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Laser monitors for high speed imaging of materials modification and production

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ABSTRACT

The methods for real-time visual diagnostics of high-speed processes of materials modification and production are presented. The main problem of visualization of such processes is the intense glare which blocks the investigated area. To decrease the negative effect of the glare (high intensive background light) the copper bromide vapor brightness amplifier is used. It has been shown that the imaging method with a brightness amplifier proposed in this paper proves to be the most reliable to obtain the information about objects or processes in a real time mode using high frequency copper bromide vapor brightness amplifier. The results of visualization of different processes, including nanoparticles production, are presented. The benefits and limitations of both methods used for imaging have been also demonstrated.

1. Introduction

Nowadays laser, beam and plasma methods are actively used for new material production and modification of material properties [1–3]. In most cases the methods are based on the interaction of intense energy fluxes with matter. These fluxes are laser pulse, electron beam, different discharges and plasma. In this case visual and optical monitoring of energy-matter interaction is often blocked by the background radiation or glare. This radiation can be of different origin, for example, equilibrium and non-equilibrium plasma, intense magnetic field, ionizing field, etc. [4]. For visualizing processes through the glare it is necessary to use laser diagnostic methods that allow to reduce its effect on the obtained images [5–8]. The research problems are related to the increase in time resolution of instruments for visual and optical monitoring and development of methods for diagnostics of zones of interaction of intense energy fluxes with matter. In particular, the problem of monitoring and diagnostics of processes of nanosize materials production using the technique of laser evaporation followed by the deposition of particles is still of scientific interest. New methods for visual and optical monitoring are also required to study the processes of formation of a cloud of nanoparticles.

As it has already been mentioned in a number of previous works, imaging of fast processes blocked by the broadband background radiation is possible with the use of different laser systems. In our work the active elements of metal vapor lasers were used both as brightness amplifiers and illumination sources. The use of such systems allows to perform high speed imaging of processes, while the time resolution is limited by a recorder (camera) and the brightness amplifier PRF (pulse repetition frequency). Nowadays high speed CCD and CMOS cameras allow to capture images at high time resolution enabling thereby the diagnostics of processes of nanosecond time scale. On the other hand, the possibility of producing generation within a visible spectral range in metal halide vapors lasers operating at 700 kHz is demonstrated [9]. Thus the theoretical maximum in the time resolution of an optical system based on CuBr active media is less than 1.5 μs?

In the present work, the ability of using the CuBr active elements for high-speed imaging of processes which are blocked by the intense background radiation is discussed. The most common method used for imaging of such processes is laser illumination

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with the filtration of the reflected signal. Imaging of materials production and modification using both methods based on CuBr active media is discussed.

2. Experimental setup

In this work two copper vapor bromide active elements were used. The gas discharge tube of the first element (GDT1) had the active length of 90 cm and bore diameter of 5 cm, the active length of GDT2 was 50 cm, and diameter of 2.5 cm. The buffer gas (neon) pressure was 25 torr in both cases. The construction of the active element was similar to that demonstrated in Ref. [10]. The tube wall, containers with copper bromide and HBr generator of GDT1 were heated by independent external heaters which stabilized the temperature as the pumping rate was varied. For GDT2 the tube wall temperature was not stabilized; it was heated by the power supply energy. It allowed to simplify the active element construction. The active elements were pumped using a direct discharge circuit on a storage capacitor [11] and with a solid state power supply [12]. Tiratron TGI1-1000/25 was used as a commutator in the direct discharge circuit. Images were registered by the high-speed cameras MotionPro X3 with the frame rate of 40000 frames per second and FastCam HiSpec1 with the frame rate up to 100000 frames per second. The optical schemes were constructed using different objectives (standard micro-objectives of different magnification factors, objective Industar-51, etc.), the optical elements were positioned using optomechanical equipment made by Standa.

A typical configuration of a laser monitor with frame-by-frame imaging is given in Fig. 1. The main elements of the laser monitor are as follows: a brightness amplifier, a power supply, a high speed CCD-camera, a sync circuit and optical elements. A test object is illuminated by the amplified spontaneous emission (ASE) of the brightness amplifier, the image of the object is formed with objective 1, then the reflected radiation is amplified throughout the same radiation pulse of the amplifier. Objective 2 was used to form an image on the camera matrix. It was necessary because the camera operated without its own objective in our experiments. The gray filter was used for reducing the level of the output signal, which protected the camera from damage. To register the image at one of the wavelengths of the brightness amplifier it is necessary to use a band-pass filter.

Copper bromide vapor laser active media with active HBr-additives are used as brightness amplifiers for active optical systems. The addition of HBr of 0.1–0.3 Torr allows to improve the frequency-energy and amplifying characteristics [13].

A distinctive feature of the designed instrument is the possibility of obtaining images generated in a real-time mode by a single pulse of the ASE of the brightness amplifier. It requires the use of a circuit synchronizing the radiation pulses with the camera exposure. The sync circuit allows to obtain pulses with the frequency multiple to the ASE frequency of the brightness amplifier, which makes possible to change the imaging frame rate [13].

For visualization with a laser illumination method the copper bromide active elements were also used. It requires the use of a plane-parallel cavity which consists of a fully reflective mirror and a quartz plane from the other side of active elements. It allows to form laser beam with enough energy for the registration of images formed by one reflected pulse. The optical scheme of a laser illumination visualization method is shown in Fig. 2.

3. SHS material production visualization

Using the designed laser monitor a series of experiments on imaging of self-propagating high-temperature synthesis (SHS) were made. This work was performed in collaboration with colleagues from the Department of Structural Macro-Kinetics of Tomsk Scientific Center SB RAS (Dr. Kirdyashkin et al.). In the experiments the frame rate was reduced to 2808 frames per second by the synchronization circuit providing the resolution of 300×300 pixels. In this configuration of the laser monitor the filed of view 1.5×1.5 mm was achieved. The combustion of the (Ni+20% Al) mixture was visualized (Fig. 3) [14].

For studying Ni-Al combustion process we also used a laser illumination method. The main advantage of this method compared to the laser monitor is lower image distortion. The images obtained in active optical systems are distorted, which is caused by the active elements of the laser monitor configuration and amplification of the active medium. The laser illumination imaging of SHS processes was made using GDT1 with a cavity, with the average laser power being 5 W. Motion Pro camera and the synchronization circuit were used. In the experiments the frame rate was reduced to 1404 frames per second which allowed to increase the camera resolution up to1200 $\times$ 600 pixels. The visualization results are shown in Fig. 4.

The results of imaging allow us to study the combustion process and reveal a number of specific features of the synthesis. The synthesis of the structure includes the motion of the spin. The average speed of the "head" spin motion is equal to 100 mm/s, the period of the track is equal to 100 μm. Revealing the features of the processes in the spin "head" is of great importance. But it requires serious changes in the diagnostic equipment, namely the increase in the time resolution of the laser monitor and magnification, i.e. it

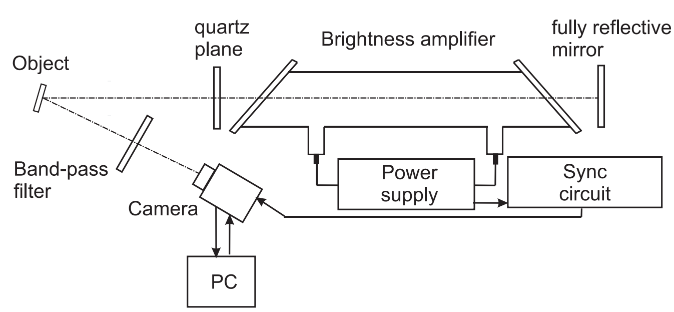

Fig. 2. A simplified laser illumination configuration.

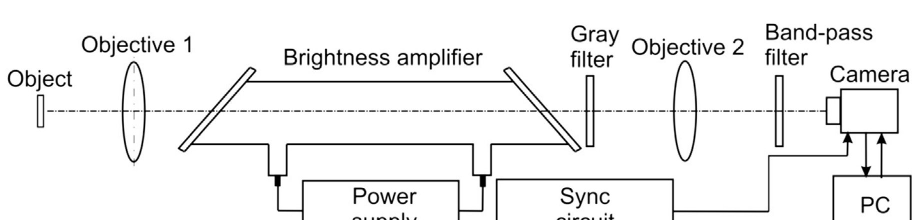

Fig. 1. A simplified laser monitor configuration.

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