Optimization of power supply mode of single-mode laser diode by ratio of current and integral spectrum parameter

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Abstract. Bursting development of the technological base of semiconductor quantum electronics determined the width of the domain for use of semiconductor lasers in optical-electronic measuring systems based on the optical methods of stream research. In order to improve the accuracy of such systems, it is proposed to use a simple technique for optimizing the supply mode of a single-mode laser diode, based on an analysis of the current dependence of its integral spectral parameter. It is shown that the optimal value of the pumping current appears when the radiation spectrum envelope line tends to match the normalized Gaussian curve within the width of the spectral line.

1. Introduction

The aim of this work is to develop a method for optimizing the power supply mode of laser modules with a single-mode laser diode based on the current dependence of the integral parameter \( A \). This parameter characterizes the degree of deviation of the \( f_{\text{emp}}((\nu - \nu_0)/\Delta \nu) \) function, which describes the shape of the line that envelopes the single-mode laser diode radiation spectrum, from the normalized Gaussian function \( f_G((\nu - \nu_0)/\Delta \nu) \) within the line width \([1, 2]\)

\[
A = 1 - \frac{1}{\Delta \nu} \left[ f_{\text{emp}}((\nu - \nu_0)/\Delta \nu) - f_G((\nu - \nu_0)/\Delta \nu) \right] d\nu,
\]

where \( \nu_{1/2\text{max}} \) and \( \nu_{1/2\text{min}} \) are the boundaries of the frequency range within which the values of the \( f_{\text{emp}}((\nu - \nu_0)/\Delta \nu) \) function and the normalized Gaussian function are compared, and the value of the central frequency \( \nu \) of this range is calculated by the formula

\[
\nu_0 = \frac{1}{2} (\nu_{1/2\text{min}} + \nu_{1/2\text{max}}).
\]

Of practical interest is the development of a method for quickly determining the optimal mode of operation of a single-mode laser diode without unproductive consumption of its resource. Such a technique should be based on determining the parameters of a single-mode laser diode in as little time as possible from the beginning of laser operation. Therefore, instead of the slowly changing parameter...
A, we use the parameter $A_{\text{initial}}$, which characterizes the degree of difference between the $f_{\text{emp}}(\nu - \nu_0)/\Delta \nu$ function and the Gaussian function at the initial stage of operation of a single-mode laser diode, that is, for a time not exceeding 200 hours [1].

With the optimal power supply mode of the laser module (hereinafter referred to as the LM), which includes a single-mode laser diode, the required level of radiation power and its stability must be provided while maintaining a stable laser beam profile, as well as a long laser service life [3, 4]. To meet all these requirements, it is necessary to ensure the optimal pumping current of the laser diode $I_{\text{pump\,optimal}}$ [5].

2. Method for optimizing the power supply mode of laser modules based on the current dependence of the integral spectral parameter $A_{\text{initial}}$

When determining the optimal value of the pump current $I_{\text{pump\,optimal}}$, it was taken into account that the service life of the LD with the $A_{\text{initial}}$ parameter close to one is maximum [1], and the current value itself must be searched for in the operating range of the pump current $I_{\text{pump\,optimal}}$.

To determine the limits of this range, the volt-ampere characteristic and the watt-ampere characteristic of the LM are considered [4–6].

The volt-ampere characteristic is clearly divided into two parts. First, there is a sharp dependence of the pump current on the voltage on the driver $U_{\text{drive}}$ [5, 6], then – extremely weak. Of practical interest is the flat part of the volt-ampere characteristic corresponding to the values of the voltage $U_{\text{input}}$ at the input of the driver, at which it operates in the mode of limiting the pump current. When the LM operates in this mode, high stability of the pump current and, as a result, the radiation power of a single-mode laser diode is ensured.

![Figure 1. Determination of the optimal pump current of a single-mode laser diode: $I_{\text{pump\,min}}$ – pump current; $U_{\text{drive}}$ – voltage on the LM driver; $U_0$ – opening voltage of the LD; $U_{\text{threshold}}$ – threshold voltage value at which the threshold pump current $I_{\text{threshold}}$ is reached; $U_{\text{min}}$ – minimum voltage value on the LM at which the transition to the flat part of the volt-ampere characteristic is carried out; $U_{\text{max}}$ – recommended in the passport value of the voltage on the LM; $I_{\text{pump\,optimal}}$ – optimal value of the pump current; $I_{\text{pump\,min}}$ and $I_{\text{pump\,max}}$ – limits of the operating range of the pump current; $\Delta U$ – voltage range from $U_{\text{min}}$ to $U_{\text{max}}$. $A_{\text{initial}}$ is the integral parameter $A$ in the initial stage of operation of a single-mode laser diode; $A_{\text{initial\,min}}$ and $A_{\text{initial\,max}}$ – the value of the parameter $A$ at the pump currents $I_{\text{pump\,min}}$ and $I_{\text{pump\,max}}$.](image-url)
The lower current limit of the flat part of the volt-ampere characteristic of the pump $I_{\text{pump min}}$ is defined as the pump current, at which a sharp decrease in the derivative of the pump function begins $I_{\text{pump}}(U_{\text{drive}})$ by $U_{\text{drive}}$, and the upper limit $I_{\text{pump max}}$ – as the current at the input of the LM when the voltage $U_{\text{operating}}$ specified in the technical data sheet is applied to it.

At the final stage of determining the operating range of the pump current $\Delta I_{\text{pump optimal}}$, an extremely important additional condition was used – the range boundaries must be within the linear part of the watt-ampere characteristic of the LM.

The search for the optimal value of the pump current of a single-mode laser diode $\Delta I_{\text{pump optimal}}$ using the dependences $A_{\text{initial}}(I_{\text{pump}})$ was carried out in the entire range of $\Delta I_{\text{pump operating}}$. At the same time, the maximum value of the pump current was taken as the optimal value of the current, at which the maximum value $U_{\text{drive}}$ is still preserved and the radiation power lies within the range specified in the passport.

The algorithm for determining the pumping current of the single mode laser diodes, are optimal from the point of view of increasing its service life, illustrated in figure 1.

Use this sequence of actions:

1. Find the operating range of the pump currents of a single-mode laser diode $\Delta I_{\text{pump operating}}$, which overlaps with the flat part of the volt-ampere characteristic of the LM and the linear part of its watt-ampere characteristic.
2. At the boundaries of this range, it is checked whether the single-mode generation mode is preserved in it.
3. If it persists, then the dependency $A_{\text{initial}}(I_{\text{pump}})$ is found.
4. This dependence determines the optimal pump current $I_{\text{pump optimal}}$.

3. Results of experimental studies of the current dependence of the integral spectral parameter $A_{\text{initial}}$

A batch of 22 single-mode laser modules KLM 650-5-5 was studied. Single-mode laser diodes, which are part of the LM, are manufactured in a single technological cycle. The use of the standard method for determining the range of linearity of the watt-ampere characteristic and the threshold current $I_{\text{threshold}}$ allowed us to establish that the range of pump currents found by analyzing the flat part of the volt-ampere characteristic $\Delta I_{\text{pump operating}}$ is located within the range of currents of the linear part of the watt-ampere characteristic. Therefore, the operating range of the pump currents of all LMS is determined by the boundary values of the pump current within the flat part of their volt-ampere characteristic [1]. The lower current limit of the flat part of the volt-ampere characteristic of the LM from the batch of devices varied from 25.3 to 26.1 mA. The values of the upper limit $I_{\text{pump max}}$ determined at the supply voltage at the input of the module $U_{\text{max}} = 5$ V, varied from 26.2 to 26.9 mA.

Figure 2 shows the results of measurements of the shape of the line $f_{\text{emp}}((v–v_0)/\Delta v)$ which envelopes the radiation spectrum of single-mode laser diodes from LM2, at several values of the pump current. Each line corresponds to a certain value of the integral parameter $A_{\text{initial}}$.

It can be seen that in the frequency range from $v_{1/2\text{min}}$ to $v_{1/2\text{max}}$ the value of the $A_{\text{initial}}$ parameter increases as the curves $f_{\text{emp}}((v–v_0)/\Delta v)$ and $f_{\text{c}}((v–v_0)/\Delta v)$ converge. The graph of the dependence $A_{\text{initial}}(I_{\text{pump}})$ for a single-mode laser diode included in LM 2 is shown in figure 3. This is curve 2. The analysis of this curve using the algorithm proposed in this paper for determining the optimal pump current $I_{\text{pump optimal}}$ of LM 2 allows us to find this value. It is equal to 26.1 mA.

Figure 3 also shows the characteristic dependencies of $A_{\text{initial}}(I_{\text{pump}})$ for four more LM instances: line 1 for LM3, line 3 for LM 6, line 4 for LM21, and line 5 for LM8. The analysis of these dependences using the algorithm proposed in this paper for determining the optimal LM pump current allows us to find this value. It is equal to 26.2 mA; 25.9 mA; 26.6 mA and 26.4 mA, respectively.
The values of $I_{\text{pump, optimal}}$ for all 22 LM samples from the studied batch of devices are shown in table 1. There are also the results of calculating the parameter $A_{\text{initial}}$ of each single-mode laser diode in the corresponding LM within the horizontal section of the curves $A_{\text{initial}}(I_{\text{pump}})$, as well as the current boundaries of the flat part of the volt-ampere characteristic of the laser modules.
Table 1. The results of the calculation of the parameter $A_{\text{initial}}$ and the definitions of: $I_{\text{pump min}}$ – the lower boundary of the shallow part of the volt-ampere characteristic; $I_{\text{pump optimal}}$ – the optimal pump current of a single-mode laser diode as part of the LM; $I_{\text{pump max}}$ – the pump current when the voltage on the driver LM5 W.

| № LM | $A_{\text{initial}}$ | $I_{\text{pump min}}$, mA | $I_{\text{pump optimal}}$, mA | $I_{\text{pump max}}$, mA |
|------|---------------------|-----------------|---------------------|-----------------|
| LM1  | 0.946               | 25.30           | 26.20               | 26.20           |
| LM2  | 0.966               | 25.60           | 26.10               | 26.50           |
| LM3  | 0.963               | 25.60           | 26.20               | 26.50           |
| LM4  | 0.937               | 25.90           | 26.70               | 26.70           |
| LM5  | 0.947               | 25.80           | 26.10               | 26.70           |
| LM6  | 0.938               | 25.50           | 25.90               | 26.40           |
| LM7  | 0.939               | 25.70           | 26.30               | 26.50           |
| LM8  | 0.959               | 25.90           | 26.40               | 26.80           |
| LM9  | 0.954               | 25.90           | 26.60               | 26.70           |
| LM10 | 0.945               | 26.00           | 26.10               | 26.80           |
| LM11 | 0.942               | 25.40           | 26.00               | 26.20           |
| LM12 | 0.956               | 26.10           | 26.10               | 26.90           |
| LM13 | 0.964               | 25.30           | 25.70               | 26.20           |
| LM14 | 0.962               | 25.90           | 26.40               | 26.80           |
| LM15 | 0.941               | 25.30           | 26.10               | 26.20           |
| LM16 | 0.951               | 25.80           | 26.70               | 26.70           |
| LM17 | 0.943               | 26.10           | 26.30               | 26.90           |
| LM18 | 0.960               | 25.90           | 26.70               | 26.70           |
| LM19 | 0.938               | 25.60           | 26.20               | 26.40           |
| LM20 | 0.955               | 26.00           | 26.70               | 26.90           |
| LM21 | 0.952               | 25.80           | 26.60               | 26.60           |
| LM22 | 0.965               | 25.40           | 26.20               | 26.20           |

It can be seen that the values of the $A_{\text{initial}}$ parameter at optimal pump currents of a single-mode laser diode varied from 0.937 to 0.966. The highest value of the parameter $A_{\text{initial}}$ is LD2. According to [1], this means that the single-mode laser diode from LM2 has the longest service life, and therefore the most perfect heterostructure.

4. Conclusion
A method for optimizing the LM power supply mode with a single-mode laser diode, based on the analysis of the dependence of the integral parameter of the $A_{\text{initial}}$ on the pump current, is considered. An algorithm for determining the optimal value of the pump current of a single-mode laser diode $I_{\text{pump optimal}}$ is formulated, according to which the optimal current is the highest value of the pump current, at which the $A_{\text{initial}}$ parameter still retains the maximum value, and the radiation power is closest to that specified in the passport. Optimization of the power supply mode of a laser module with a single-mode laser diode makes it possible to simplify and speed up the choice of its power supply mode, which ensures the required level of radiation power and its stability, as well as a long laser service life. All this makes it possible to increase the efficiency of the use of LM in optoelectronic measuring systems designed for the implementation of optical methods for studying flows.
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