Quantum Electronics **32** (3) 210 – 212 (2002)

PACS numbers: 42.55.Rz; 42.55.Xi; 42.79.Qx
DOI: 10.1070/QE2002v032n03ABEH002162

Highly efficient minilaser with transverse pulsed semiconductor pumping for eye-safe laser range-finding

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Abstract**. The lasing characteristics of a Cr, Yb, Er : glass minilaser transversely pumped by a pulsed laser diode array are investigated. A single 30-ns pulse of energy 3 mJ, and a beam divergence of 4 mrad was generated for an electric pump pulse energy of 0.5 J in the *Q*-switching mode.**

Keywords: *semiconductor pumping, Cr, Yb, Er:glass, minilaser, laser range-finding*

1. Introduction

Despite the considerable progress in designing and production of laser diode arrays (LDAs) for transverse pulse pumping of solid-state lasers [1], flashlamp-pumped solid-state lasers dominate the world market [2]. This is due to problems associated, as a rule, with the use of LDAs in specific laser devices. The short lifetime of the excited state (less than 1 ms) of the traditionally employed laser media (required for achieving a sufficient population inversion in the active medium) necessitates the use of LDAs in ultimate permissible regimes [3] (which has an adverse effect on their service life), or an increase in the total number of arrays to 10 or more (which considerably increases the cost of the device). The thermal stabilisation of the LDA with the help of thermoelectric coolers, required for maintaining an efficient operation of arrays, not only complicates the construction of the lasers, but also lowers their overall efficiency. In one field of laser technology, however, the use of LDAs for transverse pulse pumping is found to be expedient from all the above-mentioned points of view. This is the field of solid-state Yb, Er:glass lasers for laser rangefinders with an eye-safe radiation wavelength.

The operation of a laser rangefinder is characterised by the pulse repetition rate that does not exceed 0.3 Hz, and hence no special measures involving an additional energy expenditure are needed for cooling the LDA. To ensure the efficient operation of an array, it is sufficient to establish its thermal contact with the casing of the laser. For an LDA emitting at 940 nm at +20 °C, a variation in the ambient temperature from −40 to +50 °C leads (for $\Delta\lambda/\Delta T = 0.33$ nm (°C)$^{-1}$ [4]) to a change in the radiation wavelength from 920 to 950 nm. This allows an efficient Yb, Er : glass pumping over the entire temperature range mentioned above, since the absorption of Yb (which acts as the sensitiser) varies rather weakly in the wavelength range 915 – 965 nm. The lifetime of the excited state of Er in glass (about 7 – 8 ms) allows the necessary population inversion in the active medium by varying not only the pump current, but also the pump cycle duration, which makes it possible to optimise the operating conditions for the LDA, as well as the active medium.

This work is devoted to an experimental study of an eye-safe rangefinder minilaser with transverse pulsed semiconductor pumping, having a simple construction and high efficiency.

2. Laser Diode Array

An LDA fabricated at the Polyus Research and Development Institute was used as the pump source. The active medium was grown by the MOS-hydride epitaxy and had a double InGaAs/AlGaAs/GaAs heterostructure with separate electronic and optical confinements and with a single quantum well of width 120 Å. The planar construction of an array of total length 1 cm consists of 50 stripe lasers separated by grooves with an active layer etched to the *n*-emitter. Such a construction ensures the suppression of amplified spontaneous emission in a direction at right angles to the cavity axis. A cavity of length 750 μm was prepared by cleaving the heterostructure faces and depositing reflective dielectric coatings on them.

Fig. 1 shows the light – current characteristic of the LDA used in the experiments. One can see that for a pump current of 120 A, the array emits pulses of about 100 W power, the total efficiency being 50 % at a pump current of 100 A. Note that the laser array did not contain any additional optical elements for forming the spatial characteristics of the radiation. The radiation pattern was in the form of a beam with divergence 45° in a plane perpendicular to the $p-n$ junction plane, and 10° in the $p-n$ junction plane.

3. Active medium

We used in our work Cr, Yb, Er : glasses fabricated at the Institute of Radioengineering and Electronics, Russian Academy of Sciences, for flashlamp pumping [5, 6]. Along with the main sensitiser Yb^{3+}, an additional sensitiser Cr^{3+} was introduced for a fuller utilisation of the

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Received 11 February 2002
Kvantovaya Elektronika **32** (3) 210 – 212 (2002)
Translated by Ram Wadhwa

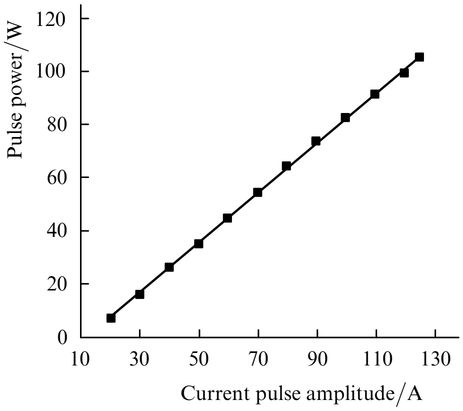

Figure 1. Light – current characteristic of a LDA for a 1-ms pump pulse.

radiation from the lamp. Note that while the presence of chromium ions in glass helps enhance the efficiency of a flashlamp-pumped laser, it is undesirable in the case of selective pumping to the absorption band of ytterbium. This is due to the fact that in addition to the direct energy transfer from donor ions (Cr^{3+}) to acceptor ions (Yb^{3+}), the reverse process of energy transfer also occurs. In the case of flashlamp pumping, when both chromium and ytterbium are excited, the direct energy transfer prevails over the reverse transfer, making it possible to attain a positive effect from chromium sensitisation.

In the case of laser-diode pumping into the ytterbium absorption band, the situation is reversed, and unexcited chromium becomes an acceptor, absorbing a part of the energy of excited ytterbium. The rate of reverse energy transfer in the Cr – Yb pair increases with the concentration of chromium or ytterbium ions [6].

Note that an increase in the concentration of ytterbium ions up to 2.5×10^{21} cm^{-3} is also accompanied by an increase in the rate of energy transfer from ytterbium to an erbium ion at whose transitions lasing occurs. In addition, the concentration of Yb ions determines the absorption of the pump radiation by the active medium, which taking into account a strong inhomogeneity inherent in transverse pumping is one of the factors determining the energy parameters of the output radiation.

Because the erbium glass laser operates according to a three-level lasing scheme, the concentration of erbium ions must be as low as possible to minimise the threshold pump energy. However, in order to ensure a high coefficient of transformation of the pump energy into the energy of laser radiation, the concentration of erbium ions must be increased. It follows from the above arguments that an independent analysis should be carried out for determining the concentration of activators in the erbium laser glasses used as the active elements (AEs) in a transversely pumped laser. We studied the dependence of the energy characteristics of a laser on the composition of the glass for three types of Cr, Yb, Er : glass. Table 1 shows the concentrations of activator ions in these glasses.

4. Experimental conditions and results

The active elements of size $\varnothing 2.5 \times 10$ mm were specially modified to create the optimal spatial distribution of pump radiation in them for obtaining laser action with satisfactory spatial characteristics without using any additional optical elements between the LDA and AE (focusing lens, cylindrical lens, etc.) Such a modification was necessitated by the fact that the astigmatism of LDA radiation increases after the passage through the cylindrical AE surface. In order to optimise the pumping, the side surface of cylindrical AEs was polished, and pumping was carried out through the plane face thus formed. The opposite side surface of the AE was covered with a layer of the sealing compound KLT-30A, which served the dual purpose of reflector of LDA radiation, not absorbed during the first pass in the active medium, and the structural element used for fastening the AE to the laser casing. To ensure the acceptable quality of the beam and laser radiation energy, the LDA was installed parallel to the AE axis at a distance of 0.2 – 1.5 mm from its side surface.

Table 1. Concentration of activator ions in glasses used in this work.

Glass	$[Er^{3+}]/cm^{-3}$	$[Yb^{3+}]/cm^{-3}$	$[Cr^{3+}]/cm^{-3}$
LGS – KhM	1.2×10^{19}	2.3×10^{21}	2.2×10^{19}
LGS – Kh	1.6×10^{19}	1.6×10^{21}	4.0×10^{19}
LGS – KhK	1.6×10^{19}	2.0×10^{21}	3.0×10^{19}

A 50 mm-long optical cavity was formed by the plane output mirror with reflectivity $R = 89\,\%$ at the laser wavelength, and a highly reflecting spherical concave mirror with a radius of curvature 816 mm. The AE was placed near the output mirror. To produce Q-switching, an ATR shutter was placed between the AE and the highly reflecting mirror.

The output energy was measured by an IMO-2N calorimeter. The laser pulse shape was monitored with a LFD-2 photodetector and a TDS 220 Tektronix oscillograph. The LDA power supply provided independent variations of the amplitude and duration of the pump current pulse. Experiments with a free-running laser showed that the output energy of the laser depended almost linearly on the optical pump energy for variations of the pump current and pulse duration in the range 70 – 110 A and 1.2 – 4.5 ms, respectively. For this reason, subsequent experiments were carried out for a fixed amplitude of the LDA pump current pulse (100 A), for which the pulse radiation power of the LDA was 80 W for a 50 % energy efficiency.

The pump pulse energy was changed by varying the pump-pulse duration. Fig. 2 shows the output characteristics of a laser with active elements made of Cr, Yb, Er : glasses of various compositions. One can see that irrespective of the glass composition, the output characteristics of the laser (curves *1 – 4*) are identical in the Q-switching mode. Upon an increase in the pump pulse energy, the growth of the single pulse energy becomes slower and tends to saturation. This is due to a deficiency of Er^{3+} ions in the glasses used, as a result of which all working ions in the region of pumping prove to be inverted beginning from some pump energy, and further increase in the energy is not observed. A slight increase in the output energy with increasing the pump energy is possible only due to a certain expansion of the above-threshold region in the nonuniformly pumped AE region. An increase in the Er concentration in the glass increases the saturation level of the laser output energy, which makes it possible to attain a higher energy of the single pulse (curves *2 – 4*).

The best energy characteristics were obtained by using active elements made of LGS-KhK glass (curves *3*, *4*). This

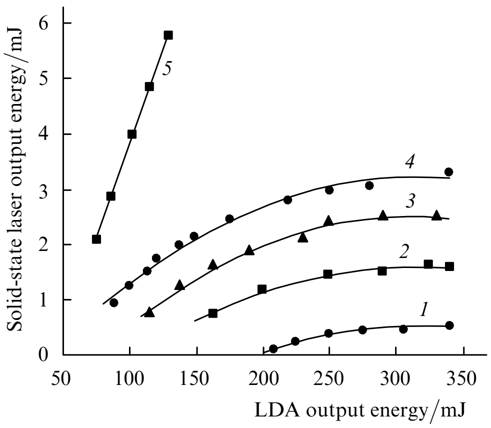

Figure 2. Output characteristics of a laser with the active element made of chromium, ytterbium, erbium glasses: (*1*) LGS-KhM, (*2*) LGS-Kh, and (*3*, *4*) LGS-KhK in the *Q*-switching mode, and (*5*) the glass LGS-KhK in the free-running mode for $R = 89\%$ (curves *1–3*) and 96 % (curves *4*, *5*).

may be attributed to a better combination of the activator concentrations in this glass (see Table 1), which ensures that the condition of above-threshold inversion is satisfied over a larger volume of the active medium. The energy parameter of the laser was further improved (curve *4*) by using in its optical cavity a more optimal output mirror (in view to a low gain of the active medium) with the reflectivity of 96 % instead of 89 %. However, one can see that even in this case, the laser energy characteristic attains saturation, which was not observed in the free-running mode (curve *5*).

For the LDA pulse energy of 250 mJ (which corresponds to a pumping energy of 0.5 J in view of the 50% efficiency of the array) a single pulse enrgy of 3 mJ was attained in the *Q*-switching mode for the FWHM pulse duration of 35 ns, a spot size of 0.6 mm of the beam at the output mirror, and a beam divergence 4 mrad. In such a mode, the laser was capable of operating at a pumping pulse repetition rate of up to 0.5 Hz. Note that such parameters were obtained for a laser working near the saturation of its energy characteristic which is caused by an insufficient concentration of erbium ions in the glass (see above). The highest efficiency corresponds to the output energy 21 mJ for a pump pulse energy of 0.3 J.

Despite the fact that the composition of glasses used in our investigations was not optimal for transverse semiconductor pumping, the parameters obtained by us are undoubtedly of practical interest, and the minilaser described here can be treated as a prototype of the laser transmitter in a microlaser rangefinder [7] with a range of up to 3 km. The obtained results allow us to predict a significant increase (by several times) in the energy parameters upon optimisation of the laser glass composition. The optical scheme used by us makes it possible to modernise the construction of lasers in the micromodular version, where the AE is a prism with total internal reflection of the radiation at one of the faces, and the *Q*-switching is attained by a piezoelement mounted at this face.

Acknowledgements. The authors thank P.I.Sadovskii of the Institute of Radioengineering and Electronics, Russian Academy of Sciences, for consultations on the composition of laser glasses used in this research.

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