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High-power pulsed hybrid semiconductor lasers emitting in the wavelength range 900–920 nm

T.A. Bagaev, N.V. Gul'tikov, M.A. Ladugin, A.A. Marmalyuk, Yu.V. Kurnyavko, V.V. Krichevskii, A.A. Morozyuk, V.P. Konyaev, V.A. Simakov, S.O. Slipchenko, A.A. Podoskin, N.A. Pikhtin, A.E. Kazakova, D.N. Romanovich, V.A. Kryuchkov

Abstract. **High-power hybrid semiconductor lasers–thyristors (λ = 900–920 nm) consisting of thyristor crystals soldered in series with an integrated semiconductor laser with three emitting sections are studied. A monolithic laser–thyristor with three emitting sections is used as a reference sample. The output power of the triple monolithically integrated laser–thyristor is ~120 W at a turn-on voltage of 18 V. The turn-on voltage of a hybrid laser–thyristor with three emitting sections is 28 V, and the peak output power reaches ~170 W.**

Keywords: *integrated laser–thyristor, hybrid laser–thyristor, output power.*

1. Introduction

High-power lasers emitting in the spectral range 900–920 nm can be used to solve many applied problems, including the rapidly evolving field of development of mobile lidar complexes [1]. To provide operation of pulsed semiconductor lasers, use is traditionally made of a controlled switching scheme with a capacitor and an electronic switch (transistor, dinistor, or thyristor). Epitaxial monolithic integration in one semiconductor crystal is a next step in improving the functional characteristics of these emitters. Lasers–thyristors designed according to this scheme have demonstrated an output power of ~50 W in short pulses (100 ns, 10 kHz) [2]. The use of two and three tunnel-coupled emitting sections in the laser unit makes it possible to increase the quantum efficiency of these devices and increase their output power to 90 and 120 W, respectively [3, 4]. At the same time, monolithically integrated lasers–thyristors exhibit a decrease in the switch-on voltage due to the absorption of the spontaneous emission of the active region of the laser section by the reverse-biased region of the base of the thyristor section [5]. This decreases the pump current flowing through the device and, hence, restricts its output power. The monolithic lasers–thyristors also exhibit the current turn-on effect in a local region of the heterostructure plane, which leads to additional optical losses and to a decrease in the slope of the light–current characteristic [2]. A way to decrease the negative influence of these effects is to create a hybrid laser–thyristor in which the thyristor unit and the semiconductor laser are used as discrete independent components connected in series via a solder contact and having no optical interaction. In [6] we presented the results of controlling laser microarrays (three laser diodes) using three thyristors in a hybrid design. The achieved peak output power was 78 W at a wavelength of 1060 nm and a turn-on voltage of up to 22 V. However, hybrid devices are characterised by higher heat release and weight and size parameters, which may restrict their practical application.

The present work is devoted to experimental comparison of the mentioned approaches to the development of high-power semiconductor lasers–thyristors operating in a pulsed regime.

2. Experimental

To fabricate hybrid and monolithically integrated semiconductor lasers, (In)GaAs/AlGaAs/GaAs heterostructures were grown on GaAs substrates by MOCVD. A hybrid emitter of the laser–thyristor type consisted of a laser heterostructure with three emitting sections and a thyristor heterostructure, which were grown separately. These heterostructures are schematically shown in Figs 1a and 1b. To form a hybrid laser–thyristor, these heterostructures were connected in series via a solder contact as is shown in Fig. 1c.

The heterostructure of a triple monolithically integrated laser–thyristor was formed by adding the second and third emitting laser sections to a single laser–thyristor via tunnel junctions (Fig. 1d).

We used a triple integrated laser heterostructure [7], a monolithically integrated triple laser–thyristor [4], and a thyristor heterostructure as a separate unit [4].

Based on the grown heterostructures, we fabricated hybrid and monolithic laser–thyristors and studied their operation in a pulsed regime (100 ns, 10 kHz) in a circuit with a capacitance of 0.47 μF.

T.A. Bagaev JSC M.F. Stelmakh Polyus Research Institute, ul. Vvedenskogo 3, korp. 1, 117342 Moscow, Russia; Peoples' Friendship University of Russia (RUDN University), ul. Miklukho-Maklaya 6, 117198 Moscow, Russia; e-mail: tim_himik@mail.ru;
N.V. Gul'tikov, M.A. Ladugin, A.A. Marmalyuk, Yu.V. Kurnyavko, V.V. Krichevskii, A.A. Morozyuk, V.P. Konyaev, V.A. Simakov JSC M.F. Stelmakh Polyus Research Institute, ul. Vvedenskogo 3, korp. 1, 117342 Moscow, Russia;
S.O. Slipchenko, A.A. Podoskin, N.A. Pikhtin, A.E. Kazakova, D.N. Romanovich, V.A. Kryuchkov Ioffe Institute, Russian Academy of Sciences, Politekhnicheskaya ul. 26, 194021 St. Petersburg, Russia; e-mail: nike@hpld.ioffe.ru

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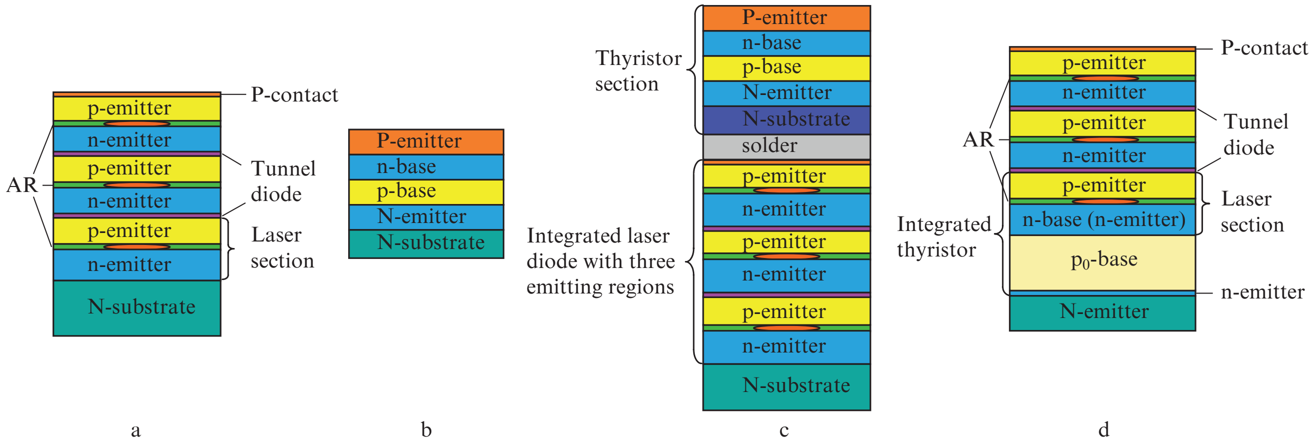

Figure 1. (Colour online) Schematic of heterostructures of (a) triple integrated laser, (b) thyristor, (c) hybrid triple laser–thyristor, and (d) integrated triple laser–thyristor. AR is the active region.

3. Results and discussion

The idea of increasing the efficiency of pulsed laser diodes led to the creation of monolithically integrated lasers–thyristors with a highly efficient small-signal control and a wide range of operation regimes [8]. To increase the output power of these devices, the laser part was made using several tunnel-coupled emitting sections, which made it possible to increase the quantum efficiency by 1.5–1.8 times for devices with two sections and by 2.2–2.4 times for devices with three sections [3, 4]. However, the absorption of the spontaneous emission of the active region of the laser section occurring in the reverse-biased region of the base of the thyristor section of this device decreases the turn-on voltage, which, in turn, limits the maximum pump current and restricts the growth of the output power [9, 10]. The process of photoactivation of carriers in the base of the integrated laser–thyristor is schematically shown in Fig. 2.

Such factors of localisation of current flow regions as the residual absorption in the unpumped region, an increase in the current density in the localisation region, and a decrease in the optical confinement factor in the gain region, decrease the laser–thyristor efficiency in comparison with lasers in which uniform pumping is possible [2].

The use of the hybrid laser–thyristor design, in which the optical interaction between the emitter and the electronic switch is absent and current localisation in the laser itself does not occur, should eliminate the mentioned effects. Therefore, we fabricated hybrid lasers–thyristors consisting of discrete crystals of a laser with three emitting sections and a thyristor, which were connected by soldering. The output characteristics of these devices were compared with the corresponding characteristics of monolithically integrated triple lasers–thyristors. Note that the individual heterostructures of the thyristor and triple integrated laser of the hybrid devise were identical in composition, doping, and thickness of layers to the corresponding heterostructures of the monolithically integrated laser–thyristor. We expected to obtain an increase in the turn-on voltage and in the output optical power of the hybrid laser–thyristor.

Figure 3 presents the current–voltage characteristics of the studied samples. One can see that the absence of the optical interaction between the emitting and controlling parts in the hybrid laser–thyristor made it possible to increase the turn-on voltage by 1.4–1.5 times in comparison with the monolithic laser–thyristor.

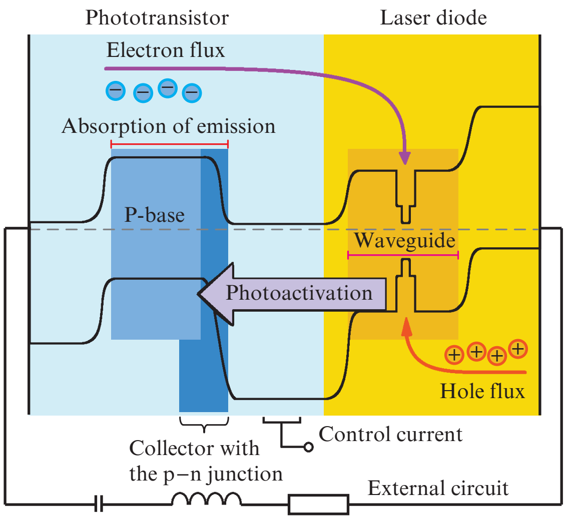

Figure 2. (Colour online) Scheme of photoactivation of additional carriers in the base of the integrated laser–thyristor.

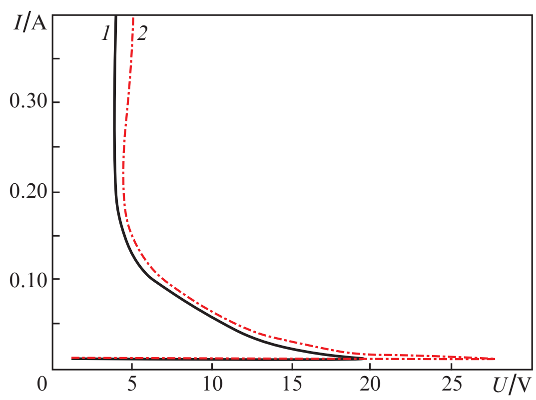

Figure 3. Current–voltage characteristics of (*1*) monolithic and (*2*) hybrid triple lasers–thyristors.

The use of hybrid rather than monolithic integration of the laser and control sections allowed us to obtain the peak output power P_{imp} = 170 W at a pump current of 80 A in a short-pulse regime, which exceeds the output power of monolithically integrated lasers–thyristors by a factor of 1.4 (Fig. 4). An important component of the achieved result is, in our opinion, an increase in the operation efficiency of the thyristor part in the hybrid devices.

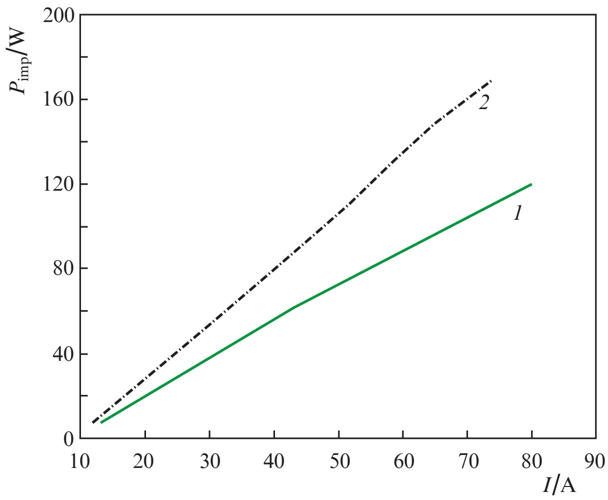

Figure 4. Light–current characteristics of (*1*) monolithic and (*2*) hybrid triple lasers–thyristors (100 ns, 10 kHz).

It should be noted that the slope of the light–current characteristic of the triple hybrid laser–thyristor (Fig. 5) is close to the corresponding parameter for the monolithically integrated triple laser without the controlling section (the data are taken from [7]). One can see from Fig. 5 that the absence of the optical interaction between the laser and thyristor parts of the hybrid laser–thyristor positively affects the stability of the output power growth with increasing pump current.

The specific features of switching on of integrated lasers–thyristors related to the localisation of the current flow regions when they are switched from the closed to the open

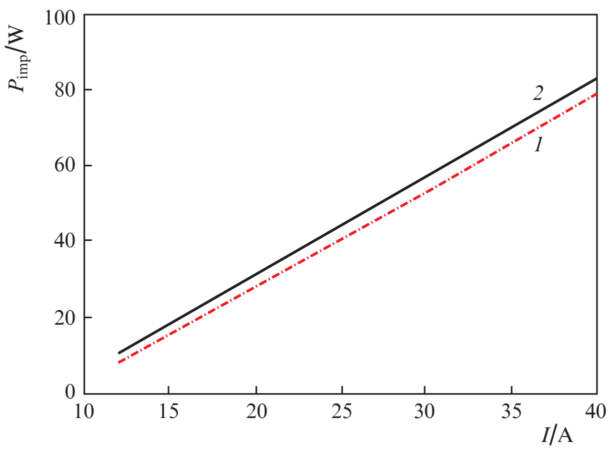

Figure 5. Light–current characteristics of (*1*) a hybrid triple laser-thyristor and (*2*) a monolithically integrated triple laser (100 ns, 10 kHz).

state lead to a decrease in their efficiency [11]. In the present work, the use of the hybrid integration instead of the monolithic one allowed us to obtain a 40% increase in the output power. At the same time, the authors of [11] noted a high sensitivity of the current localisation effect in integrated lasers–thyristors to the size of the contact and to the active element design, which gives hope for achieving an increase in the output characteristics of these devices by changing the designs of both the heterostructure and the laser as a whole.

4. Conclusions

It is shown that the use of the hybrid design of integrated lasers–thyristors instead of the monolithic one leads to an increase in the output power. In particular, the fabricated hybrid lasers–thyristors with three emitting sections allowed us to obtain a peak output power of 170 W in a pulsed regime (100 ns, 10 kHz) in the spectral range 900–920 nm.

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