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TRANSVERSE MODE LOCKING IN AN INJECTION LASER

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Mode locking in optical lasers can be the consequence of the nonlinear interaction of the modes in the active volume of the resonator [1]. In the case of longitudinal mode locking the laser emits, as is well known, a periodic sequence of ultrashort light pulses. Axial-mode locking was observed in an injection semiconductor laser with inhomogeneous excitation, operating with an external resonator [2], and in a semiconductor laser with electronic excitation [3].

In the case of transverse mode locking, the generation region should experience a periodic displacement over the resonator mirror, and swinging of the directivity pattern of the radiation should occur. The frequency of such a displacement is equal to the difference between the frequencies of the neighboring transverse modes [4]. Transverse-mode locking was observed in neodymium-glass solid-state lasers [3] and in CO_2 gas lasers [6].

In this paper we present the results of an investigation of the effect of transverse-mode locking in an injection semiconductor laser.

We investigated samples of GaAs laser diodes obtained by the epitaxial and diffusion methods and operating in the pulsed regime at 300°K. The laser-diode resonator length was 300 - 400 μ. The pump pulse duration was adjustable from 30 to 100 nsec. The threshold currents of the investigated samples were usually 20 - 60 A.

The dynamics of the emission of laser diodes in the near and far zones was investigated by the method of electron-optical chronography [7]. The time resolution of the developed apparatus was $\sim 10^{-11}$ sec.

Figure 1a shows a time scan of a glowing laser-diode p-n junction. The excess of the pump current over threshold was 1.5%. It is seen from Fig. 1a that the generation region moves periodically over the resonator mirror along the p-n junction.

Figure 1b is a time scan of the far zone of the laser diode emission. To obtain the photograph in Fig. 1b, a cylindrical lens was placed in front of the photocathode of the electron-optical converter and "compressed" the directivity pattern of the radiation in a plane perpendicular to the plane of the p-n junction.

For the sample investigated, the maximum displacement of the generation region over the resonator mirror was 50 μ, and the length of the generation region along the p-n junction was ~15 μ. The maximum swing angle of the directivity pattern was ~5°.

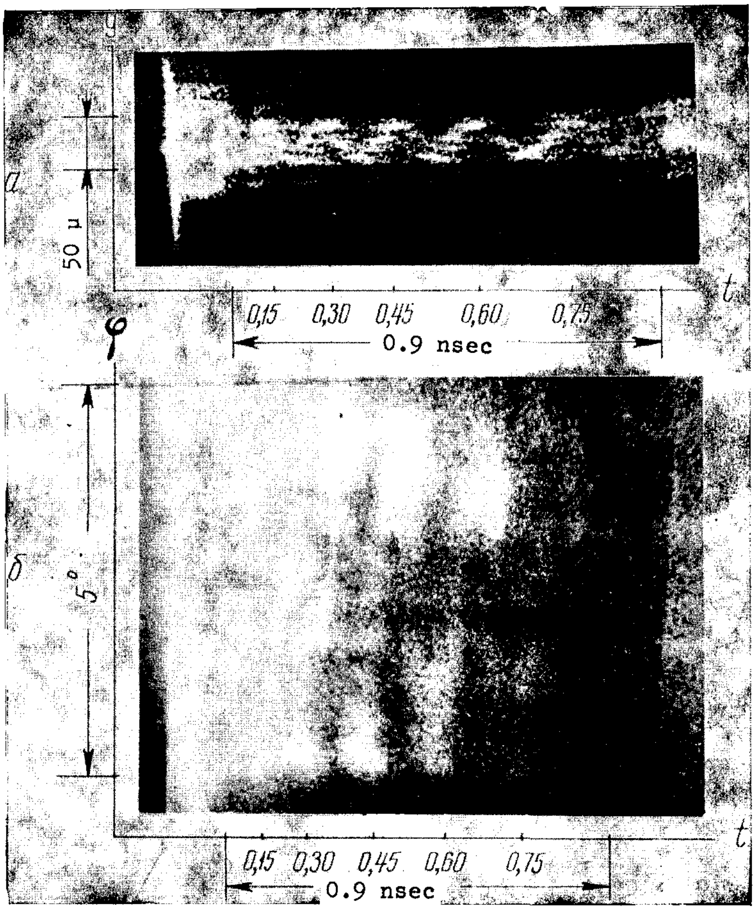

Fig. 1

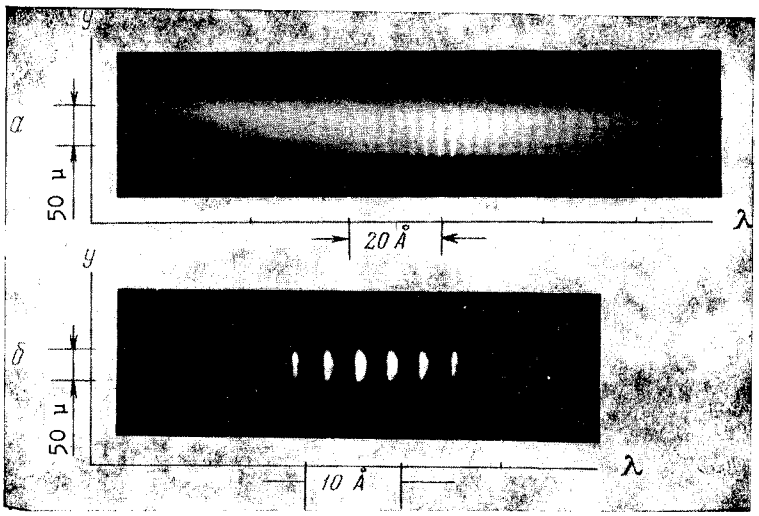

Fig. 2

The frequency of the displacement of the generation region over the resonator mirror and of the swing of the directivity pattern was ∿6.7 GHz, corresponding to a spectral interval ∿0.18 Å at an emission wavelength 9100 Å.

The periodic character of the displacements of the generation region over the p-n junction remained practically unchanged from pulse to pulse of the pump current. The emission of the laser diode operating in the mode-locking regime was linearly polarized. The mode locking was observed during the entire pump pulse of duration 60 nsec. When the pulse duration was increased to 100 nsec, the generation stopped because of the heating of the diode.

Figure 2a shows a photograph of the spectral-spatial distribution of the spontaneous emission of the glowing region of the investigated sample. Such photographs can be used to determine quantitatively the inhomogeneity of the refractive index n(y), where y is the coordinate along the p-n junction, and to calculate the spectrum of the transverse modes [8]. It is seen from Fig. 2a that the refractive index n(y) has a smooth maximum. It has been shown in [8, 9] that for such a resonator, without allowance for the dispersion of the refractive index, the frequencies should be equidistant for both the longitudinal and transverse modes.

In a real injection semiconductor laser at a slight excess above the generation threshold, the nonlinearity of the active medium should also lead to the appearance of an equidistant spectrum of the transverse modes, even in a medium having a large dispersion.

The spectrum of the coherent radiation of the investigated sample, obtained at the same pump currents as for Fig. 1, is shown in Fig. 2b. The photograph reveals six spectral groups corresponding to the longitudinal modes. Each group consists of lines corresponding to the transverse modes. The spectral inverval between the neighboring transverse modes is at the limit of the resolution of the spectrograph and equals ∿0.2 Å.

Experiments performed on a number of samples show that transverse mode locking in an injection semiconductor laser is observed only in those regions of the p-n junctions where n(y) has a smooth maximum.

For this case, we calculated the dependence of the radiation intensity in the near and far zones on the coordinate y and on the time under the assumption of superposition of four equidistant transverse modes of lower orders (m = 0, 1, 2, 3). The quantitative agreement between the calculation and experimental data is compatible with the accuracy of the measurements. Calculations have shown that the characteristic "dips" of the emission intensity along the coordinate y, observed in Fig. 1, are connected with locking of a small number of transverse modes.

The effect of transverse-mode locking is observed most stably in injection lasers prepared by the epitaxial-diffusion method, at a definite degree of clamping of the crystal in the holder.

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