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Triple integrated laser–thyristor

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Abstract. **A triple laser–thyristor, i.e., a semiconductor laser with three emitting sections monolithically integrated with an electronic switch (thyristor) is experimentally studied. For comparison, the output characteristics of single and double laser–thyristors are presented. It is shown that the functional integration of a laser with a thyristor in one heterostructure allows the laser to efficiently operate in a pulsed regime (output power ~50 W), the use of vertical integration of two laser sections increases the power to ~90 W, and the integration of three laser sections makes it possible to increase the output optical power to ~120 W with all other conditions being the same.**

Keywords: *integrated laser–thyristor, output power, heterostructure, quantum well.*

1. Introduction

The formation of combined heterostructures containing several functionally different components in one growth process is a promising way to develop monolithically integrated compact devices with improved characteristics. Recently, integrated lasers–thyristors based on heterostructures containing simultaneously thyristor and laser components have been extensively studied. Owing to the introduction of an electronic switch in the laser scheme, this integration helps to solve the problem of control of light pulses [1, 2]. Similar lasers–thyristors with a turn-on voltage of 15–25 W demonstrated an output power up to 50 W in a pulsed regime [3, 4].

There are known successful attempts to develop vertically integrated semiconductor lasers with several emitting regions. In these devices, individual laser sections are serially connected via tunnel junctions, which multiply increases the quantum efficiency. For example, it was reported that the quantum efficiency of lasers with two and three active regions increases by 1.7–2 and 2.5–3.0 times, respectively [5–7].

Combining the described approaches, we demonstrated a double laser–thyristor containing two laser sections and a thyristor (controlling component) [8]. This device at a turn-on voltage of ~20 V reached an output power of ~90 W in a pulsed regime (100 ns, 10 kHz). The quantum efficiency increased by 1.5–1.8 times in comparison with a single laser–thyristor with other conditions being the same.

The present work is devoted to further development of the mentioned approaches and is aimed at the study of the possibility of creating a triple laser–thyristor using epitaxial integration of three laser sections with a thyristor responsible for pulsed operation in one heterostructure.

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2. Experiment

The InGaAs/AlGaAs/GaAs semiconductor heterostructures were grown on GaAs substrates by MOCVD. The active region of the laser section consisted of one InGaAs quantum well positioned in the centre of an AlGaAs waveguide 0.4 μm thick. The waveguide was sandwiched between two wide-gap AlGaAs cladding layers. The thyristor section contained a wide-bandgap AlGaAs emitter and a narrow-gap GaAs base 4 μm thick. The N emitter layer of the laser section simultaneously served as a wide-bandgap N collector of the thyristor section. The heterostructure design of the single laser–thyristor is described in more detail in [4], while the energy band diagram of this heterostructure is schematically shown in Fig. 1a.

To form a double laser–thyristor, the second laser section of the same geometry was connected to the single laser–thyristor via a tunnel junction (Fig. 1b) [8]. Figure 1c shows the energy band diagram of a triple laser–thyristor, in which one more laser section was added to the double laser–thyristor via, as before, a tunnel junction. The obtained heterostructures were used to fabricate stripe lasers–thyristors with the control contact to the n-collector [4]. The measurements were performed in a circuit with a capacitance of 0.47 μF in a pulsed regime (100 ns, 10 kHz).

3. Results and discussion

Successful experience of designing double lasers–thyristors [8], which demonstrated an almost twofold higher differential quantum efficiency than single lasers–thyristors, initiated the present study aimed at searching for ways to further increase the output power of such devices. Based on the results of development of integrated laser diodes with several emitting regions [6], we have grown heterostructures for lasers–thyristors containing three emitting regions in the laser section. For comparison, we also made single and double lasers–thyristors with the same dimensions of the active emitting elements. Figure 2 shows the current–voltage characteristics of the studied lasers–thyristors in the absence of signal transmission through the controlling section.

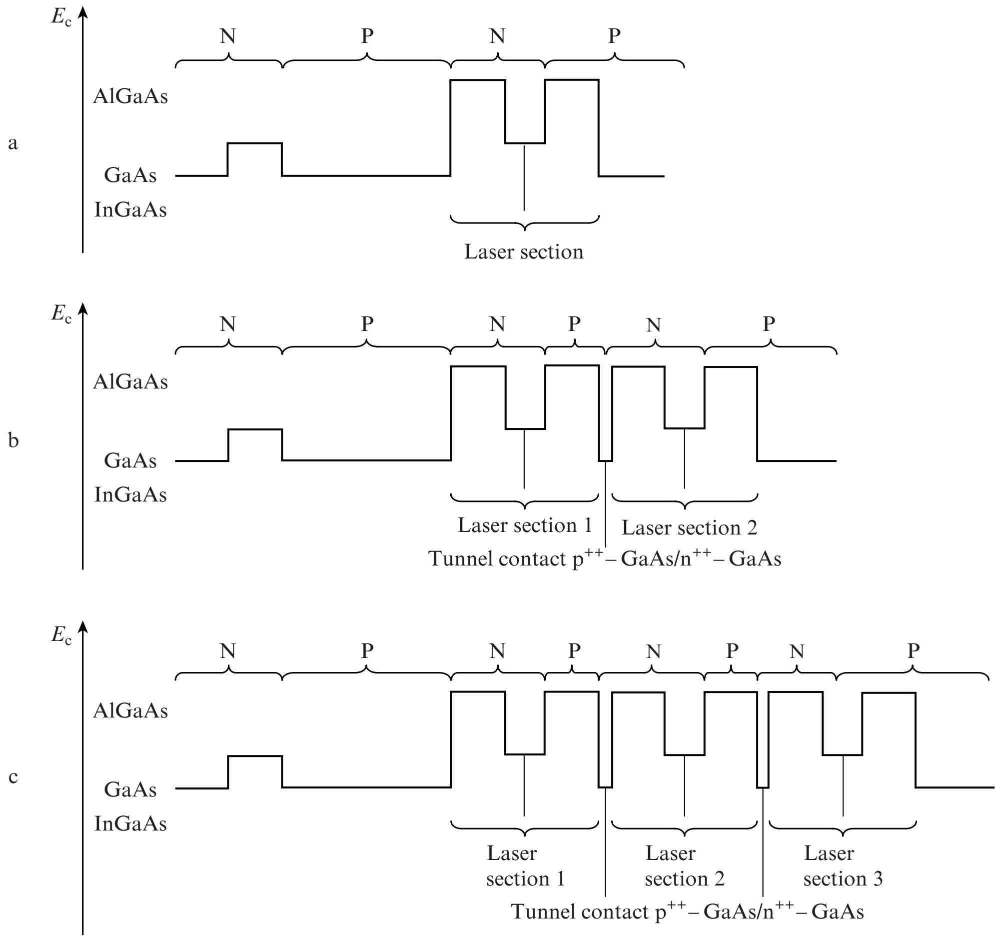

Figure 1. Energy band diagrams of (a) single, (b) double, and (c) triple lasers–thyristors.

One can see that all devices have close turn-on voltages (18–20 V) because they all have identical thyristor sections responsible for this parameter. The on-state voltages in double (~2.75 V) and triple (~4.1 V) lasers–thyristors are higher than that in a single laser–thyristor (~1.37 V) approximately by factors of two and three, respectively, which is caused by the presence of, correspondingly, two and three p–n junctions in the laser section. It is important to note that, in the case of both double and triple lasers–thyristors, the existence of tunnel junctions did not negatively affect the on-state voltage.

The light–current characteristics (LCCc) of the studied lasers–thyristors are presented in Fig. 3. These characteristics were obtained by varying the turn-on voltage of the las-

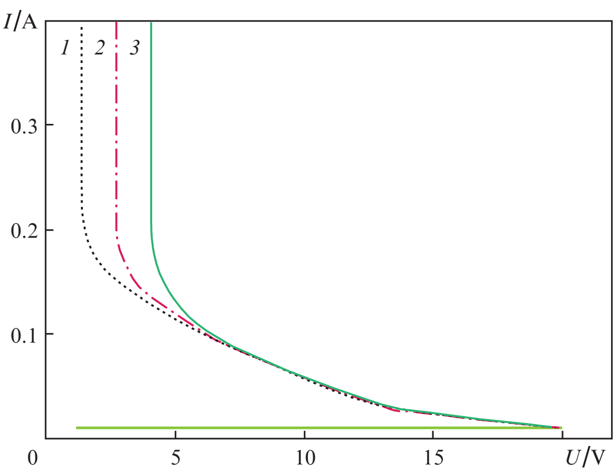

Figure 2. Current–voltage characteristics of (*1*) single, (*2*) double, and (*3*) triple lasers–thyristors.

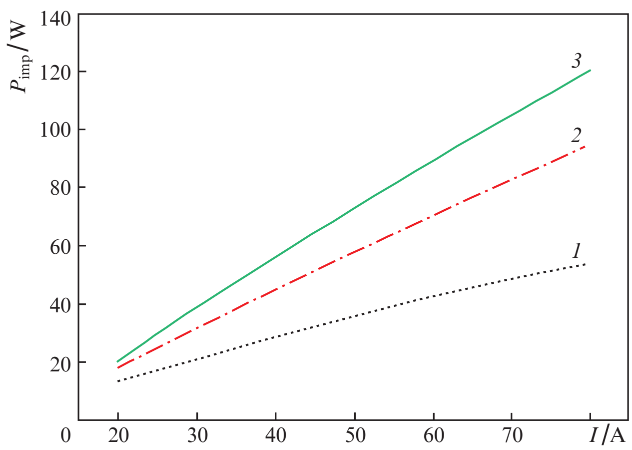

Figure 3. Light–current characteristics of (*1*) single, (*2*) double, and (*3*) triple lasers–thyristors in a pulsed regime (100 ns, 10 kHz).

ers–thyristors by applying a signal to the controlling section. The peak current was determined by variation of the capacitor voltage. One can clearly see a difference in the slopes of the curves corresponding to different numbers of integrated laser sections. In particular, the slope of the LCC of the double laser–thyristor at the initial stage exceeds the corresponding slope of the single device by 1.7 times, while the slope of the LCC of the triple laser–thyristor is even 2.3 times higher. The corresponding increase for integrated lasers without a thyristor section was somewhat larger, namely, 1.7–2.0 times for double and 2.5–3.0 times for triple lasers [5–7]. This difference is probably caused by loss of carriers in the control section. The output optical power of the triple laser–thyristor reached 120 W in a pulsed regime (100 ns, 10 kHz).

Note a specific feature of the LCC behaviour depending on the number of emitting sections. Although the LCC slope for the triple laser–thyristor at the initial stage exceeds the LCC slope of the single laser–thyristor by 2.2–2.4 times, the output power of the triple laser–thyristor at high pump currents (80 A) exceeds the output power of the single device even by about 3 times. This is related to a faster saturation of the LCC of the single laser–thyristor with increasing the pump current than in the case of devices with several emitting sections, which is clearly seen from the slope of curve (*1*) in Fig. 3. This LCC behaviour was not observed in integrated lasers without a control section [9], the existence of which was probably responsible for the described effect.

All the samples emitted in the region of 900 nm because they were based on identical InGaAs quantum wells. The far-field divergence of the lasers–thyristors at half maximum was 26–29° in the plane perpendicular to the p–n junction and 6–8° in the plane parallel to the p–n junction. The directional pattern of these devices is determined by the design of the laser section. At the same time, the divergence does not depend on the number of laser sections and the presence of the thyristor component.

Our experimental results show that an increase in the number of emitting laser sections facilitates an increase in the output power of lasers–thyristors, namely, the triple lasers–thyristors demonstrated a threefold increase in the output power (120 W) in comparison with single lasers–thyristors (40 W).

Thus, we have studied the developed triple integrated lasers–thyristors. A thyristor (controlling) and three laser (emitting) sections are combined in one heterostructure. It is shown that this device, all other things being equal, is characterised by a 2.2–2.4 times higher quantum efficiency with respect to a single laser–thyristor in a pulsed operation regime and can achieve an output optical power of 120 W.

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