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Double integrated laser-thyristor

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Abstract. **Comparative experiments are performed on a semiconductor laser with different numbers (one or two) of emitting sections monolithically integrated with an electronic switch (thyristor). It is shown that the functional integration of a laser with a thyristor in one heterostructure makes it possible to achieve efficient operation of the laser in a pulsed regime (up to 50 W), while the use of vertical integration of two laser sections in this device additionally increases the optical output power to 90 W with all other conditions being the same.**

Keywords: *semiconductor heterostructure, epitaxial integration, integrated laser-thyristor, output power.*

1. Introduction

Recent advances in epitaxial technologies, in particular, MOCVD, make it possible to form complex semiconductor heterostructures required for developing devices with improved characteristics [1]. A successful example of practical implementation of new semiconductor heterostructures in quantum electronics is the development of vertically integrated semiconductor lasers with several emitting regions. In these devices, several independent laser sections are connected in series by tunnel junctions, which multiply increases the quantum efficiency. The development of this approach after demonstration of the principal possibility of epitaxial integration of several emitting regions [2, 3] led to the fabrication of various devices with high output characteristics [4 – 6]. In particular, the quantum efficiency was increased by 1.7 – 2.0 times for lasers with two active regions, by 2.5 – 3.0 times for lasers with three active regions and by 3.4 – 4.0 times for lasers with four regions [7 – 9]. Laser diode arrays made of the mentioned heterostructures allowed one to achieve a pulsed output power exceeding 1 kW [6, 10]. As a rule, the emitting regions in such devices are identical, but there are no obstacles to development of a device in which each of the laser sections emits at each own wavelength, which extends the range of possible applications of these light sources [11, 12].

Epitaxial integration also opens the way to combining several functionally different components in one crystal. For example, to control light pulses, it is necessary to introduce an electronic switch (dinistor, thyristor, transistor) [13 – 16] in the laser emitter. It is shown that, to miniaturise high-power light sources, increase their reliability and make the control the output characteristics more convenient, it is promising to integrate two successively formed structures (laser and thyristor) in a single growth process. Although the idea of producing these integral devices (lasers-thyristors) was proposed rather long ago [17, 18], their successful practical implementation became possible only with development of epitaxial technologies [19, 20]. Such lasers-thyristors demonstrated output powers of 50 – 60 W in a pulsed regime with a turn-on voltage of 15 – 20 V.

The present work is aimed at further development of the aforementioned approaches and at studying the possibility of epitaxial integration of several laser regions in one heterostructure with an electronic switch (thyristor) providing a pulsed operation regime.

2. Experimental

The InGaAs/AlGaAs/GaAs semiconductor heterostructures were formed on GaAs substrates by MOCVD. The heterostructure of a single laser-thyristor is described in [20], and its energy band diagram is schematically shown in Fig. 1a. Similarly to [7], the second laser section was added to the structure of a single laser-thyristor through a tunnel junction (Fig. 1b). The obtained heterostructures were used to fabricate stripe lasers-thyristors with the control contact to the *n*-collector [20]. The measurements were performed in a circuit with a capacitance of 0.47 μF in a pulsed regime (100 ns, 10 kHz).

The present study is focused mainly on increasing the output power of pulsed lasers-thyristors. Based on successful experience of making integrated laser diodes with several emitting regions [7 – 9], we developed heterostructures and used them to fabricate lasers-thyristors with two emitting regions in the laser section. By analogy with integrated laser diodes [7], let us call them double integrated lasers-thyristors or, for brevity, double lasers-thyristors. Figure 2 shows the current – voltage characteristics of single and double lasers-thyristors without passing a signal through the control section.

One can see that both devices have close turn-on voltages (18 – 20 V) because they have identical thyristor sections responsible for this parameter. The holding voltage is approximately two times higher in the case of a double laser-thyristor (~2.6 V) than in the case of a single laser-thyristor (~1.3 V),

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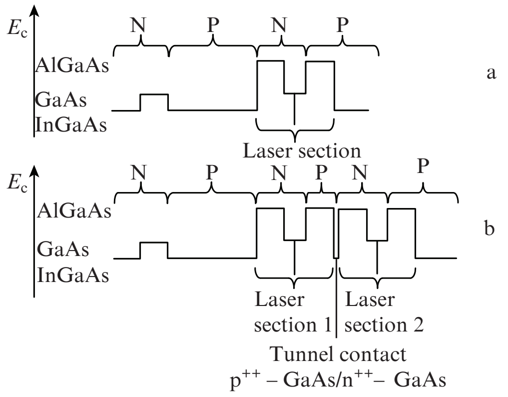

Figure 1. Energy band diagram of (a) single and (b) double laser-thyristor.

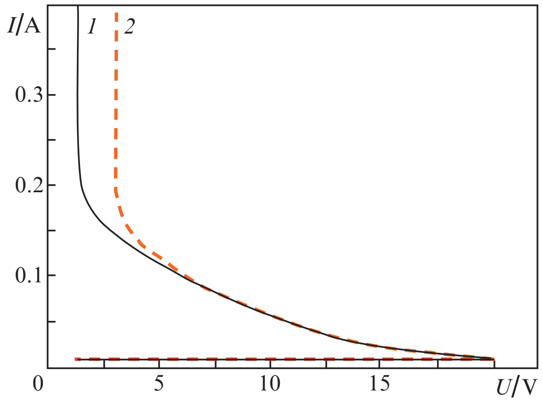

Figure 2. Current–voltage characteristics of (*1*) single and (*2*) double laser-thyristor.

which is caused by the existence of two p–n junctions in the laser section. It is important to note that the tunnel junction connecting the two laser sections makes no considerable contribution to the increase in the holding voltage of the double laser-thyristor.

At the same time, the slope of the light–current characteristic of the double laser-thyristor is by 1.5–1.8 times higher than that of the single one (Fig. 3). The corresponding increase in the slope for double integrated lasers without a thyristor part was somewhat more pronounced, i.e., 1.7–2.0 times. The difference between these values is caused by loss of carriers in the control section. The output optical power of the double laser-thyristor reached 90 W in a pulsed regime (100 ns, 10 kHz).

The temperature stability of the double laser-thyristor operation is illustrated in Fig. 4. It is seen that the laser-thyristor stably operates in the temperature range from −60°C to + 60°C.

Our experiments show that an increase in the number of emitting regions positively affects the output power of the laser-thyristor and opens the way to a further increase in the output power by, for example, designing a triple laser-transistor.

Thus, we presented the results of fabrication and study of a double integrated laser-thyristor. A thyristor (controlling) and two laser (emitting) parts are combined in one heterostructure. It is shown that, other conditions being equal, this device is characterised by a 1.5–1.8-fold higher quantum efficiency that that of a single laser-thyristor in a pulsed regime, as well as by reliable operation in a wide temperature range.

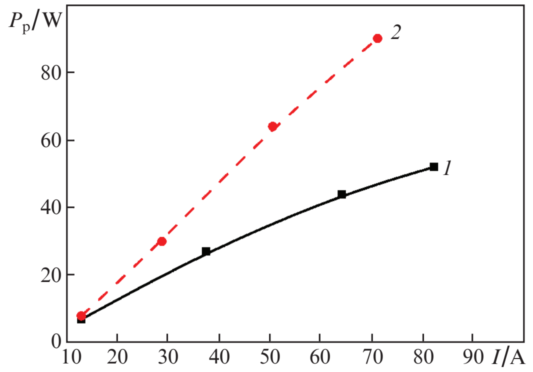

Figure 3. Light–current characteristics of (*1*) single and (*2*) double laser-thyristor in a pulsed regime (100 ns, 10 KHz).

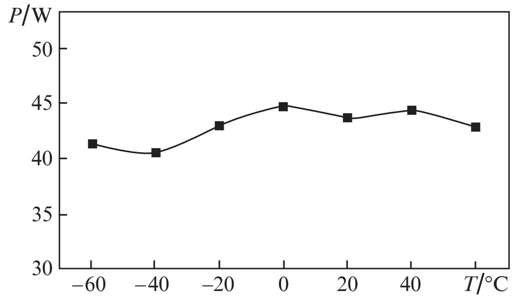

Figure 4. Temperature dependence of the output power of a double laser-thyristor at different turn-on voltages.

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