RADIATION SPECTRA AND THE QUALITY EVALUATION OF A HIGH-POWER LASER DIODE WHEN ENTERING THE OPERATING MODE

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Abstract. A method for evaluating the quality of the heterostructure of a high-power 200 MW laser diode based on measurements of radiation intensity spectra in the over-threshold generation mode is proposed. The method is based on the fixation and analysis of groups of generation modes related to spatial radiation channels. The spectra are measured at different pumping currents, which are lower than the standard, for a short (no more than 30 min) time interval.

Keywords: *semiconductor laser, high-power laser diode, frequency spectrum, degradation, coherence*

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INTRODUCTION

High-power laser diodes (LDs) with radiation output via optical fibers are widely used in fiber-optic communication lines, for pumping lasers generating in different ranges of the optical spectrum, as well as in medical laser devices. Such lasers are usually considered to be all lasers with a 1 μm wide strip of electrical contact that emits radiation with a power of 10 mW or more [1].

The most important technical and economic parameter of LD is the service life.

The most commonly used technique is the classical method of controlling the state of the LD heterostructure and predicting its lifetime. It is based on analyzing the time dependences of the emission power while maintaining a constant pump current. The lifetime in this case is defined as the time after which the power drops to a certain, predetermined level (as a rule, twice as compared to the initial value) [2].

In addition to the classical methodology, the methodology for determining the lifetime of the laser is quite often used, which is based on maintaining its radiation power at a constant level by increasing the pump current. The laser lifetime is taken as the laser operating time, after which it becomes impossible to maintain the power at a constant level [2].

Much less frequently, the methods based on the analysis of time dependences of the radiation pattern and the degree of linear polarization of radiation (contrast) are used to predict the LD service life [3-5].

However, the implementation of the above techniques is associated with a significant consumption of LD resource and does not allow solving the problem of rapid determination of the quality of a single laser - a fundamental problem, without the solution of which it is impossible to ensure high-quality mass production of electronic devices [6].

That is why for several decades in the leading scientific centers of the Russian Academy of Sciences: FIAN in Moscow and A.F. Ioffe Physical-Technical Institute in

St. Petersburg have been paying the closest attention to the development and improvement of new techniques for controlling the state of LD heterostructure and predicting their service life.

One of the earliest works devoted to the development of a new methodology for optimizing the parameters of single-mode LDs based on quantum-size heterostructures of split confinement is [7]. In this work, the laser radiation patterns in the *p-n junction* plane and in the plane perpendicular to it at different levels of output optical power are considered in detail. The spectra of LD emission at two values of the resonator length and pump current equal to twice the threshold current $I_{th}$are also presented. The criteria for determining single-mode laser generation mode by its radiation pattern and emission spectrum are formulated. It follows from the comparison of these criteria that the violation of the single-mode mode of LD generation caused by the deterioration of its heterostructure is most clearly manifested in the laser spectrum.

High sensitivity of spectral characteristics of different types of laser diodes to degradation processes occurring in their heterostructure allows us to use time dependences of LD emission spectra in predicting their service life.

That is why during the last five years we have been engaged in the development of new techniques for controlling the state of LD heterostructure based on measurements and analysis of their emission spectrum [8-14].

TECHNIQUES FOR CONTROLLING LASER DIODE DEGRADATION

In [8], a technique for measuring the degradation rate of a high-power continuous laser with a wide contact by monitoring the state of its heterostructure every fifty hours of operation at a fixed pump current is considered. The number of laser generation channels determined by the emission spectrum is proposed to be used as a controlled parameter. It has been experimentally established that the number of generation channels increases with increasing laser operation time. We attribute the increase in the number of generation channels to the decrease in the coherence length of LD radiation caused by the growth of internal losses, which is a characteristic sign of laser degradation.

It is also experimentally established that the degradation rate increases with increasing pumping current. This is confirmed by the appearance of an additional LD generation channel at a fixed operating time.

An algorithm has been developed to determine the optimal value of the pumping current of an LED, which ensures its long lifetime [8,9]. The algorithm takes into account that the emission spectrum of a high-power LED is characterized by a complex type of its envelope and represents a superposition of the emission spectra of the individual generation channels. Analysis of the radiation spectrum in each generation channel makes it possible to determine the value of the integral parameter A_i, *which* is a quantitative measure of the difference between the line contour enveloping the radiation spectrum in the channel and the Gaussian function [5].

It was shown in [9] that the emission spectrum in each generation channel is close to the generation spectrum of a single-mode laser, and therefore LD can be formally represented as a set of single-mode lasers with the number of emitting elements changing during the operation.

For each i-th emitting element, we apply a method of fast prediction of the lifetime of a single-mode laser by the value of the integral parameter $A_{(\mathrm{onset})\,(i)}$in the initial period of laser operation [5]. We use the fact that the lifetime of a single-mode laser is shorter the smaller the value of the parameter $A_{(\mathrm{onset}).}$Since a decrease in the parameter $A_{\mathrm{onset}}$of even one of the emitting elements leads to a deviation of the LD emission spectrum from the optimal one, the laser lifetime is determined by the smallest value of the parameter $A_{(\mathrm{onset})\,(i)}$.

If the values of the parameter $A_i$in all generation channels are close to unity, it indicates a high quality of the LD heterostructure and that the LD operates at the optimal pumping current.

Thus, it has been established that the current dependence of the radiation spectrum at the initial stage of LD operation can be used along with the time dependence of the number of radiation generation channels as a parameter that can be used to determine the heterostructure state of a particular serial high-power LD. This considerably simplifies the diagnostics of LDs for their durability.

The methodology of current control of heterostructure state in the process of its slow degradation is described in [11,12]. It is taken into account that noticeable signs of LD degradation appear after two or three thousand hours of operation. Therefore, the time dependence of the heterostructure state is determined using accelerated aging of devices at elevated ambient temperature. However, in the course of accelerated aging tests of LDs their resource is rapidly consumed, which does not allow to solve the problem of determining the quality of a particular LD without consuming a significant part of the lasers' resource. The increase in the resolving power of the MDR-

23 spectral instrument allowed us to distinguish the fine and coarse structure of the spectrum in the emission spectrum of a high-power LD [12, 13]. Due to this, the relationship between the spectrum parameters and internal parameters of structure of the laser, changing in the process of device degradation, has been established and experimentally verified. It has been experimentally shown that during LD degradation there is a significant growth of internal losses, which is expressed in the deterioration of the radiation coherence, enrichment of the radiation spectrum, appearance of new spatial structures in the form of new unrelated in phase generation channels, broadening of spectral lines of longitudinal modes.

Two new factors that can be used for fast diagnostics of the laser diode resource depletion by its emission spectrum have been established: the width of the spectrum of a separate longitudinal mode and the number of peaks of the coarse structure of the spectrum. Simultaneous use of two (with power - three) aging criteria allows to increase considerably the accuracy and degree of reliability of determination of the moment of the beginning of unacceptable degradation for a given device and the necessity of LD replacement.

In the present work, the main attention was paid to the development of a technique for determining the quality of a high-power laser diode by the current dependence of its emission spectrum in the process of the laser entering the operating mode at pump currents up to four times the threshold.

EXPERIMENT

The experimental results of the emission spectra of two LDs from the new batch of devices are shown in Figs. 1a,b and 2a,b.

Comparison of the emission spectra of LD 1002 and 1005 at the same pump currents allows us to conclude about the quality of these lasers. Thus, at a pump current of 180 mA, LD 1002 has one generation channel (Fig. 1a), and LD 1005 has six channels (Fig. 2a). At a pumping current of 250 mA the number of channels in these lasers increases to two and eight, respectively. According to the previously developed methodology for determining heterostructure quality [11,12], LD 1002 has a higher quality than LD 1005. Quantitatively, such a difference will manifest itself in a significant difference in the lifetime of the lasers under consideration.

The transformation of LD spectra when the pump current is changed allows us to draw some conclusions about the quality of the devices.

After overcoming the generation threshold with pumping current growth, there is a gradual increase in both the spatial and spectral generation region. First, new groups of longitudinal modes united into spatial generation channels appear and switch, accompanied by a general shift to the long-wave region; second, the spatial region of generation increases due to the appearance of new channels without their narrowing. The spectral interval of amplification of the active medium also increases, which is manifested in the appearance of new groups of longitudinal modes.

An important experimental result in this study is the fact that the widths of the individual generation channels should and do remain constant under suprathreshold pumping current variation. This is due to the very specific value of the losses in the resonator, which depend weakly on the pumping current. At the same time, these losses are different in the two devices under study, which we observe in the experiment.

To obtain more accurate estimates of the heterostructure quality of high-power LDs, the above studies should be supplemented with measurements of the spatial parameters of LD radiation, especially in the near field.

CONCLUSION

Thus, we have proposed a method for evaluating the quality of a high-power laser diode heterostructure based on the analysis of the emission intensity spectra obtained at pump currents not exceeding four threshold values. It is shown that using this method, it is possible to judge both the quality of the heterostructure of a laser diode with zero operating time and its maximum operating time in the normal mode.

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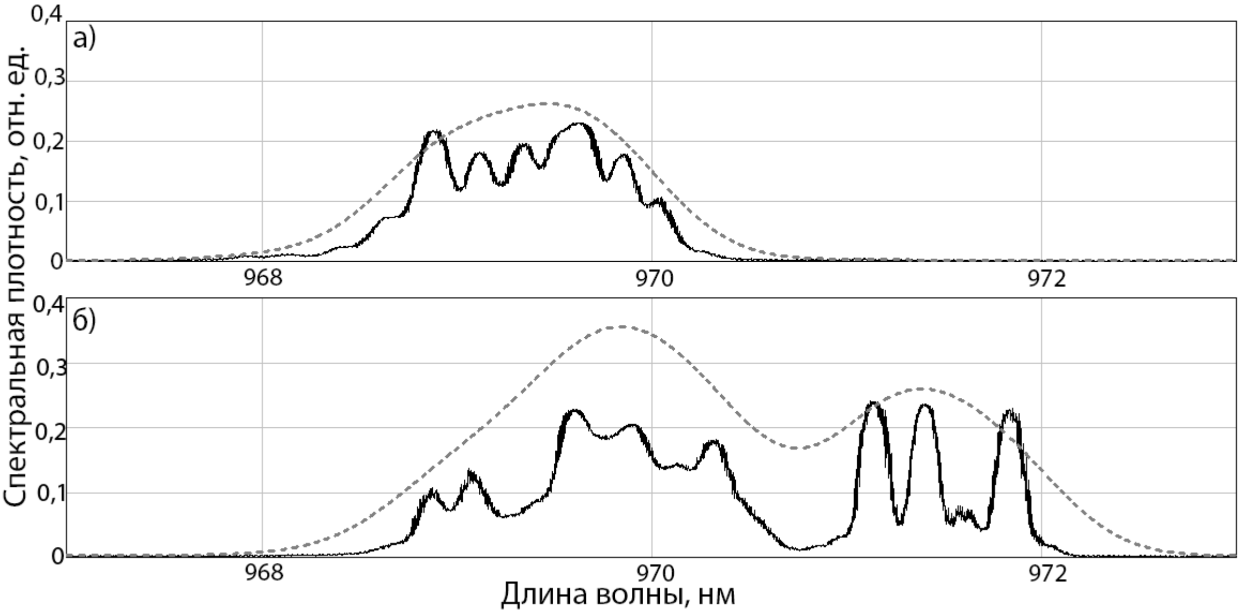
FIGURE CAPTIONS

Fig. 1. Spectra of LD 1002 at pump current: 180 (a) and 250 mA (b).

Fig. 2. Spectra of LD 1005 at pump current: 180 (a) and 250 mA (b).


а)
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Спектральная плотность, отн. ед.
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968
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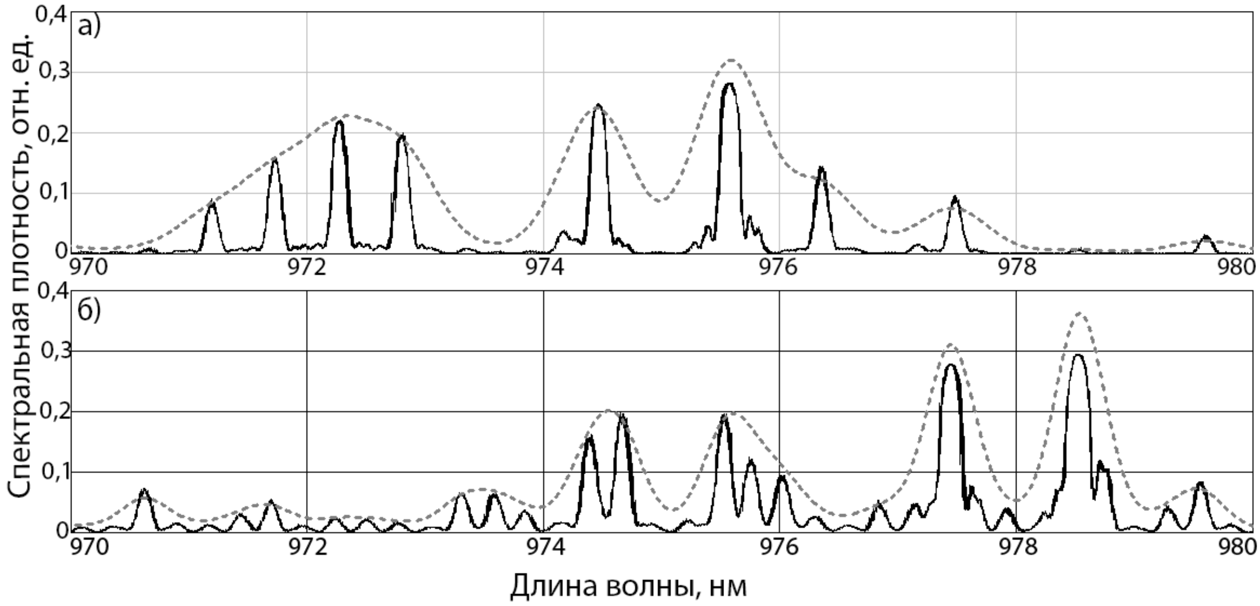
Длина волны, нм

Fig. 1.


а)
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Спектральная плотность, отн. ед.
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970
972
974
976
978
980
Длина волны, нм

Fig. 2.