Study of the reliability of Light-Emitting Diodes to the impact of Mechanical and Climatic Loads

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ABSTRACT

This paper examines light-emitting diodes to the effects of mechanical and climatic loads. Typical dependence of the rate of failure of the OES on time. the radiation propagates mainly in the confining layer, which, due to the large bandgap, has small absorption losses.

Key words: *light-emitting diode (LED), converter, optoelectronic element converter (OED), the superluminescent diode (SLD).*

I. Introduction

Reliability is the property of an object to perform specified functions, maintaining over time the values of established performance indicators within specified limits, corresponding to specified modes and conditions of use. Reliability is quantitatively expressed by probabilistic functions [1-2].

Reliability function (probability of no-failure operation) R (t) It is the probability that no failure will occur under the given operating (or test) conditions by the time t. The quantities Q (t) = l - R (t) is called the function of cumulative failures and corresponds to the probability of a failure occurring under the same conditions at time t [3-4].

The failure rate is the probability of device failure D unit of time

$$\lambda (t) = - 1/R(t) \cdot dR(t)/dt. \quad (1)$$

The failure rate function can also be expressed in terms of the failure rate f (t).

Thus, four main probability functions are introduced: R (t), Q (t), λ (t), f (t), each of which fully characterizes the reliability of the device, since, knowing any of them, three other functions can be determined. Functions λ (t) and f (t) have dimension inverse to time, and functions R (t) and Q (t) are dimensionless.

In fig. 1 shows a typical dependence of the failure rate over time. In the AB section, the failure rate drops. This area is called the running-in period. The high failure rate here is associated with the loss of performance of devices that have significant hidden technological defects. Such devices, as a rule, are revealed (rejected) in the process of technological tests (training) and are not supplied to the consumer [1-8].

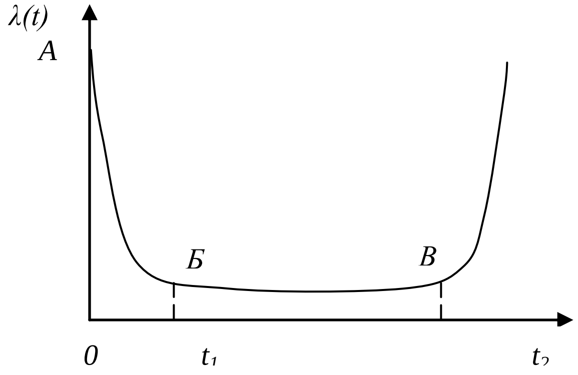

Figure 1 - Typical dependence of the rate of failure of the ECD on time

On the BV section, the failure rate is almost constant and can be described by the exponential distribution of failures in time, for which the probability functions are as follows:

$$R(t) = \exp(-\lambda t); \qquad (2)$$

$$Q(t) = 1 - \exp(-\lambda t); \quad \lambda(t) = \lambda = \text{const}. \qquad (3)$$

The failure rate, in this case, does not change during operating time and is calculated by the formula $\lambda = d/T_\Sigma$,

Where, d - is the received number of failures;

$T_\Sigma = \sum_{i=1}^{n} t_i$ - a total operating time of products;

t_i - operating time;

i - product year;

If the number of failures is zero, the failure rate $\lambda = 0.69 / T_\Sigma$. In the area to the right of point B, the failure rate increases due to the processes of wear and aging of materials. This section is typical for ECDs, in which degradation of parameters takes place. The dependence of the failure rate in this section, which is the most important for ECD, is described, as a rule, by a logarithmically normal law, for which the failure rate is not constant over time. In the initial period, it increases, then, having reached a maximum, it decreases [5-6]. The logarithmically normal distribution of failures is widely used in assessing the reliability index of the OES, however, in some cases, it is possible to use other laws: Weibull, normal, exponential gamma distribution, beta distribution. The listed distribution laws can be used not only to find the quantitative characteristics of the operating time to the moment of failure, but also to describe the distribution functions of the parameters of devices, physical characteristics of materials, and manufacturing processes subject to random variations [7-8].

II. Materials and Methods

Investigation of the reliability of OES is closely related to the methods of predicting quantitative indicators, which can be divided into two main groups: forecasting based on the results of forced tests and statistical forecasting using models of degradation of parameters [9-10]. Prediction based on the results of forced tests is based on a change in the test process of the parameter x of devices associated with the physicochemical processes occurring in the devices and causing their failure. The parameter x is a random variable and changes depending on the time and load on the device. Therefore, the distribution of failures (uptime) is also related to the operating mode of the device. However, the distribution law remains at the same time for different loads [11-12]. Only the characteristics of the law change, which are invariants concerning the test modes, and the acceleration coefficient K can be found through the characteristics of the distribution law.

If the uptime of the product obeys a lognormal distribution for the load ε_i

$$F[x(\varepsilon_1)t] = \Phi[(\ln t - m_1)/\sigma_1), \quad (4)$$

Where Φ (и) - Laplace function; m, σ are distribution characteristics, then for load ε_2

$$F[x(\varepsilon_2)Kt] = \Phi\left(\frac{\ln K + \ln t - m_1}{\sigma_1}\right) = \Phi\left[\frac{\ln t - (m_1 - \ln K)}{\varepsilon_1}\right] = \Phi(\ln t). \quad (5)$$

From (5) it can be seen that the acceleration coefficient $K = e^{m_1 - m_2}$.

For the Weibull distribution with characteristics η and α

$$F[x(\varepsilon_1), t] = 1 - \exp(t^{\alpha}{}_1/\eta_1). \quad (6)$$

The parameter α does not depend on the test mode, therefore the acceleration coefficient is calculated by the formula

$$K = (\eta_1/\eta_2)^{1/\alpha}. \quad (7)$$

For the exponential distribution law, which is a special case of Weibull's law at $\alpha = 1$ and $\lambda = 1/\eta$, it follows from (34) that the acceleration coefficient is $K = \lambda_2 / \lambda_1$.

If the refusals are described by Arrhenius's law, then

$$K = \exp\left[\frac{E_\alpha}{k}\left(\frac{1}{T_1} - \frac{1}{T_2}\right),\right] \quad (8)$$

Where k - is the Boltzmann constant.

The properties of the invariance of the distribution law and the presence of invariant quantities can be used as CRITERIA for the correct decision-making on a particular model of failure development when predicting reliability characteristics based on the results of accelerated tests in forced modes [13-14].

When statistically predicting the reliability characteristics of OES using models of the development of degradation of parameters from time and the load, failures are divided into two types: partial and complete. Partial ones are characterized by a change in at least one parameter and an exit of its value beyond the established boundaries (or norms). As a rule, such boundaries serve to control the quality and reliability of devices during manufacture, acceptance, and delivery to the consumer. Complete failures are characterized by the loss of device properties for one or more parameters - failure criteria.

The behavior of any parameter x can be described by a continuous function x (t), increasing or decreasing. The conditions for the continuity and monotonicity of the function x (t) in this case are: for the upper bound x

$$dx(t)/dt \geq 0,\ x(t) - x\ (t + \Delta t) \leq 0 \tag{9}$$

To limit x from below

$$dx(t)/dt \leq 0,\ x(t) - x\ (t + \Delta t) \geq 0 \tag{10}$$

Taking into account expressions (9) and (10), the condition of partial failure can be defined as the value x (t) going beyond some boundaries x_l (lower) and x_u (upper):

$$x(t) = \begin{cases} x_l \leq x(t) \leq x_u \\ x(t) > x_u \\ x(t) < x_l \end{cases} \quad for \quad \begin{cases} 0 \leq t < t_0, \\ t \geq t_0, \\ t \geq t_0, \end{cases} \tag{11}$$

where t_0 is the time of failure.

From equation (11), taking into account (36) and (37), it can be seen that the probability of failure depends on the boundary values (either x_l or x_u).

A complete failure in the parameter x can be described by a function of the form

$$x(t) = \begin{cases} x_l^{к} < x(t) \leq x_{в} & for\ \ 0 \leq t \leq t_0; \\ \delta\,[x(t_0) - x_u^{к}] & for\ \ t = t_0\ and\ x(t_0) = x_l^{к}\ or\ x_u^{к}, \\ \dfrac{1}{\delta\,[x_l^{к} - x(t_0)]} \end{cases} \tag{12}$$

where $x_l^{к}$, $x_u^{к}$ are the lower and upper critical values of the parameter x, upon reaching which there is a loss of performance or destruction of devices. The critical values of x are constant for devices united by a technological commonality * and are related to the norms for this parameter, according to which quality and reliability are monitored:

$$x_u - x_u^{к},\ x_l^{к} - x_l \tag{13}$$

From expressions (11) and (12) it follows that total failures do not depend on the established norms for parameters. The reliability characteristics for complete and partial failures are formally the same; however, for partial failures, they are functions of the norms for the parameter x, according to which the failure is recorded. For complete failures, defined as (12), independence from the norms for the parameter x allows us to assume that the probability of failure at time t + Δt does not depend on Δt. Such failure events are described by an exponential distribution.

Given that the physical processes leading to complete and partial failures, defined in the form (11) and (12), are usually independent, the probability of failure-free operation can be written as the product of two probabilities:

$$R(t) = R_{п}(t)\ R_{ч}(t) = e^{-\lambda t}\ R_{ч}(t) \tag{14}$$

where Rп (t) and Rч (t) are the probabilities for complete and partial failures, respectively. It can be seen from expression (14) that to restore the distribution law R (t), it is sufficient to know the distribution law Rч (t).

To restore the distribution function R4 (t), we use the fact that the change in the parameters for which a partial failure is registered in time can be described by some function of the form x = ω (t). There is an inverse transformation t = η (x).

In this case, the technological community is understood as the similarity of the manufacturing technology, crystal material, contact material, method of connecting current-carrying elements, protection of p - n - junction.

In this case, there is a relationship between the initial distribution of the parameter x (at t = 0) and the probability density function of the distribution of operating time to failure in form

$$f(t)=f[x(t)]dx(t)/dt. \qquad (15)$$

An analysis of equation (15) shows that for many practical problems, depending on the form of the function x (t) and the initial distribution density of the parameter f (x), one can obtain fairly simple distributions of the probability density of the operating time to failure f (t)

For the log-normal law

$$f(x) = \frac{1}{t_{\sigma}\ln\sqrt{2\pi}} \exp\left[\frac{-(\ln x_i - \overline{\ln x})^2}{2\sigma_{\ln x}^2}\right]; \qquad (16)$$

$$m = \overline{\ln} = \frac{1}{n}\sum_{j=1}^{n} \ln x_j = \ln x_j = \frac{1}{n}\ln\prod_{j=1}^{n} x_j \qquad (17)$$

- average value;

$$\sigma_{\ln x} = \sigma = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n}(\ln x_j - \ln x)^2} \qquad (18)$$

- root mean square (standard) deviation.

The value of x in time is described by the functions:

1) $x = a + bt, \sigma = \text{const}$ (19)

$$f(t) = \frac{b}{t\sigma\sqrt{2\pi}} \exp\left\{-\frac{\left[\ln\frac{a+bt_i}{a+bt}\right]^2}{2\sigma^2}\right\}; \qquad (20)$$

2) $x = \ln t, \sigma = \text{const}$ (21)

$$f(t) = \frac{1}{t\ln t_{\sigma}\sqrt{2\pi}} \exp\left[-\frac{(\ln\frac{\ln t_i}{\ln t})^2}{2\sigma}\right]; \qquad (22)$$

3) $x(t) = \exp Kt, \sigma = \text{const}$ (23)

$$f(t) = \frac{K}{t_{\sigma}\sqrt{2\pi}} \exp\left[-\frac{(t-\bar{t})^2 K^2}{2\sigma}\right]. \qquad (24)$$

III. Results

Thus, knowledge of the processes of changing the parameters - the criteria of suitability in time, allows you to restore the probability density of the MTBF distribution and, accordingly, other reliability characteristics.

Promising methods for obtaining data on the reliability of OES are methods based on non-destructive testing in terms of characteristics and parameters. Such methods are called parametric. They are based on the relationship between the physical structure of the device and the reliability characteristics. The method is based on the hypothesis of causality, which states that the degradation of parameters is completely determined by the physical state of the device before the operation. Since the physical state of the device before the operation cannot be described by a complete system of characteristics, the quantitative characteristics of reliability, in this case, are also probabilistic. In this case, one should distinguish between a one-dimensional assessment, if it is based on taking into account one parameter, and a multidimensional one when taking into account a large number of parameters.

IV. Discussion and Conclusions

Currently, there are two main LED modifications: surface and end. In surface LEDs, radiation is output in a direction perpendicular to the plane of the active layer, and in end-face LEDs from the active layer in a plane parallel to it. A schematic representation of the construction of both LED types is shown in the figure. To improve the heat removal from the active layer at a high pump current density, heat sinks are used.

The output of radiation in a surface type LED on gallium arsenide is carried out through a circular hole etched in the cover. An optical fiber is inserted into this hole and secured with epoxy resin. This LED design is called a Barras diode. Also known are the design of surface LEDs with radiation output directly through the substrate. Such designs are used in LEDs based on a GaInAsP four-component compound. In this case, the InP substrate is a transparent window [15-16].

In end-face LEDs with a double heterostructure, the radiation of the active layer is output from the end, as in laser diodes. Due to total internal reflection, optical radiation propagates along the junction. With the help of the strip design of the lower ohmic contact, as well as the slot at the rear of the active layer, the active region is limited, which makes it possible to avoid losing. Since the generated radiation passes through the active layer when it is removed outside, self-absorption of radiation takes place in this layer. To reduce self-absorption, the active layer is made very thin (0.03 - 0.1 μm). As a result, the radiation propagates mainly in the confining layer, which, due to the large bandgap, has a small absorption loss.

Radiation diabetes arises from the spontaneous radiative recombination of carriers and therefore is incoherent, and therefore relatively broadband and omnidirectional.

Special mention should be super luminescent (SLD). In addition to these diodes, the spontaneous recombination radiation-induced recombination process is used with radiation; the output radiation is amplified in an active environment.

The average radiation power during the operation of the emitter in continuous mode determines the total power emitted by the surface of the active region of the device in the direction of radiation output.

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