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High-power compact laser with segmented longitudinal pumping of coupled laser channels

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Abstract. **The characteristics of a compact Nd:YAG/Cr:YAG laser with segmented end pumping using a bundle of seven optical fibres are presented. In the regime of optical coupling of thus formed seven laser channels, 3-ns pulses with an energy up to 20 mJ, as well as their trains, are obtained. The used method makes it possible to scale the energy and power of lasers of this type with controlled spatial beam profile.**

Keywords: *Nd:YAG/Cr:YAG, microchip laser, end pumping, coupling of laser channels, laser power scaling.*

High-power compact pulsed lasers find ever-growing application in laser ranging, laser-induced breakdown spectroscopy, and engine fuel ignition systems [1–4]. Passively *Q*-switched lasers are quite popular due to their simplicity, reliability, and low cost [5–9]. The use of longitudinal diode pumping of the active medium allows one to decrease the laser dimensions providing good matching between the pumped and lasing regions, while the short cavity enables generation of short high-power pulses. In [10], the energy $E \sim 6$ mJ was achieved in pulses with the duration $\tau = 1.5$ ns, while an energy up to 3 mJ in 230-ps pulses was obtained in similar systems designed for generation of optical harmonics [11]. However, a further increase in the output energy of these lasers is difficult. In the case of end pumping, the active medium length is limited by the absorption depth, and the energy stored in the medium can be increased only by enlarging the pump region cross section or, to some extent, by increasing the initial cavity losses. The use of the second approach is limited by the optical strength of elements. The pumped domain inside the active medium, under the conditions of the cavity mode control, can be enlarged by formation of several laser channels in one active element, i.e., by spatial separation of pumped regions. Using this principle, the authors of [12] achieved a threefold increase in the output energy of a Nd:YAG/Cr^{4+}:YAG laser, but the pulses in the three formed channels were generated independently ($E = 2.4$ mJ per channel, $\tau = 0.85$ ns) and the temporal mismatch between them exceeded 10 μs. Segmented longitudinal pumping was also used in [13] to create a laser channel with a single transverse cavity mode. As a result, the pulse energy was low and its scaling potential was not realised. As an approach conceptually closest to that described in this work, one can consider coupling of closely spaced semiconductor, fibre, or gas superluminescent sources in one cavity [14–18].

The laser presented here contains seven pumped channels, which can lase either independently or in the optical coupling regime (depending on the alignment of the optical system of end pumping). The laser scheme is shown in Fig. 1. The 24-mm-long cavity is formed by a plane mirror on the rear of a Nd:YAG active element 12 mm long and by a plane output mirror. A free standing Cr^{4+}:YAG element was used for *Q*-switching. Pumping at a wavelength of 808 nm was performed by seven fibre-coupled pulsed diode modules (DILAS) with a power of 100 W each. The multimode optical fibres with a core diameter of 400 μm were gathered into a bundle, whose output was projected onto the active crystal by means of an AR-coated two-lens objective. Similar to [6], a set of correlated optical parameters, including output mirror reflection R, initial transmission of the saturable absorber T_0, objective magnification Γ, and the longitudinal position of the active element, was optimised in order to obtain the maximum output energy of pulses shorter than 5 ns. The maximum total energy (20 mJ) was achieved at $R = 45\%$, $T_0 = 40\%$, and $\Gamma = 3$.

The lasing regime strongly depended on the distance L between the output lens of the optical system and the Nd:YAG

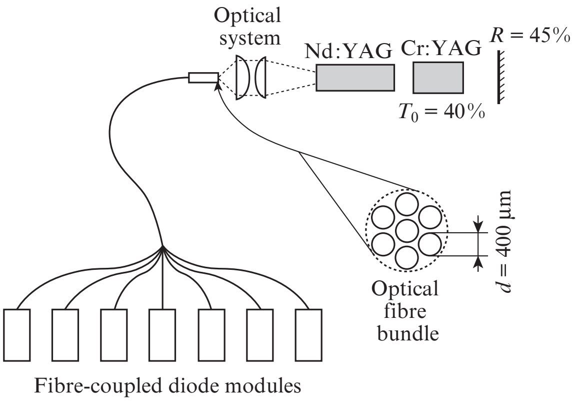

Figure 1. Laser scheme.

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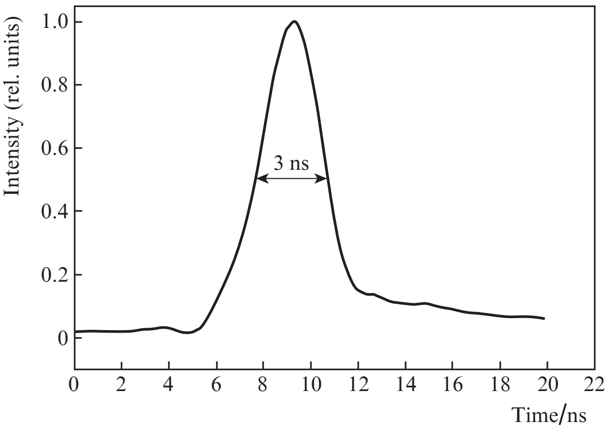

Figure 2. Pulse shape of synchronous lasing.

crystal. When the crystal was close to the image plane of the fibre bunch, pulsed lasing occurred in seven independent channels. The time mismatch between the pulses of these channels reached several tens of microseconds, while the energy of each pulse was 2.8–3.0 mJ. With decreasing distance L, the channels became conjugated and a single pulse of 3 ns FWHM was emitted (Fig. 2). The observed change in the lasing regime is caused by a transformation of the transverse pump beam profiles affecting the absorbed energy distribution over the active element, which eventually determines the gain profile inside the active medium in the direction of the cavity axis. The diagram in Fig. 3 allows one to compare the transverse profiles of the absorbed energy or gain for different alignement parameters of the optical system, i.e., for different L. For each of distances L, we measured a series of pump profiles with a small step in the region of the active crystal position using a CCD array, and the obtained values were summed along the crystal axis taking into account the decrease in the pump intensity according to the Bouguer law. The need in longitudinal scanning is explained by a noticeable change in the beam profile along the axis due to the short depth of focus for the objective in use (~5 mm). The crystal rear end position coincided with the image plane of the optical system in the case of L = 47 mm, while conjugation of lasing channels occurs at L = 42 mm. As follows from Fig. 4, this coupling appears at a small (~20%) overlap of the pump profiles in the segments. The maximum energy in the channel synchronisation regime (20 mJ) was measured near the coupling threshold (L = 40–42 mm). The output radiation profile in this range was formed by seven beams with a diameter of ~1 mm and a divergence of about 7 mrad. A further decrease in the distance between the objective and the crystal was followed by a gradual decrease in the single-pulse energy. It is assumed to be caused by a decrease in the diameter of the pumped domain inside the crystal and by deterioration of spatial matching between the pump and lasing domains. Simultaneously, the spatial distribution of the output beam became noticeably smoother and was gradually transformed into a distribution typical of multimode lasing.

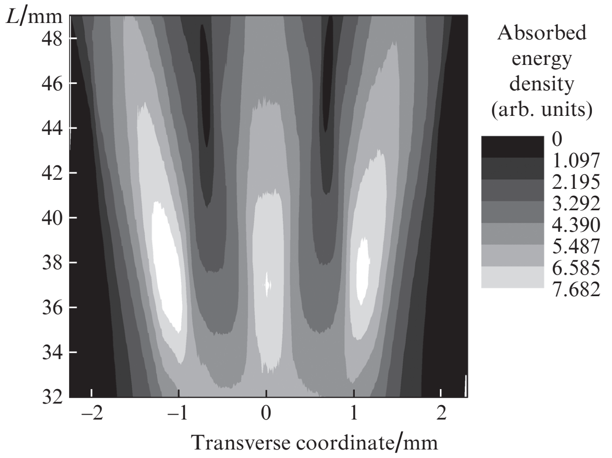

Figure 3. Transverse profiles of absorbed pump energy in the active element as a function of the optical system adjustment parameter L.

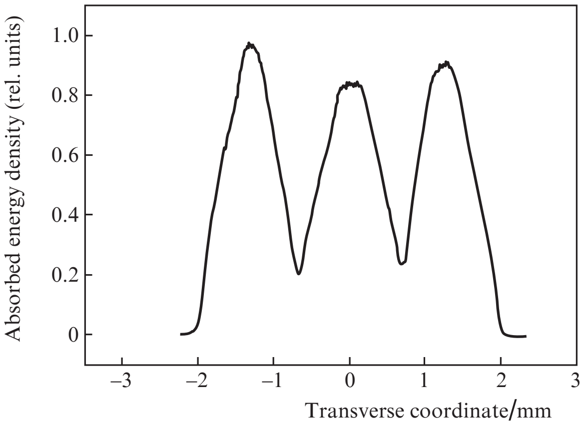

Figure 4. Absorbed pump energy profile in the active element in the regime of conjugated lasing of channels (L = 40 mm).

With increasing pump pulse duration in the regime of conjugated channels, two and more short pulses of approximately the same energy were generated with a characteristic interval between them of 200 μs. The duty cycle of the quasi-cw diode modules allowed successions of up to four pulses to be obtained.

The approach described in this work provides a simple way for scaling the output energy and power of end pumped lasers by increasing the number of pumped segments. It also allows one to control the mean profile by overlapping the pump segments and, in addition, to trim the output by balancing the pump between the channels. A record-high pulsed energy and a close-to-record values of power for such systems are achieved.

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