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Researching of The Cause of Failure of Semiconductor Laser Diodes in Optical Communication Networks

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Abstract – This article analyzes the reasons for the failure of semiconductor laser diodes. Also, based on the experimental results, a mathematical model of the process of degradation in power of DFB-type laser diodes, widely used in optical communication systems, will be developed.

Keywords – Optical communication systems, degradation, reliability, wavelength division multiplexed optical communication systems, approximation.

I. Introduction

Currently, the telecommunication services market is one of the most harmoniously and actively developing sectors of economy of any state. The construction of corporate communication networks for commercial and government structures, the widespread penetration of the Internet, an increase in the number of users of cellular communication networks, the introduction and expansion of data storage networks, the liberalization of the long-distance communication services market - all this requires reliable and high-speed trunk communication channels.

Until recently, the main technology for building backbone communication networks was the technology of synchronous digital hierarchy (SDH, Synchronous Digital Hierarchy). Over the years, the bandwidth provided by SDH systems has proven insufficient to meet the ever-increasing demands of the telecommunications market. To increase the throughput of backbone channels, several options were considered, the most expedient of which was recognized as the option of introducing new transmission systems based on wavelength division multiplexing (WDM), which make it possible to simultaneously transmit several channels over a single fiber on different optical carriers. This made it possible to drastically increase the bandwidth, create an adequate supply of it, and provide ample opportunities for further development and scaling of the communication network.

II. Formulation of the Problem

Nowadays, the most widely used on backbone communication networks are dense wavelength division multiplexing systems (DWDM, Dense WDM). The International Telecommunication Union (ITU) issued ITU-T G.692 in October 1998 to standardize a set of optical DWDM carrier systems with spacing of 50 GHz (about 0.4 nm) and 100 GHz (about 0.8 nm). It provides for the division of the entire working area of the optical fiber into L, C and S bands. In the B and C ranges with a step of 0.4 nm, up to 100 channels can be placed, which, assuming the transmission speed in the range of 2.5 - 10 Gbit / s, gives the information capacity of one fiber 250 - 1000 Gbit / s. At the European Conference on Optical Communications (ECOC), held in September 2006, it was reported that the Japanese corporation NTT managed to achieve a total data transfer rate over one fiber of about 14 Tbit / s over a distance of 160 km. For this, 140 optical channels of 111 Gbit / s were used. Today the channel speed of a network built using DWDM technology can reach 100 - 600 Gbit/s, and the total bandwidth is 28 Tbit/s and more. It should also be noted that new systems are being investigated that support the 25 GHz interval and the 12.5 GHz interval. In such systems, the channel spacing decreases to 0.2 nm. This is why DWDM networks require very precise wavelengths of light to operate without inter-channel distortion or crosstalk. By transmitting traffic at such high speeds, modern backbone networks become vulnerable even to minimal and short-term communication interruptions. That is why there is a need for the timely development and implementation of measures to improve the reliability of DWDM communication networks.

The use of separate optical channels / optical wavelengths allows for high switching speeds and increases the efficiency of the backup system. Thanks to this, it becomes possible to implement in communication networks much more efficient schemes for organizing backup and recovery [1].

The creation of a redundancy system for the backbone network is inevitably associated with additional costs. The largest part of the cost comes from the network backup system, since it is the network backup that has the highest cost compared to other elements of the backup system and is used only in case of network failures. Therefore, it is necessary to develop a solution that will ensure high reliability of the communication network while maintaining an acceptable level of financial investment. All of these reasons confirm the relevance of issues of increasing the reliability of DWDM communication networks and the development of optimal solutions. As practice shows, the reliability indicators of a DWDM network largely depend on the reliability of the optical transmitting module, namely, on the radiation source in it. The increased reliability of this radiation source directly affects the reliability of the complete communication system. Today, DWDM networks use mainly DFB (Distributed feedback laser) type laser diodes. Laser diodes of the DFB type are distinguished by a small width of the emission spectrum, high emission power and stability of the emission spectrum. The main objective of this article is to study the main reasons for the failure of semiconductor laser diodes of the DFB type in an optical communication network. The study of the reasons for the rejection of laser diodes of this type makes it possible to determine the mathematical laws of the aging process. According to the established laws, it will be possible to predict the moment of failure of DFB lasers [2].

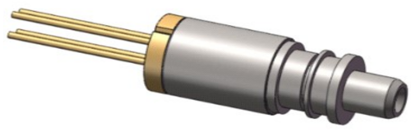

Fig.1. External view of a DFB type laser inside an optical transceiver

III. Methodology

There are several ways to speed up the study of the aging process of optical light sources:

- Thermal overload;
- Electrical overload.
- Optical overload and others.

In high-temperature tests, the LD is tested at temperatures above the allowable one. This accelerates the aging process and allows obtaining experimental results in a short time. However, it should also be borne in mind that not only an increase in temperature, but also a decrease in temperature can lead to failure of the LD. For example, lowering the temperature leads to a decrease in the threshold at a fixed pump current and to an increase in the radiation power up to critical values. As a result, the mirrors begin to be damaged. The result is optical overload. Thermal overload can sometimes interfere with optical overload because overheating reduces the radiation power (at a given pump level). In the general case, the watt-ampere characteristic of the LD can change during the aging of the LD as follows (Fig. 2). This can also occur, in particular, as a result of temperature instability [3].

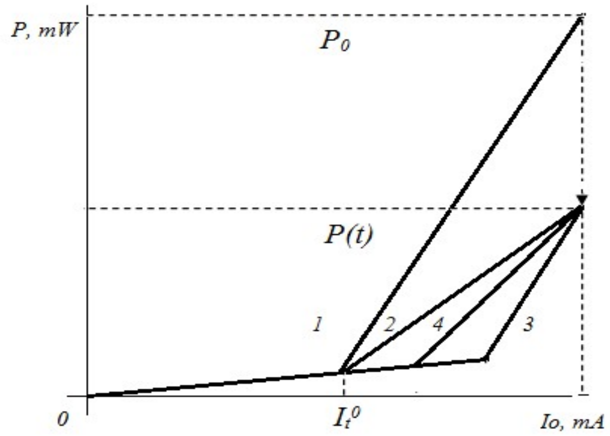

Fig.2. Change in the watt-ampere characteristic of a laser diode during aging of the laser

The graph of the dependence of the radiation power on the current shows possible examples of degradation with a concomitant change in the watt-ampere characteristic of the laser (curve 1 is the initial characteristic). The figure shows the power reduction in the constant (fixed) pump current mode I_0. Changes can occur due to either a decrease in the differential efficiency (line 2), or an increase in the threshold (line 3), or both at the same time (line 4). Here we are talking about degradation in power, whereas in principle, failures are also caused at constant power due to degradation of the spectral composition or dynamic characteristics.

The investigation of the process of failure of laser diodes is mainly carried out in one of two methods of work [4]:

- Automatic current control mode. In this method, the value of the current applied to the LD remains constant throughout the test;
- Automatic control of optical power. In this method, the value of the optical power at the laser output is kept constant by continuously adjusting the laser current.

When investigating the process of LD failure, the method of automatic current control was chosen. This method ensures that the value of the current supplied to the LD is constant. When the LD is tested at a high temperature, the radiation power decreases at a constant value of the current applied to the LD, as a result of an increase in its current threshold by determining the regularity of the change in power versus time, a mathematical law of the process of degradation of a laser diode in terms of power is formed. This is the mathematical law of the LD power failure process.

In the course of the testing, 8 DFB type LDs were stored in a high-temperature chamber with a constant operating current for 1000 hours. The chamber was kept at a constant temperature of 80ºC. At the beginning of the test, the lasers generated radiation with a power of 2 mW at an operating current I = 80 mA. During the test, the radiation power values LD were measured every 12 hours. As a result of measurements, it became clear that the average value of the radiation power received a set of the following values depending on time.

The graph of the dependence of the average value of the radiation power of laser diodes in time, obtained because of measurements, shows that the power value initially practically does not change. After a certain time, its value gradually decreases. As soon as the change in the radiation power of a certain value, its value again becomes almost unchanged. This represents the aging limit state of LD.

As a result of the approximation of the graph according to different laws, it will be possible to obtain different laws of the change in the amount of radiation for a laser diode in time. For example, approximating the resulting graph to an exponential law corresponding to its maximum leads to the following law of change:

$$P(t) = 2{,}1186e^{-0{,}009t}$$

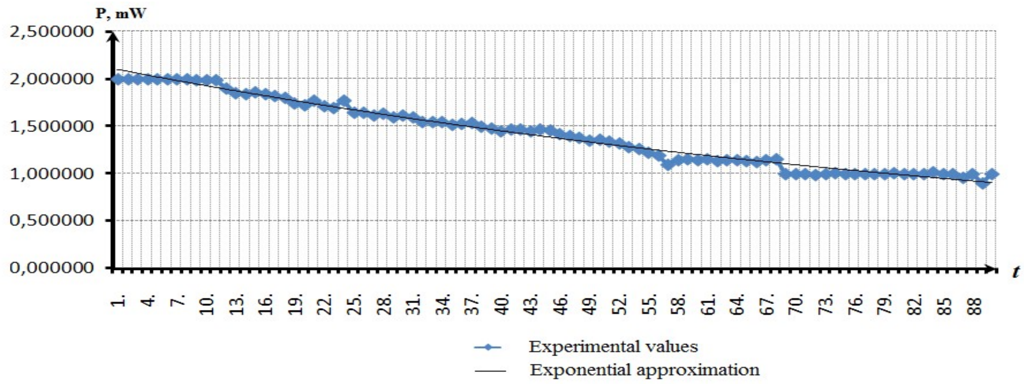

Fig.3. Change in the average value of the radiation power over time.

Using this expression, we can determine the value of P (t) for an arbitrary moment.

IV. Conclusions

There are several reasons that lead to laser diode failure. This includes:

- Manufacturing defects;
- due to improper operation;
- Instability of the supply current of laser diodes;
- Temperature instability and then.

As mentioned above, there are different ways to test LD reliability in fast mode. That is, the method of automatic control of the current strength, the method of automatic power control, and then. That is, the method of automatic control of the current strength, the method of automatic control of the current is based on measuring the value of the radiation power while ensuring the stability of the value of the current supplied to the LD. This method is important for the feasibility and accuracy of measurement results. According to the exponential law obtained on the basis of the experiment, it is possible to estimate the change in the value of the radiation power with time during the operation of a DFB LD. This makes it possible to predict failures in terms of laser diode power.

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