A mirror based scheme of a laser projection microscope

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Abstract. The paper discusses the design of a laser projection microscope with a mirror-based scheme of image formation. It is shown that the laser projection microscope with the mirror-based scheme of image formation is well suited for distant objects monitoring. This scheme allowed obtaining a field of view of more than 3 cm at the distance of 4 m from the brightness amplifier

1. Introduction

The laser projection microscope invented by authors of [1] became the basis for building laser monitors. A laser monitor based on the active media of copper vapor lasers or copper bromide vapor lasers is one of the powerful tools for observing objects and processes shielded by intensive background lighting [2–6]. A number of non-destructive testing tasks require visualization of such processes. These processes occur under interaction of powerful flows of energy (laser radiation, electron beam etc.) with the matter, self-propagating high-temperature syntheses, discharge plasmas etc. The copper vapor lasers and brightness amplifiers, based on them, radiate at two different wavelengths in the visible range of the spectrum, namely 510.6 nm (green) and 578.2 nm (yellow). The temperature of objects under observation by means of the copper bromide laser monitor can reach up to 40000 K and higher [6].

The operating principle of the laser monitor is similar to the operating principle of a laser projection microscope [1] and is as follows. The object under observation is illuminated by amplified spontaneous emission of a brightness amplifier. The radiation reflected from the object is returned then back to the brightness amplifier, amplified by the gain medium, and projected onto a screen or the sensor of a digital camera. The image is conventionally formed by the system of optical lenses.

In the present paper we suggest using the concave mirrors instead of the traditional collecting optical lenses or objectives.

2. Schemes of laser projection systems for distant objects visualization

The conventional laser monitor scheme includes the brightness amplifier, high-speed camera, lenses (or objectives), optical filters, and an object under observation (Figure 1). Physicists pay particular interest to the visualization of distant objects (distances of a few meters or tens of meters) by means of the laser monitor [7]. Figures 1, *b* and *c* shows the modifications of the typical scheme of the laser monitor for visualization of distant objects depending on the relative position of the brightness amplifier, the lens forming image, and an object under observation. The scheme in Figure 1, *b* has the evident disadvantage caused by the need of placing the lens close to the object. Such scheme is not proper for visualization of processes with high temperature or accompanied by the combustion product splashing. Moreover, when the lens is placed at a long distance from the brightness amplifier the area of vision is reduced [8]. The scheme used in paper [8] is depicted in Figure 1, *d*.

The better suited variant of a laser monitor monostatic scheme (based on a single brightness amplifier) for observing distant objects is the one illustrated in Figure 1, *c*. The long-focal-length lens is located far from the object observed. Both schemes for distant objects observation (Figure 1, *b* and *c*) have the principal limitation caused by the gain medium properties. Thus, the duration of existence of population inversion of the laser levels limits the longest possible distance to an object under observation. A typical lasing pulse duration of copper vapor laser is 20-40 ns [9]. In case of the CuBr laser the typical pulse duration of lasing can reach 80 ns [10]. The increase in the pulse duration of lasing is possible by means of varying excitation conditions. The method of the discharge current control [11-13] allowed obtaining the radiation pulse duration of 230 ns for copper vapor laser [12] and 320 ns for CuBr laser [13]. In paper [14] the increase of the lasing pulse duration up to 235 ns was obtained in an unstable discharge mode. In a stable discharge mode the 150-160 ns pulse duration is quite achievable.

Thus, the temporal properties of the active medium of the copper bromide laser can ensure observation of objects located within 25-30 meters. However, the main limiting factor is the optical scheme of the laser monitor. Therefore, a key issue in the design of the laser monitor for the distant objects observation is development of a proper optical configuration.

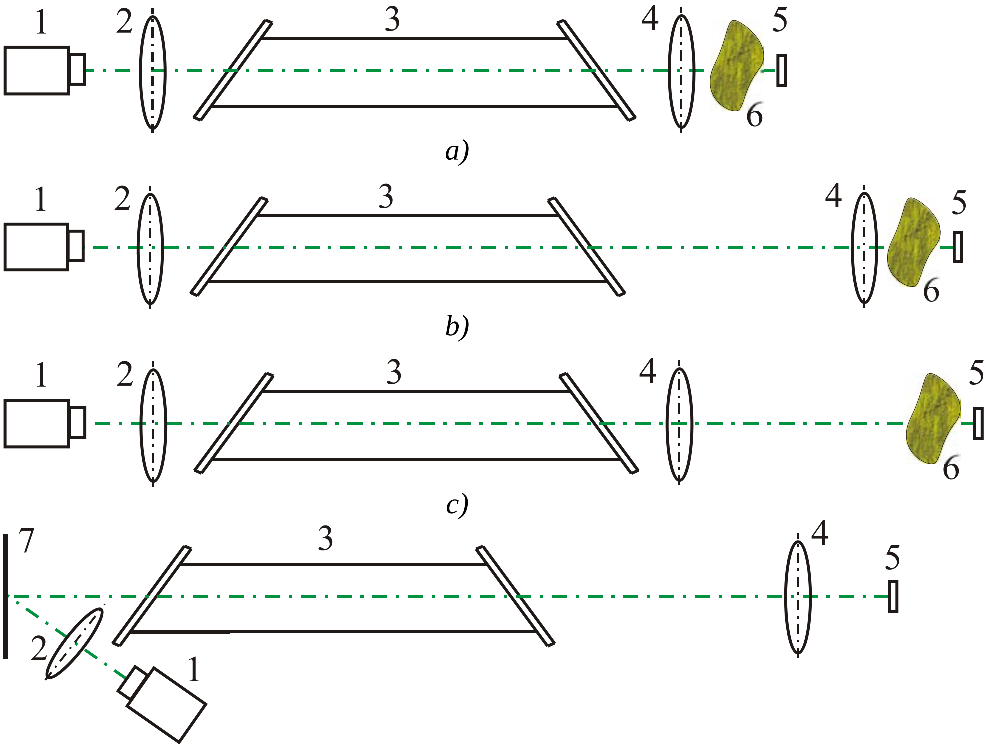

Figure 1. Laser monitor schemes: 1 – camera; 2, 4 – optical lenses (objectives); 3 – brightness amplifier; 5 –object under observation; 6 – background lighting. *a* – short-focus lens is located close to the brightness amplifier (typical scheme), *b* – short-focus lens is located at a distance of several meters from the brightness amplifier, *c* – long-focal-length lens is located close to the brightness amplifier, and *d* – scheme with the image recorded from the screen

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3. Mirror based schemes and visualization results

In the present research, we used two CuBr lasers with external heating of the active region of the gas discharge tube (GDT). Such a type of lasers was studied earlier in [15–17]. First, the gas discharge tube (GDT1) has 50 mm in diameter and 90 cm at length and was pumped by means of a circuit of pulsed charge of a storage capacitor and its direct discharge by a thyratron (TGI1-1000/25) [15, 16]. Second, the gas discharge tube (GDT2) has 25 mm in diameter and 40 cm at length and was pumped by the circuit with a solid-state switch [17]. For the image capture the CMOS camera FastCam HiSpec1 was used.

It should be noted that when the observed object is moved away over long distances, it is necessary to increase the signal intensity. Otherwise, the contrast of the object images decreases with the increasing of the distance of visualization. To overcome this problem one needs to use more powerful active elements of copper (copper bromide) vapor lasers. It should be pointed out that a partial issue solution can be obtained by using lenses (4 in Figure 1) with a large aperture. However, the manufacture of large aperture lenses is more difficult. In contrast with lenses, spherical mirrors are easier to manufacture and, in addition, they have no chromatic aberration. The second benefit can provide high contrast of object images obtained simultaneously at both 510.6 nm and 578.2 nm operating wavelengths.

In the present work, the concave mirrors are used instead of the traditional collecting lenses or objectives. Figure 2 shows a variant of the laser monitor scheme for imaging of distant objects with a spherical mirror. We used two types of concave mirrors with radii of curvature (R_c) of 1 m and 3 m, which allowed observing objects moved away over the distance of 1 and 3 m, respectively. The distance between the GDT output window and the mirror was 1 m. The GDT1 is used as a brightness amplifier.

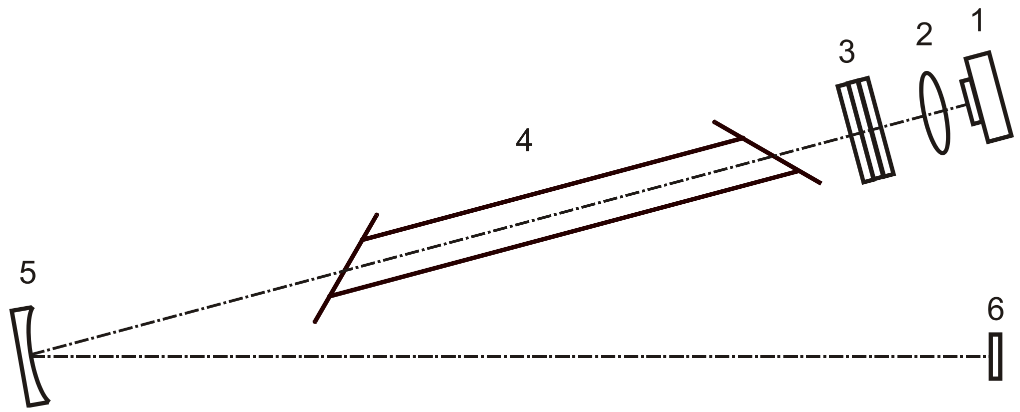


Figure 2. The scheme of a laser projection microscope with one concave mirror: 1 – CMOS camera; 2 – objective; 3 – gray filters; 4 – brightness amplifier; 5 – concave mirror; 6 – object

Figure 3 shows the results of visualization of a steel ruler using this scheme. As one can see the field of view has been obtained to be ~10 mm in case of mirror with R_C=1 m and ~35 mm in case of mirror with R_C=3 m. These values are much greater than those obtained in paper [8], i.e. 4 mm at 0.9 m distance and 3 mm at 1.5 m distance.

We have also tested a variant of the laser monitor scheme with two concave mirrors (Figure 4). This scheme allows us to take away the recording system from the brightness amplifier. In some cases it is necessary to reduce the electromagnetic influence of the discharge on the camera performance. We used mirror 5 (Figure 4) with the radii of curvature of 1 m and 3 m and mirror 3 with the radius of curvature of 3 m. The distance between the GDT output window and the mirror was 0.3 m. We used two types of concave mirrors with radii of curvature (R_c) of 1 m and 3 m, which allowed observing objects moved away over the distance of 1 and 3 m, respectively. GDT2 is used as a brightness amplifier.

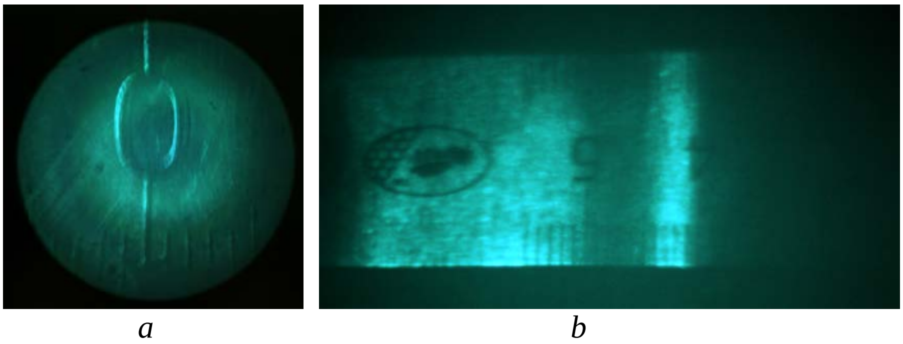


Figure 3. Images of a metal ruler obtained with mirrors of different radius of curvature: *a* – 1 m; *b* – 3 m

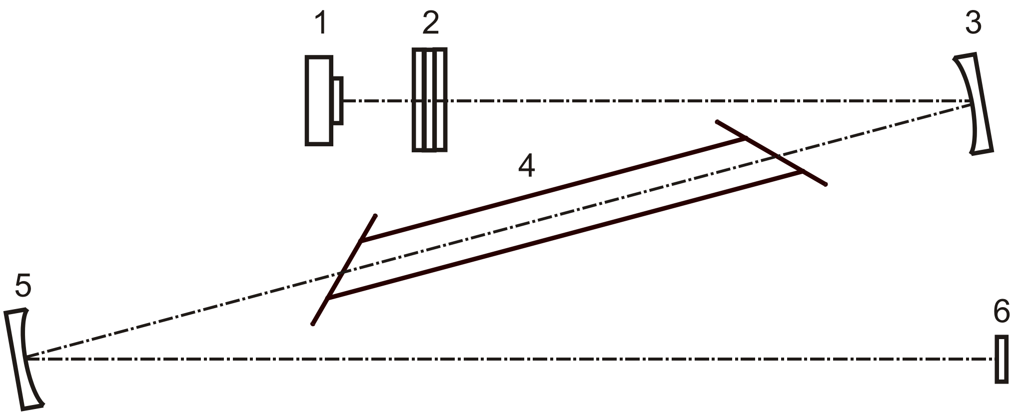


Figure 4. The scheme of a laser projection microscope with two concave mirrors: 1 – CMOS camera; 2 – gray filters; 3 and 5 – concave mirrors; 4 – brightness amplifier; 6 – object

Figures 5 and 6 show the results of visualization of the metal grid (grid size of 0.5 mm) by a two concave mirrors based scheme of the laser projection microscope at different operating wavelengths (510.6 and 578.2 nm).

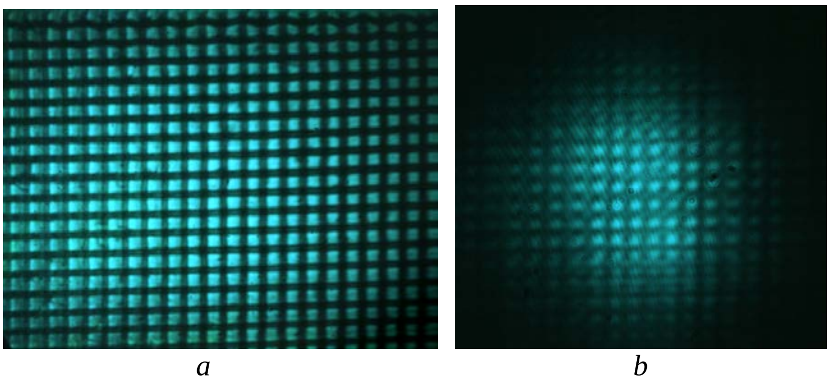
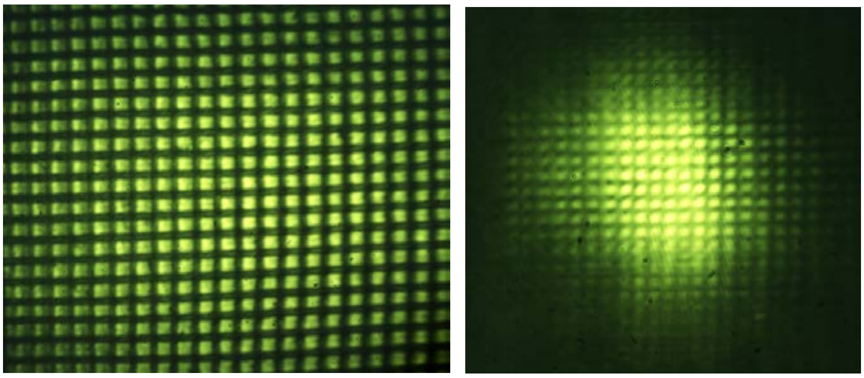


Figure 5. Images of the metal grid obtained with mirror 5 (Figure 4) of different radius of curvature: *a* – 1 m; *b* – 3 m. Wavelength of visualization is λ=510.6 nm



a *b*

Figure 6. Images of the metal grid obtained with mirror 5 (Figure 4) of different radius of curvature: *a* – 1 m; *b* – 3 m. Wavelength of visualization is λ=578.2 nm

4. Conclusions

The presented results have shown the possibility of application of a mirror based scheme of the laser projection microscope (a laser monitor) where concave mirrors are used instead of the traditional collecting lenses or objectives. The scheme can contain two as well as one concave mirrors.

It is shown that the field of view of the projection system decreases with the increase of the radius of curvature of the mirror forming the image (the mirror is between the amplifier and the object). At the same time the discussed scheme provides a greater field of view as compared with the conventional scheme of the laser projection microscope.

The next study will be devoted to improving the image quality of distant objects obtained by a mirror based scheme of the laser projection microscope.

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