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Formation of the radiation field of diode pumping in the gas laser cuvette

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The paper considers a variant of the system for transverse input of pumping radiation of the laser diode modules with fiber output into the gas laser cuvette. It included experiments for studying distribution of radiation from a unit power optical fiber of the diameter of $400\,\mu$m. Based on the results of the experiment, a software model of a fiber end-face with pre-defined spatial-angular characteristics of radiation was created. There were also experiments for studying distribution of intensity of radiation in various sections inside the laser's active zone from the radiation source of the size 20.5×10.5 mm. The software package included a digital counterpart of an optical path for inputting pumping radiation into the active medium, which demonstrates good compliance with the obtained experimental data.

Keywords: laser diodes, diode pumping, intensity, quartz optical fiber.

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Introduction

By now, there are a lot of known variants of laser designs that are based on alkali metal pairs both with end-face and transverse diode pumping [1–5]. The present study describes implementation of transverse inputting of radiation of diode pumping. It is based on laser diode rulers (modules), whose radiation is focused by an optical system inside the module to an inlet of the power quartz optical fiber. In order to form a single body of glowing, the fibers are assembled into bundles, the end faces are stripped of a protective shell, polished and place into a single plane. An advantage of such building of the glowing body is its easy scalability, a significant density of the output radiation flux $\sim 6\,\mathrm{kW/cm^2}$ and transferability of the glowing body from the diode modules and servicing equipment, thereby ensuring additional safety for personnel as well as easiness of tuning and maintenance of the entire pumping system as a whole. A disadvantage is large divergence of fiber outlet radiation ~ 0.4 rad, which forms a number of essential requirements when building the input system, as implementation of transverse diode pumping in the cuvette of the alkali metal pairs laser based requires creation of a uniform and extensive working pumping zone with the required intensity. The set requirements were fulfilled by designing several variants of optical diagrams of the input system, wherein one of them is described in the present study. The aim of this study is to create a computational model of the system for transverse pumping of the gas laser and to experimentally test it, which allowed creating the right-prism pumping field inside the cuvette, which provides improvement of the output parameters of laser radiation.

1. Optical diagram

Transverse input of pumping is realized by applying optical diagrams which rebuild the image of the radiation source into the laser cuvette [6,7]. In the present paper, the authors have considered the optical diagram shown in Fig. 1. The radiation source is placed at the distance of d to the first lens, whose focal distance is found by the formula (1). In this case, after radiation is transmitted through the first lens, there is ensured collimation of extreme beams of the source:

$$f_1' = \frac{h}{\theta} + L. \quad (1)$$

The second lens is placed in the focus of the first one. The focal distance of the second lens is calculated based on

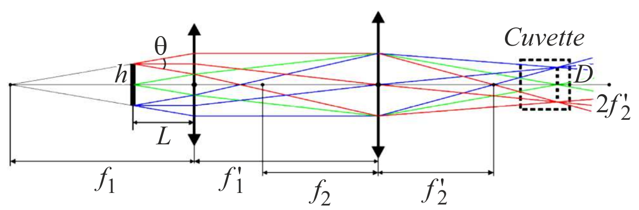

Figure 1. Rebuilding of an image of the radiation source into the laser cuvette: h — the source size, θ — divergence of radiation, L — the distance from the source to the lens, D — the transverse size of the pumping area, f_1', f_1; f_2', f_2 — the focal distances of the first and second lenses.

required sizes of the pumping working zone:

$$f_2' = \frac{f_1^2\theta}{f_1\theta + D}\frac{D}{h}. \tag{2}$$

In this variant, a length of the pumping working zone is not the maximum possilbe of all the diagrams that satisfy requirements of transverse input and are considered by the authors of this paper. The advantage is the most uniform distribution of the pumping flux density in the working zone of the laser cuvette as well as removability of the pumping working zone from the last surface of the lens, thereby enabling various design reworks of the cuvette.

2. Simulation of the pumping radiation source

For the benefit of creating the digital counterpart of the radiation source of the laser diode modules with fiber output, which takes into account all the specific features of the applied system for transmitting radiation from the diode rulers (diode rulers–microoptics–fiber), an experiment was taken to record radiation from the unit optical fiber at various distances thereto. The experimental setup is shown in Fig. 2.

The fiber was fixed in a mount and opposite the fiber end face there was a recording unit on a separate rack, which included a screen, a camera and filters. The screen was a Whatman paper sheet in the focal plane of the camera lens. The intensity distribution was recorded by taking a series of frames at three various distances to the fiber end face. Similar to the experiment, the software package of geometrical ray tracing simulated a similar diagram, but instead of the Whatman paper sheet and the camera, detecting planes were used, which are a camera matrix in a pre-defined scale. Like the Whatman paper sheet, the detecting planes were place at the distances $L = 78, 119$ and 138 mm. The general view of the diagram is shown in Fig. 3.

A model of the fiber end face was a disc of the radius R. The outlet intensity profile was pre-defined by the expression

$$I(r) = A + Br^2 + Cr^4, \tag{3}$$

where $0 < r < R$.

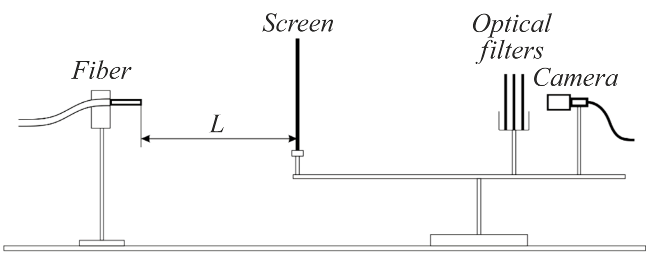

Figure 2. Experimental setup.

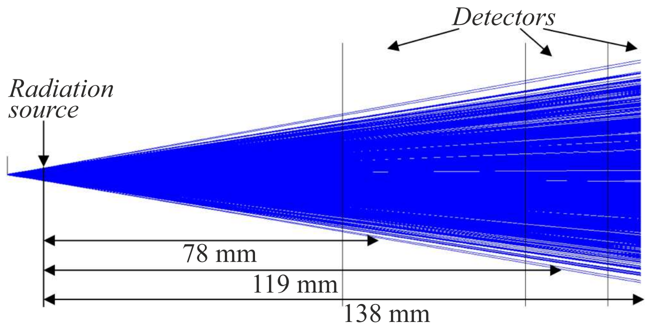

Figure 3. General view of the diagram for simulating the fiber end face.

After randomly determining a start position of the ray, rays are emitted from the surface into a cone, whose numerical aperture depends on radial coordinates:

$$NA(r) = D + Er^2 + Fr^4. \tag{4}$$

The ray distribution is homogeneous within the cone determined by the numerical aperture. The values of the parameters R, A, B, C, D, E and F are pre-defined in the software package.

The value of R is known to be 0.24 mm. The values of the parameters A, B, C, D, E and F varied until the experimentally-obtained intensity profile coincides with the intensity profile calculated in the software package. Eventually, the model of the fiber flat end face has the following parameter of the magnitudes: $R = 0.24$, $A = 1$, $B = 0$, $C = -100$, $D = 0.2$, $E = -2.2$, $F = 0$. The intensity distribution profiles that are recorded in the experiment and calculated in the software package are shown in Fig. 4.

Using the digital counterpart of the unit fiber, it is possible to simulate any desired glowing body that is a spatial set of the unit fibers.

3. System for inputting pumping radiation

For optical pumping of the alkali metal vapor laser, the glowing body of the size 20.5×10.5 mm was assembled and it consisted of 800 fibers. A forming optical diagram of the pumping system was a calculated diagram that is described above. Inputting of pumping radiation into the laser cuvette was preceded by the experiment for recording pumping intensity radiation in the planes that corresponded to the planes inside the cuvette. The experimental setup is shown in Fig. 5.

The intensity distribution was recorded in the screen that was in the focus of the camera and was the Whatman paper sheet. The initial position of the screen (0) corresponds to an external surface of the inlet cuvette window. The next positions of the screen differ by 5 mm along propagation of pumping radiation. The last position of the screen (45) corresponds to the plane that is at the distance of 2 mm to the external surface of the outlet cuvette window.

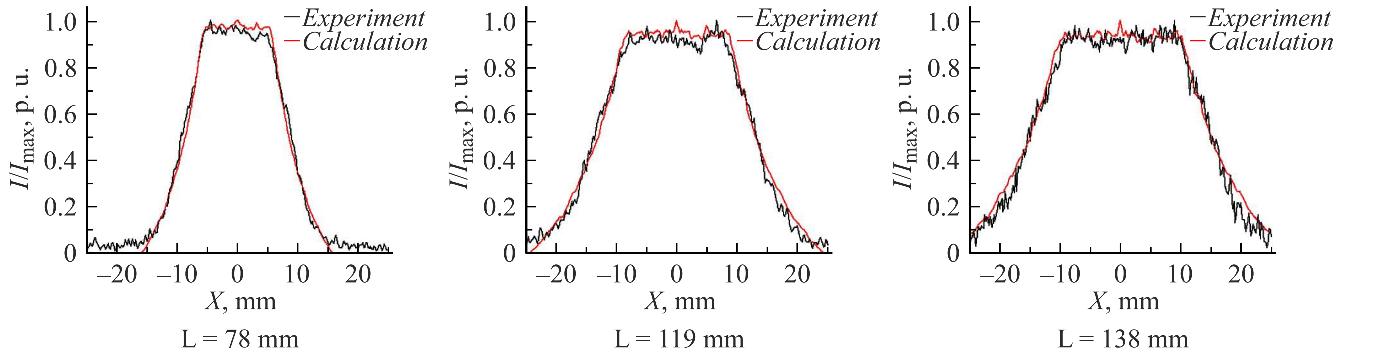

Figure 4. The intensity distribution profiles that are recorded in the experiment and calculated in the software package.

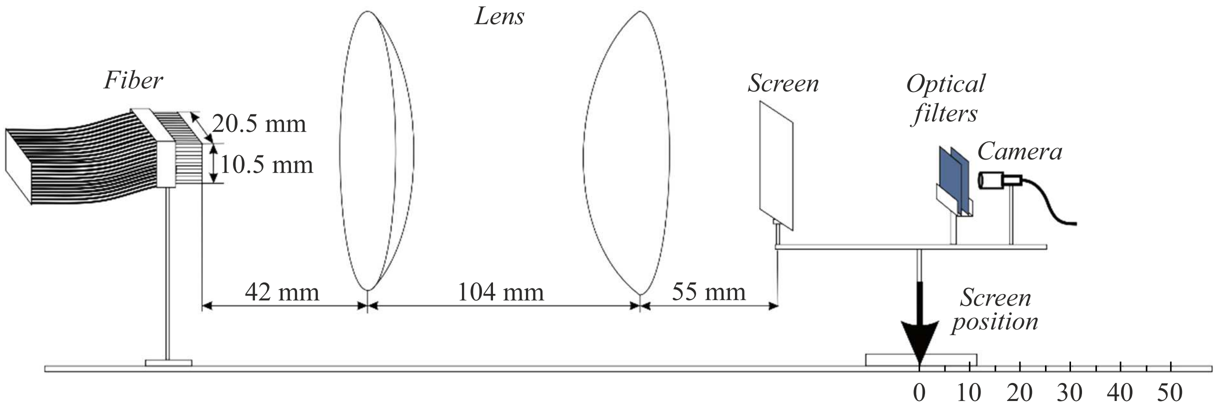

Figure 5. Diagram for recording pumping radiation intensity inside the cuvette from the glowing body 20.5 × 10.5 mm.

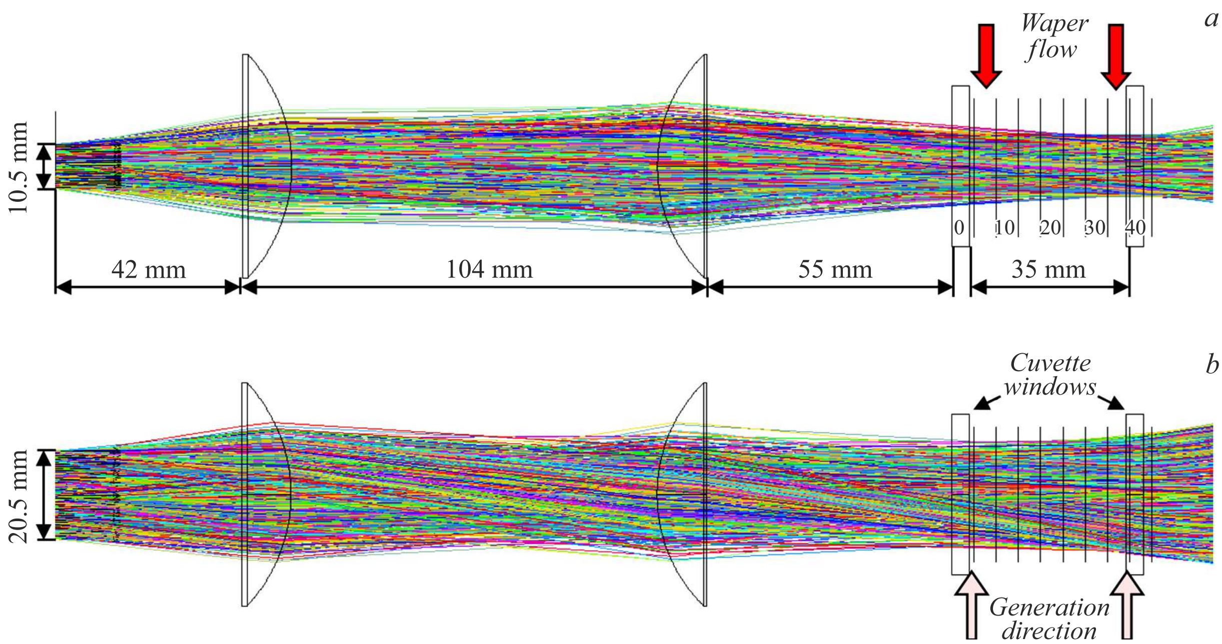

Figure 6. Optical diagram of the system for inputting pumping radiation into the laser cuvette: *a* — the side view (along a generation radiation), *b* — the top view (along a direction of the rubidium vapor flow).

The software package also simulated the experimentally similar optical diagram of the system for inputting radiation. The glowing body was 800 glowing discs that uniformly fill the rectangular size 20.5 × 10.5 mm. Fig. 6 shows the simu-

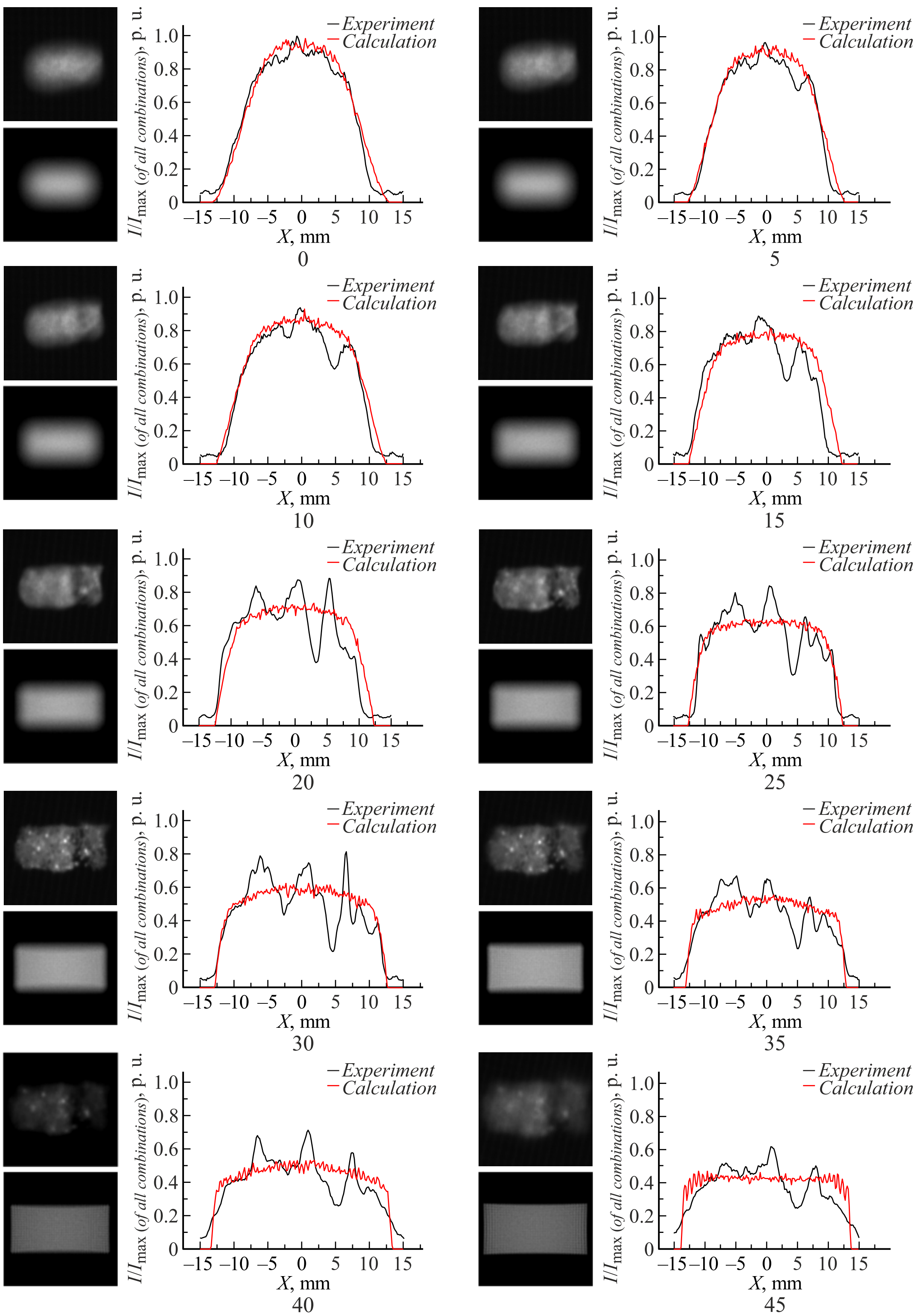

Figure 7. Experimental and calculated intensity distributions inside the laser cuvette from the glowing body 20.5×10.5 mm.

lated inputting system for the glowing body 20.5×10.5 mm with detectors that are installed for recording radiation intensity distribution.

Horizontal (along the generation direction) recordings of intensity distribution were made on frames that were obtained in the experiment and calculated in the software package. Fig. 7 shows comparison of the experimental and calculated data. The photos of Fig. 7 show the calculated (above) and experimental (below) two-dimensional radiation intensity distributions in the various planes of the laser cuvette as well as their recordings in the horizontal direction through the image center.

Bursts and dips of the intensity are well seen on the experimental sections inside the cuvette. The bursts are caused by the fact that at several diode modules the current exceeded the specified value, while the dips are caused by a failure of some power supplies of the diode modules. In general, the section recordings show good compliance of the experimental and calculated data, thereby indicating correctness of selection of the theoretical model of the fiber's unit end face.

Conclusion

The paper describes transverse inputting of diode pumping radiation with fiber output into the cuvette of the alkali metal vapor laser with a quite high and uniformly distributed density of the flux inside the laser's active zone. The model of the fiber flat end face is obtained to enable designing any glowing body that consists of the fiber end faces. The software counterpart of the system for radiation input has been simulated and it showed good compliance with the experimental data. The obtained results make it possible to use the model for carrying out various practical tasks for numerical simulation of the optical path of the system for inputting pumping radiation for the benefit of creating the geometrical models of the cuvettes of powerful gas lasers that have transverse diode pumping and a medium flow through the generation area.

Conflict of interest

The authors declare that they have no conflict of interest.

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