD degree in technical sciences*
[20] Trigub M V, Shiyanov D V and Vlasov V V 2014 *Proc. Int. Conf. of Young Specialists on Micro/Nanotechnologies and Electron Devices (EDM)* pp 301–304