Prediction of life time of high-power IR laser diode by resolution of its spectrum to single-mode components

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Abstract. The paper proposes a method for predicting the service life of high-power laser diodes used in optoelectronic measuring systems which allow adjusting the thermophysical parameters of the diagnosed flow volume in a certain range of their values. The method based on the analysis of the current dependence of the shape of the line enveloping the laser radiation spectrum after 200 hours of their operation. It is shown that for such an analysis the emission spectrum must be considered as a superposition of the emission spectra of single-mode laser diodes.

1. Introduction
One of the promising directions for the development of optoelectronic measuring systems used for the study of flows is the development of active systems that allow adjusting the thermophysical parameters of the diagnosed flow volume in a certain range of their values. As a controlled source of heat flow in such systems it is possible to use IR laser diodes (LDs) with a continuous generation power from several hundred milliwatts to units of watts [1–4]. At the same time the task of predicting the service life of such lasers is updated.

The methods for predicting the lifetime of LDs developed so far are associated with a significant expenditure of the lasers resource and the use of laborious statistical methods for processing large arrays of numbers. This does not solve the fundamentally important problem of determining the quality of a LD individual active element which is especially acute in the serial production of lasers.

To solve the problem we propose a method for quickly predicting the service life of a particular LD instance based on the analysis of the shape of the line that envelopes its radiation spectrum after 200 hours of operation.

2. Description of laser diode life time prediction method by spectrum analysis of its radiation at various pump current
As can be seen in figure 1 high-power LDs are characterized by a complex shape of the $f_{\text{emp}}(\nu)$ line which envelopes its emission spectrum. This excludes a simple interpretation of the current dependence of the $f_{\text{emp}}(\nu)$ function and therefore the possibility of predicting the particular laser instance service life.
However the situation changes dramatically if the radiation spectrum is represented as a superposition of \( N \) components each of which has a profile of the \( f_i((v − v_{0i})/Δv_i) \) line that envelopes the radiation spectrum of a single-mode laser with a central \( v_{0i} \) frequency

\[
f_{\text{emp}}(v) = \sum_{i=1}^{N} f_i\left(\frac{v-v_{0i}}{\Delta v_i}\right). \tag{1}
\]

We have experimentally established that the current dependence of the line shape \( f_{\text{emp}}(v) \) manifests itself in a change in the ratio of the amplitudes of the spectral components and the width of the emission line \( f_i((v − v_{0i})/Δv_i) \) as well as in a change in the number of such components with an increase in the pump current.

![Figure 1](https://doi.org/10.1088/1742-6596/2127/1/012046)

**Figure 1.** The line envelope of the radiation spectrum of the laser diode ATC-C200-100-980 with an operating time of 200 hours, and the single-mode components of the spectrum at two values of the pump current: \( a = 940 \) mA, \( b = 980 \) mA.

As an illustration of this process figure 1 shows the contours of the \( f_{\text{emp}}(v) \) line which envelopes the emission spectrum of a high-power LD and the \( f_i((v − v_{0i})/Δv_i) \) lines at two values of the pump current. It can be seen that with an increase in the pump current, the spectral characteristic of the LD undergoes significant changes. Instead of the four terms on the right side (1) you need to use five terms to form the \( f_{\text{emp}}(v) \) function.

Figure 2(a) shows the first component of the LD radiation as a curve \( f_1((v − v_{01})/Δv_1) \) at a pump current of 940 mA. The same figure shows a Gaussian curve \( f_G((v − v_{01})/Δv_1) \) the width of which \( Δv_1 \) is equal to the width of the curve \( f_1((v − v_{01})/Δv_1) \). It can be seen that the curves \( f_1((v − v_{01})/Δv_1) \) and \( f_G((v − v_{01})/Δv_1) \) differ slightly from each other. The current dependence of the parameters \( v_{01} \) and \( Δv_1 \) is taken into account by introducing the designations \( v_{01}/940 \) and \( Δv_{01}/940 \) indicating that the parameters of the curves \( f_1((v − v_{01})/Δv_1) \) and \( f_G((v − v_{01})/Δv_1) \) are determined at pump currents of 940 mA. Figure 2(b) shows the first component of the LD radiation as a curve \( f_1((v − v_{01})/Δv_1) \) but already at a pump current of 980 mA. A change in the pump current leads to a change in the \( v_{01} \) and \( Δv_1 \) parameters. Therefore in the numerical analysis of the \( f_1((v − v_{01})/Δv_1) \) curve the designations \( v_{01}/980 \) and \( Δv_{01}/980 \) are used indicating that the parameters of the \( f_1((v − v_{01})/Δv_1) \) and \( f_G((v − v_{01})/Δv_1) \) curves are determined at pump currents of 980 mA. The same figure shows a Gaussian curve \( f_G((v − v_{01})/Δv_1) \), the width of which \( Δv_1 \) is
equal to the width of the curve \( f_1((v - ν_0)/Δν_1) \). It can be seen that the curves \( f_1((v - ν_0)/Δν_1) \) and \( f_G((v - ν_0)/Δν_1) \) at a pump current of 980 mA differ from each other to a greater extent than at a pump current of 940 mA.

Figure 2. Comparison of the Gaussian profile \( f_G((v - ν_0)/Δν_1) \) (point line) with the profile of the \( f_1((v - ν_0)/Δν_1) \) line, which envelopes the spectrum of the first component of the radiation of the powerful LD ATС-C200-100-980 with an operating time of 200 hours at a pump current: a – 940 mA; b – 980 mA.

To estimate the degree of deviation of the \( f_1((v - ν_0)/Δν_1) \) line shape from the \( f_G((v - ν_0)/Δν_1) \) curve at a fixed pump current it is proposed to use the integral \( A_i \) parameter.

The physical meaning of this parameter is the same as the \( A \) parameter which was introduced in [5–7] as a measure of the deviation of the experimentally determined spectral characteristic \( f_{emp}(v) \) of a single-mode laser diode from the normalized Gaussian function \( f_G((v - ν_0)/Δν_1) \) within the emission linewidth:

\[
A = 1 - \frac{1}{Δv} \int_{ν_1/2min}^{ν_1/2max} \left| \frac{f_{emp}(v - ν_0)}{f_G(ν_0)/Δν_1} \right| dv, \tag{2}
\]

where \( ν_1/2max \) and \( ν_1/2min \) – are the boundaries of the frequency range within which the values of the \( f_{emp}(v) \) function and the normalized Gaussian function are compared, and the value of the central frequency \( ν_0 \) of this range is calculated by the formula:

\[
ν_0 = \frac{1}{2}(ν_1/2min + ν_1/2max). \tag{3}
\]

According to the previously developed methodology for predicting the service life of single-mode LDs, the greater it is, the closer the value of the \( A_i \) parameter is to one [6-8].

As shown by the studies carried out in the framework of this work this algorithm cannot be used directly to predict the service life of a powerful LD. This is due to the fact that the spectral characteristic of such an LD can be represented according to (1) as the sum of several components each of which has a line profile \( f_i((v - ν_0)/Δν_1) \) which is characteristic of the radiation of a single-mode laser with a central \( ν_0 \) frequency and therefore is characterized by several values of the \( A_i \) parameter.

Thus a numerical analysis of each of the four curves \( f_i((v - ν_0)/Δν_1) \) shown in figure 1(a) shows that the corresponding \( A_i \) values lie in the range from 0.93 to 0.95. From the analysis of the five contours of the \( f_i((v - ν_0)/Δν_1) \) lines in figure 1(b), it follows that they correspond to the values of the parameter \( A_i \) varying from 0.82 to 0.86.
On the one hand it can be concluded that an increase in the pump current generally leads to a decrease in the $A_i$ parameters. But on the other hand due to the large number of $A_i$ parameters there is uncertainty when choosing the initial data from them which makes it extremely difficult to develop an algorithm for predicting the service life of the LD. Therefore to estimate the service life $\tau$ of a particular LD at a fixed pump current it is proposed to find the smallest of all the values of the $A_i$ parameter and substitute it into an empirical formula similar to that used in [5–7]

$$\tau/\tau_{\text{max}} = A_{\text{imin}}^m. \quad (4)$$

The method of finding the value of the $m$ parameter is similar to that used in the studies of a control batch of single-mode lasers consisting of 25 devices [5–7]. It is also based on the classical method of determining the service life $\tau$ of each LD as the time for which the laser radiation power is reduced by 20%. The LD with the longest service life $\tau_{\text{max}}$ is selected and the minimum value of the $A_i$ parameter is determined for it among all the components of its radiation spectrum. Then the smallest value of the $A_{\text{imin}}$ parameter is determined for each LD from the control batch, and the $m$ parameter is determined by iterating over the array of numbers.

Of practical interest is the development of a technique for quickly determining the optimal operating mode of a powerful LD without unproductive consumption of its resource. This technique should be based on the determination of the LD parameters in as little time as possible from the beginning of laser operation. Therefore instead of the slowly varying $A$ parameter in this work we use the parameter $A_{\text{initial}}$ which characterizes the degree of difference of the function $f_{\text{emp}}((v - v_0)/\Delta v)$ from the Gaussian function at the initial stage of the single-mode laser diode operation that is for a time not exceeding 200 hours [5–7].

It follows from (4) that an increase in the pump current of the LD decreases its service life. However when solving a number of applied problems it becomes necessary to increase the LD power which requires an increase in the pump current. Thus the problem arises of optimizing the power supply regime of the laser diode at which the maximum possible level of the LD radiation power is provided by an acceptable decrease in its service life. Ultimately the task of determining the optimal value of the pump current is actualized. A number of our group’s forthcoming papers will be dedicated to solving this problem.

3. Conclusion

In this work we have solved the problem of fast prediction of the LD service life by analyzing the emission spectrum of a multimode laser after 200 hours of operation at various pump current. It is shown that this kind of analysis can be carried out by expanding the emission spectrum of a multimode laser into emission spectra of single-mode components. It is shown that for laser diode life time increasing the pump current optimization is necessary.

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