TOMSK POLYTECHNIC UNIVERSITY

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Laser Monitor

Laboratory Guide
to the Lab Work No 6

2017

The aim of the work:

To get acquainted with the principle of operation of active optical systems, to realize a laser monitor based on a brightness amplifier on copper bromide vapor.

Preleminary task

1. To study the principle of operation of lasers on self-terminating transitions in metal vapors.
2. To study the principle of the action of brightness amplifiers based on metal vapor lasers.
3. Determine the increase in the image at the input of the brightness amplifier and the distance l_1 from the lens to the object, if the focal length of the lens (Fig. 1) is F = 8 cm and the distance from the lens to the screen is 80 cm.
4. Familiarize with electro-coagulator EHVCH-400 used for tissue resection.

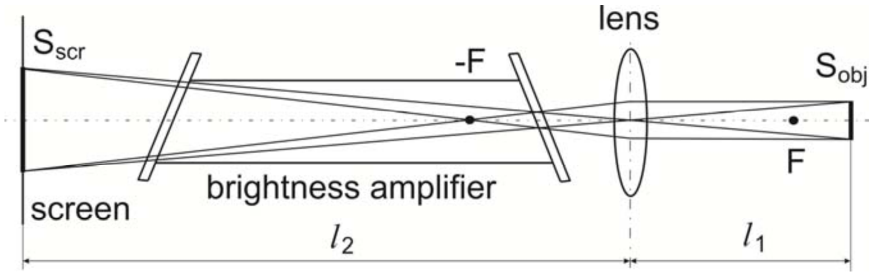


Fig. 1. Simplified scheme of laser projection microscope (laser monitor)

Theory

One of the problems of modern science, including medicine, it to visualize small objects and project the image on a large screen. In conventional systems, to provide sufficient illumination of the screen, it is necessary to illuminate the object with a beam of high power, which may be unacceptable. When using active optical systems with brightness amplifier, it is possible to reduce the level of illumination at the object by 2-5 times.

Recently, optical systems that are able to visualize fast-flowing processes, including processes shielded from the observer by a layer of brightly luminous plasma, are becoming more and more popular. Such processes occur in the interaction zone of powerful energy fluxes (laser radiation, electron beam, etc.) with matter, for example, in the creation of nanoscale structures, laser processing of materials, self-propagating high-temperature synthesis. To observe such processes it is expedient to use high-speed active optical systems – laser monitors.

To create active optical systems (AOS), it is necessary to use a quantum amplifier, which must satisfy the following requirements:

1. The optical environment of a quantum amplifier must be optically homogeneous so that the amplifier does not distort the transmitted information;

2. High gain of the medium, which will allow to work without a resonator (superlight mode);

3. The geometric dimensions and angular aperture of the amplifier should ensure the passage of light beams without loss of optical information;

4. The output power of the amplifier should be sufficient for practical use (visual inspection);

5. Work of the active medium in the pulsed mode with a high frequency of impulses.

These requirements are fully met by the active media of metal vapor lasers, in particular, lasers on copper vapor and its compounds. The brightness amplifier on metal vapors was successfully realized by the staff of Physical Institute (Moscow), who demonstrated an enlarged and intensified image of the object on a large screen. The optical amplifier based on a copper vapor laser operating in the superradiance mode with a repetition rate of 10 kHz pumping pulses. At a distance of 40-60 m, the image was magnified several thousand times, with the image size being of the order of 1 m. The results obtained by Petrash etc. have shown that based on metal vapor lasers operating in the superradiance mode, It is possible to create AOS capable to provide large (up to 10^4) magnifications of high-brightness micro-objects on large screens.

A simplified diagram of such a device, called the laser projection microscope, is shown in Fig. 2. The principle of operation is as follows. Superradiance (amplified in one pass spontaneous emission) focuses on the object of research with a lens or lens. The radiation reflected from the object partially comes back into the lens and passes through the active element. Passing through the inverse medium, the photon flux amplifies, and, the greater the intensity at the input of the amplifier, the greater the intensity at the output. Obviously, the "field of vision" of the projection microscope depends both on the parameters of the optical elements and on the diameter of the active element. Tubes with a large aperture are more preferable.

Characteristics of AOS (time resolution, amplification, etc.) are largely determined by the characteristics of the active medium used. Table 1 shows the characteristics of the enhancement of different active media containing metal vapors. The value of the effective gain was calculated as the ratio of the average powers of the output and input signals of the amplifier. As can be seen from the table, the active medium works in saturation mode with a large interval of input signals. In addition, even at large output powers, the amplification exceeds 100. Lasers on copper and copper bromide vapors possess the greatest gain.

At present, active media based on metal vapor lasers with modified kinetics are promising. That is, the active medium in which is modified by the introduction of active impurities. When working in laser mode (with a resonator), the introduction of additives improves the generation characteristics. In the recent papers, the amplifying characteristics of the active medium of a copper vapor laser with hydrogen additives and the results of studies of the characteristics of AOS with luminance amplifiers based on this medium are presented. With hydrogen additives, there is a noticeable smoothing of the distribution of the effective gain across the cross section of the active element, which makes the active medium on copper bromide vapor with additives of hydrogen or hydrogen bromide more preferable for the creation of AOC.

Obviously, the observation of static or slowly changing objects or processes in the mode of the projection microscope does not require a high temporal resolution, respectively, of high repetition rate of the radiation pulses. However, high-speed AOS are in demand when observing and photographing rapidly changing processes, for example, combustion processes. In this respect, copper vapor lasers with active additives look very attractive, since the maximum repetition rates of generation pulses for a given type of laser with active additives reach 300-400 kHz. This opens the possibility of creating AOS with a high temporal resolution.

The high spectral brightness of metal vapor brightness amplifiers makes it possible to obtain images of objects that are physically difficult to access, in particular, shielded from the observer (or camera) by strong background lighting. AOS for such observations is often called "laser monitors". The lighting can be created, directly, by the object itself (Fig. 3a), and by any external processes (Fig. 3b).

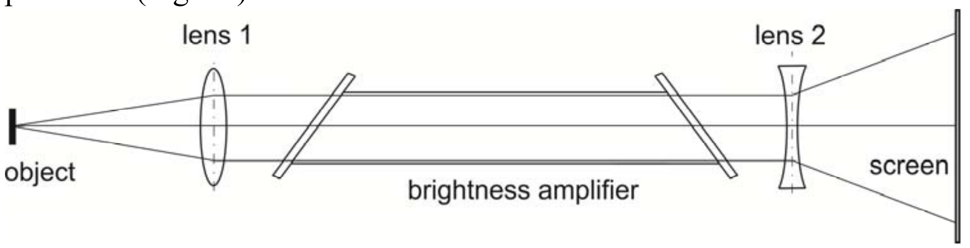
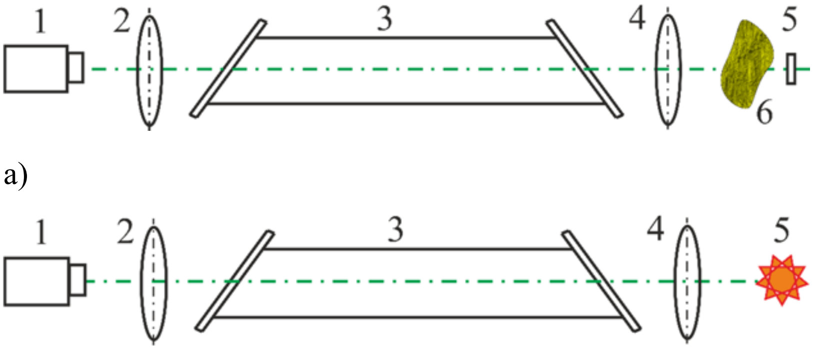


Fig. 2. Scheme of laser projection microscope

Table 1. Gain parameters of metal vapor active media

Active medium	Wavelength, nm	Input power, mW	Output power, mW	Gain
Cu	510.6	0.14	240	1700
		$0.17 \cdot 10^{-2}$	27	16000
Au	627.8	0.17	344	200
		$0.15 \cdot 10^{-2}$	16	10700
Pb	722.9	1.26	110	85
		$0.2 \cdot 10^{-2}$	6	3000
Mn	534.1	1.5	79	53
		$0.14 \cdot 10^{-2}$	14	1000
CuCl	510.6	0.24	193	805
		$0.48 \cdot 10^{-2}$	47	9720
CuBr	510.6	4.08	2900	710
		0.22	1400	6300



a)

b)

Fig. 3. Two options for laser monitor usage: monitoring of object shielded by external lighting (a) and self-emission (b). 1 – digital camera, 2 and 4 – lenses, 3 – brightness amplifier, 5 – object under observation, 6 – stray lighting.

Among the first papers devoted to such observations, it is necessary to refer works of professors Batenin V.M. with colleagues (1984 - 1988). They studied a low-current arc with graphite electrodes with copper vapor laser monitor. In the following years, active laser optical systems were used for studying various objects: particularly interaction of laser beam with the glass-carbon surface, segnetoelectric films sputtering, erosion capillary discharge study, self-propagating high-temperature synthesis monitoring, nanoparticles formation under the powerful lasing etc.

Laboratory Set-up

The design of a laser monitor or a projection microscope does not require a high-power brightness amplifier, so the laser monitor can be easily built-up in the laboratory. The scheme of the laboratory laser projection microscope is shown in Fig. 4. In this scheme, a beam of light (superradiance) from the active element passes through the collecting lens and illuminates the area of the object under study with an area of S_{obj}. Knowing the diameter of the beam D_{beam} (approximately equal to the inner diameter of the GDT) and the distance from the lens to the object l_1, it is possible to estimate the illuminated area of the object:

$$S_{obj} = \frac{S_{beam} \cdot (l_2 - F)^2}{F^2} = \frac{\pi D_{beam}^2}{4} \cdot \frac{(l_2 - F)^2}{F^2}, \quad (1)$$

where F is the focal length of the lens.

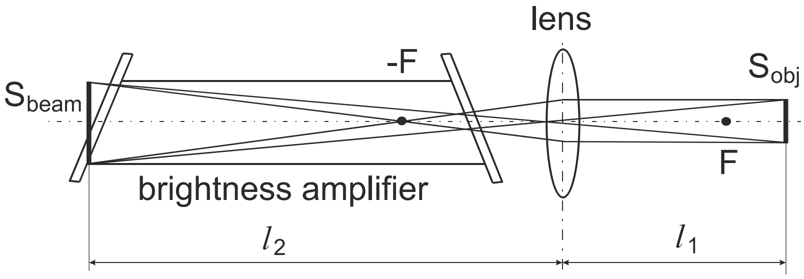


Fig. 4. Scheme of the laser projection microscope

The light reflected from the object forms in the image plane of the lens an enlarged image with an area S_{scr} (Fig. 1). The magnification can be found as

$$K^2 = \frac{S_{scr}}{S_{obj}} = \frac{(l_2 - F)^2}{F^2}, \quad (2)$$

where l_2 is the distance between the lens and screen.

From the obtained formula, it can be concluded that to increase the magnification of the laser projection microscope, it is necessary to choose lenses with a short focal length, and also to increase the distance to the screen. Often the diverging lens is used to enlarge the image on the screen. Nowadays, the system of high-speed visualization are demanded for the real-time monitoring of fast processes. Therefore, the laser projection microscope is coupled with high-speed camera (Fig. 3).

As a brightness amplifier in this work, a small-sized laser using copper bromide vapor is used. The parameters of this laser are given in Table 2. The active element operates without a resonator in the superradiation mode.

Table 2. CuBr laser parameters

Parameter	Value
Active length	50 cm
Bore	2 cm
Pulse repetition frequency	20 kHz
Lasing wavelengths	510.6 nm, 578.2 nm
Average lasing power with resonator	1 W
Average lasing power in superradiance mode	200 mW

As an object of observation in the projection microscope mode, a diffraction grating with a resolution of 600 grooves/mm is proposed. As a lens, it is proposed to use eyepieces with the multiplicity of 4x, 10x and 15x. In Fig. 5. As an example, an image of the diffraction grating is shown when using an eyepiece with a multiplicity of 10x. From the image obtained, it is possible to calculate the magnification of the projection microscope. For a diffraction grating with a resolution of 600 grooves/mm, the distance between the neighbor grooves is equal to

$$d_{groove} = \frac{1\ mm}{600} = 1.67\ \mu m$$

The distance between neighboring strokes, measured from the image obtained with the use of the eyepiece 10x, was 12 mm. Therefore, the magnification is:

$$K = \frac{d_{meas}}{d_{groove}} \approx \frac{12\ mm}{1.6\ \mu m} \approx 7500.$$

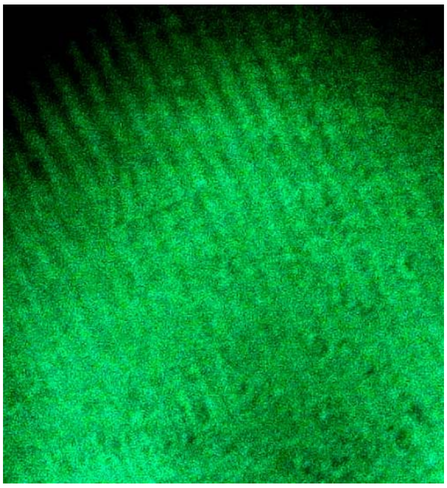


Fig. 5. The image of a diffraction grating using an eyepiece with a multiplicity of 10x

Other objects of observation may be pieces of printed circuit boards (preferably with a dense layout), as well as small text labels, for example, on integrated microcircuits. When studying the capabilities of laser monitors, it is proposed to implement two modes of operation:

• with an external source of background lighting (Fig. 2a);

• use the object's own radiation as a source of background lighting (Fig. 2b).

In the first case, it is suggested to use a grid as an object, as a background flare - the flame of a candle. In the second case, it is proposed to use a Bengal candle or aluminum nanopowder. The beam should be focused in the central part of the object, as shown in Fig. 6. The arrow shows the direction of combustion. When the flame passes through the observation area, the surface modification must be clearly visible on the screen. Moreover, unlike previous cases, observation will occur in dynamics. It is recommended to register the burning process with a video camera or high-speed digital camera.

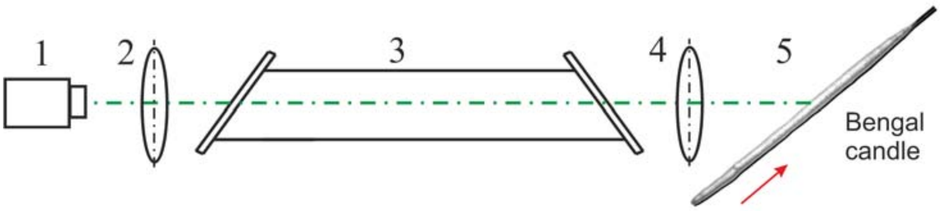


Fig. 6. Scheme of observation of combustion process

In-lab task

1. Get an image of the diffraction grating 600 grooves/mm, using eyepieces with a multiplicity of 4x, 10x and 15x.
2. For each case, measure the distance between the grooves and calculate the magnification of the projection microscope.
3. Obtain an image of a sample grid using a given lens (Fig. 1) with known focal length. Calculate the magnification of the microscope.
4. Place a lighted candle between the lens and the grid. Observe how the image on the screen changes.
5. Install the Bengal candle (or nanopowder sample) and camera. Adjust the second lens to obtain the sharp image of the candle surface
6. Burn the Bengal candle and observe the burning process on the monitor.
7. List the main changes in the surface of the object, observed in the combustion process.
8. Put an apple skin in the viewed area. Destructing the apple skin with coagulator EHVCH-400, record the video of the process.
9. List the main changes in the surface of the object, observed during the coagulation process.

Control questions:

1. What properties should have an active medium for use in active optical systems with brightness amplification?
2. What is the similarity and difference between the concepts of "laser projection microscope" and "laser monitor"?
3. What active media are commonly used in brightness amplifiers?
4. Explain the term of "superradiance".
5. How to determine in practice the gain coefficient of the active medium?
6. What is the field of view of lased monitor?
7. What is the limitation for maximum distance from the active element to the screen?
8. What should be the spectral distribution of background radiation, so that monitoring with a CuBr laser monitor becomes difficult?
9. What maximum imaging speed the metal vapor active media can provide?
10. Why are the output windows of the CuBr laser active element located at an angle to the optical axis?
11. How will the image on the screen differ if one of the output windows of the active element is positioned perpendicular to the optical axis?