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Highly Efficient High-Power Quasi-Continuous Diode Laser Bars for Pumping Solid-State Lasers Based on Yb-Containing Active Media

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Abstract—Highly efficient high-power quasi-continuous diode laser bars (DLBs) emitting in the region of $\lambda = 0.95$ μm have been developed for pumping solid-state lasers based on Yb-containing active media. The parameters of DLBs and the results of long-term tests are presented. The proposed DLBs are implemented in a solid-state laser based on an Yb–Er glass operating in the 1.5 μm range. © *2004 MAIK "Nauka/Interperiodica".*

Diode-pumped solid-state lasers (DPSSLs) are widely used in various fields of science and technology. Of special interest are DPSSLs based on Yb -containing active media, because ytterbium ions, possessing an intense and broad absorption band in the spectral range of about 0.95 μm, are capable of effectively sensitizing the ions of other rare earth elements (Er, Ho, Tm). Owing to the large lifetime of the metastable laser level, such DPSSLs generate high-power optical pulses in a spectral range of 1.5–2.0 μm safe for the human eye [1].

In order to create the inverted population of levels in rare earth ions with large lifetimes (1–10 ms) of a metastable level, it is necessary to develop highly effective pumping sources. The role of such pumps is successfully performed by quasi-continuous diode laser bars (DLBs) with a laser pulse width of several milliseconds, which is about ten times the effective pumping pulse width in widely used neodymium-based DPSSLs [2].

However, the relatively large width of the optical pulse of DLBs creates increased cyclic thermal loading of the laser structure and poses additional requirements with respect to minimization of the mechanical stresses induced in laser chips in the course of DLB fabrication and assembly. This is related to the fact that excess mechanical stresses under the conditions of increased heating of the laser structure significantly reduce the lifetime of DLBs [3, 4].

This Letter reports on the development of highly efficient high-power DLBs with an optical pulse width of up to 5 ms, emitting in the 940–960 nm spectral range and intended for the optical pumping of ytterbium-based DPSSLs.

The diode laser chips were fabricated from low-threshold $In_{0.1}Ga_{0.9}As/AlGaAs$ heterostructures grown by molecular beam epitaxy (MBE) in a domestic system of the EP1203 type. The heterostructure design, and special features of the growth setup and the growth technology were described previously [5]. Each chip comprised an array of 50 optically decoupled diode lasers [6] with a period of 200 μm and a 160-μm-wide emitting region. The total resonator length was 1000 ± 50 μm. The front and back faces of the resonator were covered by reflection and antireflection coatings with a reflection coefficient of 95 and 5%, respectively.

The diode lasers were assembled into DLBs using a special setup ensuring positioning of the chips with an accuracy of ±1 μm. The chips were soldered with *p*-side to a copper heat sink by means of an indium-containing solder. The solder layer thickness was optimized so as to reduce the level of residual mechanical stresses.

The DLB output optical power was measured using a LaserMate (Coherent Co.) calibrated bolometric power meter. The optical output power (P_{out}) in the pulse was calculated as $P_{out} = P_{av}\nu$, where P_{av} is the power time-averaged by the bolometer and ν is the duty factor of the laser pulse sequence. Oscillograms of the laser output pulses were recorded using a reverse-biased silicon photodiode equipped with a special attenuating filter based on doped GaP. The spectral measurements were performed using an automated complex setup based on an MDR-23 grating monochromator.

Figure 1 shows the typical plots of the optical output power P_{out} and the total efficiency (defined as the ratio of the output power at the front mirror to the total consumed electric power) versus the pumping current for DLBs operating at different heat sink temperatures. An

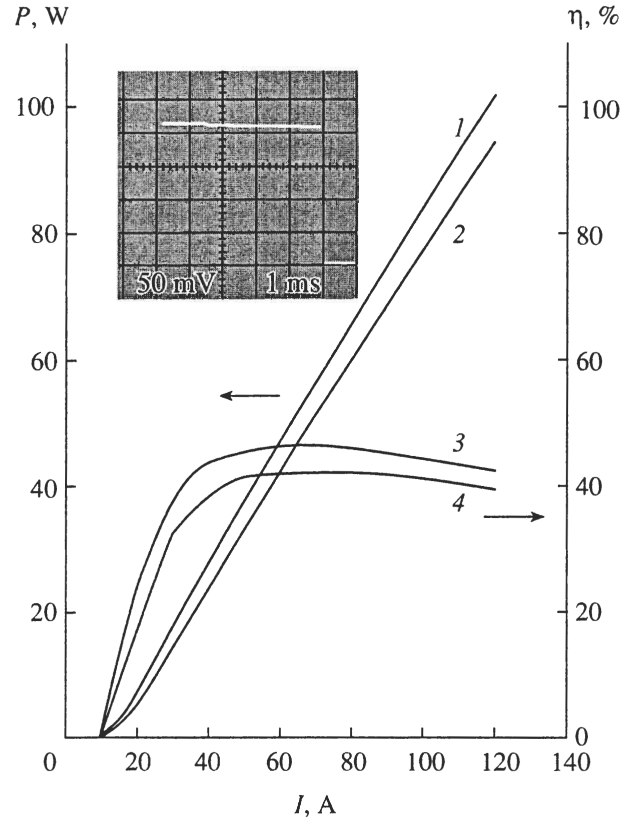

Fig. 1. Typical plots of the (*1*, *2*) optical output power P and (*3*, *4*) total efficiency η versus pumping current I for DLBs operating at a heat sink temperature of 25°C (*1*, *3*) and 55°C (*2*, *4*). Laser pulse width, 5 ms; repetition rate, 10 Hz. The inset shows an oscillogram of the laser output pulse.

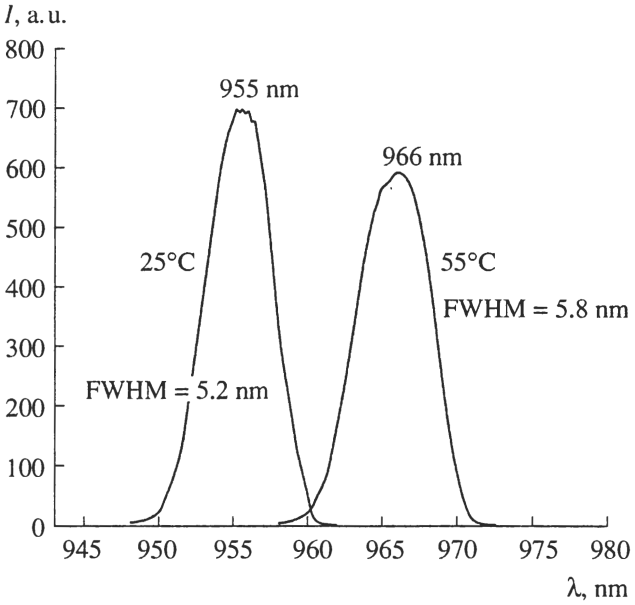

Fig. 2. The typical emission spectra of DLBs operating at different heat sink temperatures. Pumping current, 120 A; laser pulse width, 5 ms; repetition rate, 10 Hz.

analysis of these data shows that the maximum DLB efficiency is 47 and 42%, and the differential quantum efficiency is 72 and 66% for a heat sink temperature of 25 and 55°C, respectively. The critical temperature T_0 determined from the dependence of the threshold current on the heat sink temperature is 180°C.

The inset in Fig. 1 shows a typical oscillogram of the output optical pulse measured at a pumping current of 120 A. As can be seen, decay in the optical output power during the pulse does not exceed 5%. A comparison of the P_{out} values obtained for the two heat sink temperatures shows that additional heating of the DLB active region during the pumping pulse does not exceed 20°C (this estimate is obtained assuming a linear relation between P_{out} and the temperature).

Figure 2 shows the typical DLB emission spectra measured at different heat sink temperatures. Small width (FWHM, ~5 nm) of the emission band is evidence of high homogeneity of the DL chips and good quality of DLB assembly. The combination of the narrow DLB emission spectrum with a relatively broad absorption spectrum of ytterbium ions ensures effective pumping of DLBs in a wide range of working temperatures.

The proposed DLBs were subjected to long-term tests in the regime of stabilized constant pumping current (I = 100 A) and a constant pulse width (FWHM, 5 ms). The samples tested at a heat sink temperature of T = 25°C showed no evidence of any decrease in P_{out} over a series of 3×10^7 pulses. When the working temperature was increased to 55°C, the DBL power degradation was 1–2% over 10^7 pulses. Thus, using a linear extrapolation of $P_{\text{out}}(t)$ to $P_{\text{out}}(t_0) = 0.8P_{\text{out}}(0)$, the expected lifetime of DLBs at T = 55°C can be estimated as corresponding to $t_0 = 10^8$ pulses. On the other hand, assuming that an increase in the working temperature by 30°C leads to a tenfold increase in the rate of degradation (as is usually suggested in accelerated testing methods [7]), the results of the high-temperature test indicate that the expected lifetime of DLBs at T = 25°C corresponds to $t_0 = 10^9$ pulses.

The DLBs developed in this study were implemented in a solid-state laser based on an Yb–Er glass. The laser with two DLBs operated in the 1.5 μm range and generated 20-ns pulses with a pulse energy of up to 10 mJ at a repetition rate of up to 10 Hz. The laser output energy in the free lasing regime was 60 mJ at a differential efficiency of 18%.

In conclusion, we have developed, characterized, and tested highly efficient high-power DLBs with an optical pulse width (FWHM) of not less than 5 ms, intended for pumping solid-state lasers based on Yb-containing active media.

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