Quantum Electronics 30 (4) 321 – 322 (2000)

PACS numbers: 42.55.Px; 42.60.Lh; 61.80.Hg
DOI: 10.1070/QE2000v030n04ABEH001724

Statistical features of degradation of heterojunction lasers during aging and upon irradiation

A A Kochetkov

Abstract. **Specific features of degradation of the GaAlAs and InGaAsP heterojunction lasers are studied during aging at 60 °C and upon irradiation by fast particles. Analytic expressions are obtained that describe an increase in the dispersion of the threshold current distribution with the time of the operating-life test and the dose of irradiation by fast particles.**

Statistical analysis of degradation of heterojunction lasers at various temperature regimes of pumping and irradiation by fast-particle fluxes allows one to obtain a convenient reliability model that takes the test regimes, initial conditions, and failure criterion into account. This model has been obtained by assuming that the increment in parameters is caused by a dominating mechanism in the kinetics of these processes [1 – 3]. Under such conditions, which are often realised in practice, the dispersion σ^2 of the threshold current distribution does not depend on the time of the operating-life test or the irradiation dose:

$$\bar{I}_{\rm t} = \bar{I}_{\rm t0} + c_0(\ln t - \ln \tau), \quad c_0 = \frac{\sigma_1}{\sigma_0} = {\rm const}, \tag{1}$$

$$\bar{I}'_{\rm t} = \bar{I}'_{\rm t0} + c'_0(\ln y - \ln y_0), \quad c'_0 = \frac{\sigma'_1}{\sigma'_0} = {\rm const}, \tag{2}$$

where τ is the time of the operating-life test corresponding to the onset of aging; σ_1^2 is the dispersion of the threshold current distribution at the initial moment; σ_0^2 is the dispersion of the failure criterion distribution; t is the test time; y_0 is the irradiation dose at which the degradation is observed; y is the radiation dose; $\bar{I}_{\rm t0}$ is the average threshold current at the initial moment.

Nevertheless, in the case of an inadequate preliminary sorting of heterojunction lasers (a large dispersion of the performance parameter distribution) as well as at long operating-life test times and high irradiation doses, several different mechanisms of degradation may be simultaneously important or one dominant mechanism of degradation may pass to another. In this case, the dispersion will increase, which should affect the form of expressions for calculating the variation in the threshold current due to degradation caused by aging and irradiation by fast particles.

A A Kochetkov Central Research Testing Institute, Russia

Received 24 November 1999
Kvantovaya Elektronika **30** (4) 321 – 322 (2000)
Translated by M N Sapozhnikov

In the case of aging, these expressions have the form

$$\begin{gathered} \sigma = \sigma_1 + \sigma_2(t), \quad \sigma_1 = {\rm const}, \\ I_{\rm t}(z) = I_{\rm t0} + c_z(\ln t - \ln a), \\ \bar{I}_{\rm t} = \bar{I}_{\rm t0} + c_x(\ln t - \ln a), \quad c_x = \sigma/\sigma_0, \\ c_z = \begin{cases} c_0, \ \tau \leqslant t \leqslant t_0, \ a = \tau, \\ c_1, \ t_0 < t, \ a = t_0, \end{cases} \\ c_x = \begin{cases} c_0, \ \tau \leqslant t \leqslant t_0, \ a = \tau, \\ c_2, \ t_0 < t, \ a = t_0, \end{cases} \end{gathered} \tag{3}$$

where $I_{\rm t}(z)$ is the threshold current distribution for a set of heterojunction lasers during degradation; $z = [I_{\rm t}(z) - \bar{I}_{\rm t}]/\sigma = [I_{\rm t0}(z) - \bar{I}_{\rm t0}]/\sigma_1$ is the argument of the normal distribution function $\Phi^*(z)$; and t_0 is the time of the operating-life test at which an increase in the dispersion is observed. An increase in the dispersion caused by irradiation of heterojunction lasers by fast particles is described by expressions similar to (3).

It follows from expressions (3) that $I_{\rm t}(z) - \bar{I}_{\rm t} = I_{\rm t0}(z) - \bar{I}_{\rm t0} + (c_z - c_z) \times (\ln t - \ln a)$. By normalising this expression to z we obtain

$$\sigma = \sigma_1 + (c_z - c_x)z^{-1}(\ln t - \ln a). \tag{4}$$

A similar expression is obtained for irradiation by fast-particle fluxes: $\sigma' = \sigma'_1 + (c'_z - c'_x)z^{-1}(\ln y - \ln a)$. Because the quantities σ and σ' are independent of z we will set $(c_z - c_x)z^{-1} = B$, $(c'_z - c'_x)z^{-1} = B'$. Then we obtain

$$\sigma = \sigma_1 + B(\ln t - \ln a), \tag{5}$$

$$\sigma' = \sigma'_1 + B'(\ln y - \ln a). \tag{6}$$

For the case $\sigma = \sigma_1$ and $\sigma' = \sigma'_1$, we have $B = B' = 0$. The quantities B and B' may depend in the general case on the test time and irradiation conditions: regimes of operating-life tests or irradiation by fast particles are close to the conditions of the onset of a drastic degradation; in the process of degradation, a nonuniform set of heterojunction lasers was formed (with large σ and σ'); the time of the operating-life test $t \gg t_0$ or $y \gg y_1$ (y_1 is the radiation dose that causes an increase in the dispersion).

The operating-life tests of GaAlAs and InGaAsP heterojunction lasers performed at 60 °C showed that quantity B remains virtually constant during a long test duration (Fig. 1). The study of degradation of heterojunction lasers of these types irradiated by neutrons, protons, gamma quanta, and electrons showed that B' also remains constant at quite high irradiation doses y.

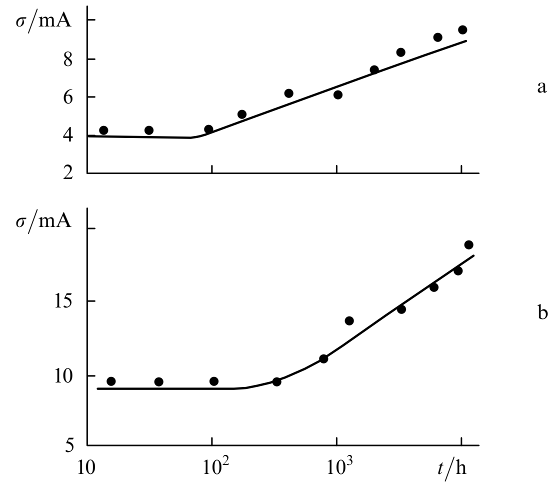

Figure 1. Dependences of σ on the time of operating-life tests for (a) GaAlAs, and (b) InGaAsP heterojunction lasers at 60 °C.

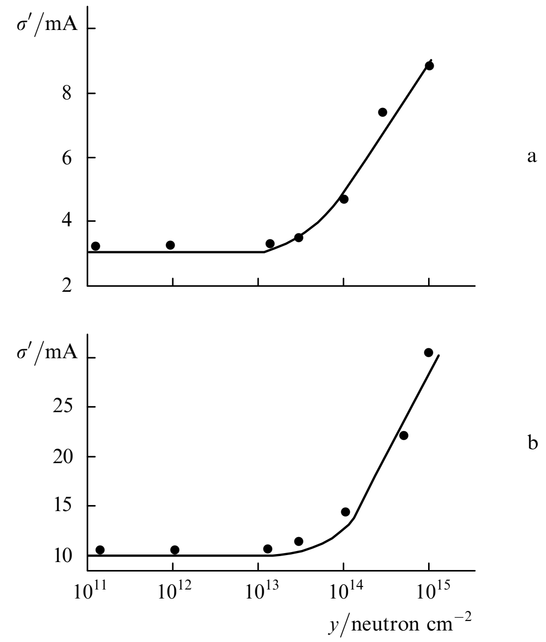

Figure 2. Dependences of σ' on the irradiation dose of neutrons for (a) GaAlAs, and (b) InGaAsP heterojunction lasers.

Fig. 2 shows typical dependences of the threshold current dispersion on the irradiation dose y for GaAlAs and InGaAsP heterojunction lasers irradiated by neutrons. The data were obtained for ten samples of heterojunction lasers of each type. The average threshold current before the test was ~ 25 mA for GaAlAs heterojunction lasers and ~ 50 mA for InGaAsP heterojunction lasers. For this reason, calculations of the threshold current of heterojunction lasers during their degradation should take into account the contribution to the increment of $\bar{I}_{\mathrm{t}}$ caused by the increase in $\sigma(t)$ or $\sigma'(y)$, which can be significant under certain conditions:

$$\Delta\bar{I}_{\mathrm{t}} = \frac{B}{\sigma_0}(\ln t - \ln a)^2 \,, \qquad \Delta\bar{I}'_{\mathrm{t}} = \frac{B'}{\sigma'_0}(\ln y - \ln a)^2 \,.$$

The results obtained show that it is appropriate to use specific features of variation in the parameters caused by degradation of the dispersion of the threshold current distribution in calculations of the reliability of heterojunction lasers. The statistical analysis of the degradation kinetics of heterojunction lasers during aging and upon irradiation by fast particles allows one to calculate analytically the dependence of the dispersion on the time of operating-life tests and the irradiation dose.

References

1. Eliseev P G, Kochetkov A A Kvantovaya Elektron. (Moscow) **10** 2118 (1983) [Sov. J. Quantum Electron. **13** (1983)]
2. Kochetkov A A Kvantovaya Elektron. (Moscow) **16** 1595 (1989) [Sov. J. Quantum Electron. **19** (1989)]
3. Kochetkov A A Kvantovaya Elektron. (Moscow) **21** 422 (1994) [Quantum Electron. **24** (1994)]