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Lifetime tests of superluminescent diodes

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***Abstract*. The process of slow degradation of a batch of 48 superluminescent diodes (SLDs) with different active-channel lengths L_a (24 diodes with $L_a = 600$ μm and 24 diodes with $L_a = 1000$ μm) made of a heteroepitaxial wafer is studied. The diodes were divided into six groups, each containing eight diodes, and were tested at the stabilised injection current $I = 140$ mA and the heatsink temperatures 25, 55, and 70 °C. The median lifetime of a SLD with $L_a = 600$ μm was 3000, 2450, and 1900 h at temperatures 25, 55, and 70 °C, respectively. The calculated lifetime for a SLD with $L_a = 1000$ μm exceeds 100000 h at 25 °C and is 53000 h at 55 °C and 30500 h at 70 °C. The obtained results confirm that a perspective technical solution providing an increase in the lifetime of high-power SLDs is the design with non-injected ends of the active channel which reduces current and, hence, thermal loads.**

Keywords: *superluminescent diode, lifetime tests, reliability*.

1. Introduction

Superluminescent diodes (SLDs) are widely used as radiation sources in optical sensors of different types, in particular, in fibreoptic gyroscopes, for which the most important characteristic is the reliability. SLDs differ from conventional laser diodes (LDs) with a plane resonator by a strong suppression of the positive optical feedback. For this reason, a specified output power is achieved in SLDs at a much higher density of the injection current than in LDs of the same design based on the same semiconductor structure. In addition, the distribution of photon density and concentration of nonequilibrium carriers along the active-channel axis in SLDs is more inhomogeneous than in LDs.

A complicated and diverse problem of the reliability of LDs was studied, unlike SLDs, in many papers [1]. However, due to the circumstances pointes out above, by no means all the results obtained for LDs can be applied to SLDs.

In this paper, we present the results of resource tests of a sampling batch of SLD-38 commercial radiation sources manufactured for several years. Such tests are performed periodically because even a small deviation from technological regimes at any stage of the SLD production can accelerate the degradation of devices. We studied only slow degradation (aging). Devices showing rapid degradation caused by the technological waste ('infant mortality') and catastrophic degradation of different types were screened during preliminary thermoelectric training for 100 – 200 h.

2. Configurations and output characteristics of SLDs

The separate-confinement (GaAl)As double-heterostructure diodes emitting in the spectral range between 820 and 840 nm had the conventional configuration of SLDs. The active channel was a ridge waveguide of width 4 μm whose axis was inclined at an angle of 7° with respect to the normal to crystal facets. The active-channel length L_a could be varied from 200 to 1200 μm. Crystal facets had AR coatings. Crystals were soldered, the *p*-side upwards, on copper heatsinks. Such a design is not optimal for heat removal; however, it considerably simplifies the assembling

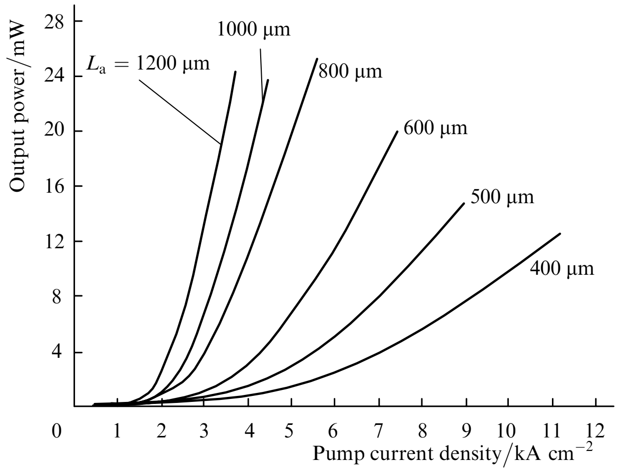

Figure 1. Light – current characteristics of SLDs with different active-channel lengths L_a.

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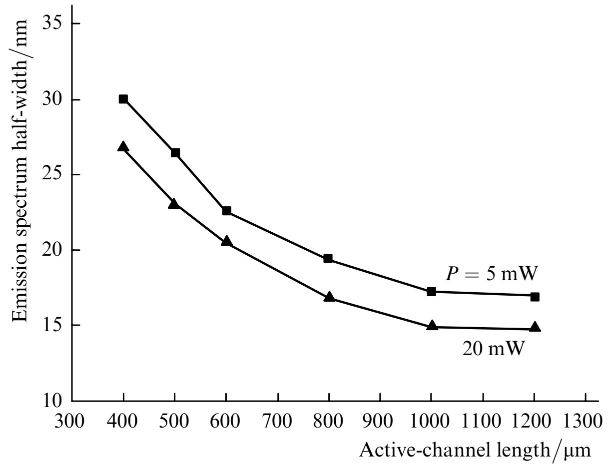

Figure 2. Dependences of the width $\Delta\lambda$ of the spectral band of the SLD on the active-channel length L_a measured at different output powers.

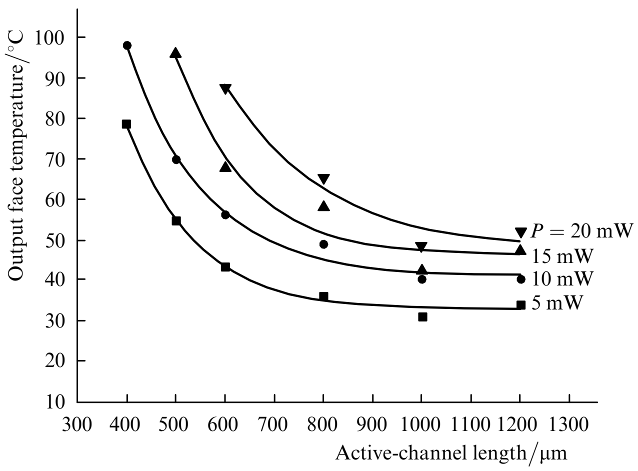

Figure 3. Dependences of the temperature of the emitting SLD facet on the active-channel length measured at different output powers.

of diodes and their coupling with optical fibres in SLD modules.

Figure 1 presents the dependences of the output power of SLDs with different L_a on the injection current density J. They show that a specified level of the output power is achieved in longer SLDs at considerably lower current densities than in short SDLs.

In the first approximation, by neglecting the saturation of the optical gain $g(\lambda)$ and residual reflections from active-channel ends, the spectral density of the output power of an SLD is described by the known expression

$$P(\lambda) \sim S(\lambda)\frac{\exp\{[g(\lambda)-\alpha]L_a\}-1}{g(\lambda)-\alpha}, \qquad (1)$$

where λ is the radiation wavelength; $S(\lambda)$ is the contribution of spontaneous radiation to the guided mode; and α is the coefficient of dissipative losses.

By assuming a linear relation of the maxima of $S(\lambda)$ and $g(\lambda)$ with J, this expression well describes the light – current characteristics presented in Fig. 1. It follows from (1) that, irrespective of the spectral band shape $g(\lambda)$, the width λ of the output emission band decreases with increasing L_a. This

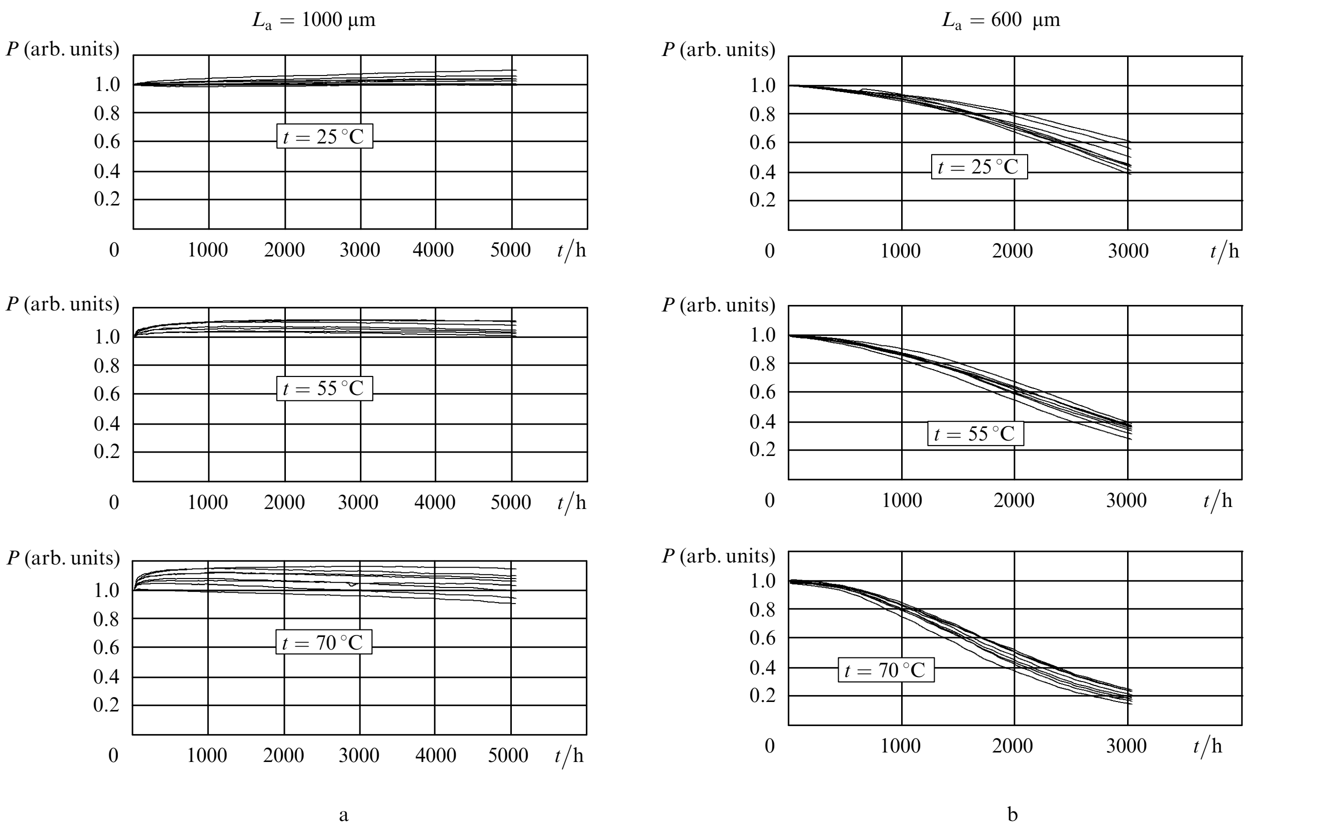

Figure 4. Dependences of the output power on the operation time for SLDs with the active-channel lengths 1000 (a) and 600 μm (b) for the injection current 140 mA and thermal stabilisation at temperatures 25, 55, and 70 °C.

is reliably confirmed by the experimental dependences $\Delta\lambda(L_a)$ obtained for the constant output power (Fig. 2).

The spectral width $\Delta\lambda$ is an important parameter of an SLD determining the time coherence of its radiation. One can see from Figs 1 and 2 that the active-channel length L_a should be selected based on a compromise between the higher efficiency of longer SLDs and the broader spectrum (low coherence) of short SLDs. The economic factor determined by the number of SLDs fabricated from one heteroepitaxial wafer also plays an important role.

Due to the reasons pointed out above, the regions of the active channel of an SLD adjacent to crystal faces experience the maximum current and radiation loads. Most of the factors determining the SLD aging have the activation nature [1]. Therefore, the temperature of these regions in the operating regime of SLDs is an important parameter determining the rate of slow degradation. The method for measuring the averaged temperature of LD end-faces by analysing the short-wavelength wing of the spontaneous emission spectrum is described in [2]. The results of similar measurements performed for SLDs at the heatsink temperature $+25\,^{\circ}$C are presented in Fig. 3.

As expected, the facets of short SLDs were heated stronger than that of long SLDs for the same output power, which suggests that aging will occur faster in the former case.

3. Lifetime tests

We studied slow degradation of 48 SLDs made of one heteroepitaxial plate. 24 SDLs had $L_a = 600$ μm and the rest 24 SLDs had $L_a = 1200$ μm. These samples were divided into six groups, each containing eight SLDs, which were tested at the stabilised injection current $I = 140$ mA and heatsink temperatures 25, 55, and 70°C.

At the heat conduction temperature of 25 °C, the output power was ~ 10 and 20 mW for SLDs with $L_a = 600$ and 1000 μm, respectively. The test results are presented in Fig. 4. According to the common failure criterion as the decrease in the output power by 50 % for $I =$ const, the median lifetime was 3000, 2450, and 1900 h at temperatures 25, 55, and 70 °C, respectively. This means that there is no point in using such SLDs in this operating regime except some technical applications where such a short service life is acceptable. The median lifetime for SLDs with $L_a =$ 1000 μm was 53000 h at 55 °C and 30500 h at 70 °C. As for the service life of SLDs at temperature 25 °C, at which most of the diodes are used, we have no at present the data sufficient for its measurement (resource tests are being continued). We can assert, however, that it exceeds 100000 h.

The results presented above confirm that the design with non-injected active-channel ends [3] providing the reduction of current and, hence, thermal loads is a promising technical solution for high-power SLDs.

Taking into account the results of this study, we used SLDs with the active-channel lengths $L_a = 1000$ and 1200 μm in high-power SLD modules. These modules assembled in a standard Butterfly housing produce more than 30 mW at the output of a single-mode fibre. The results of resource tests show that the predicted service life of these modules is no less than 30000 h.

New SLD-381-HP3 modules have the following parameters:

Optical power at the output of a single-mode fibre/mW	no less than 30
Operating current/mA	no more than 350
Operating voltage/V	no more than 2.8
Central wavelength/nm	820 – 850
Half-width of the emission spectrum/nm	no less than 10
Residual spectral modulation/%	no more than 5

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