interesting facts stimulate our further investigations of this important problem.

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SUPERRADIANCE SPECTRA OF INJECTION LASERS AND DISTRIBUTION OF INHOMOGENEITIES ALONG A p-n JUNCTION

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We investigated epitaxial and diffusion GaAs laser diodes operating in the pulsed mode at a temperature 77°K.

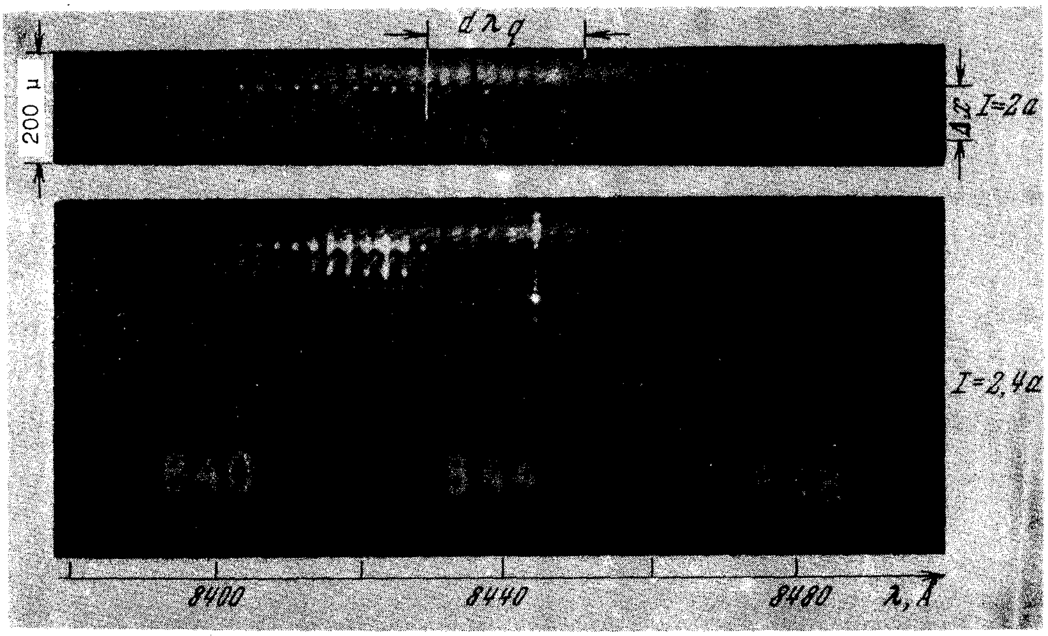

Fig. 1. Spectral-spatial picture of the emission of an epitaxial laser diode

Figure 1 shows the spectral-spatial picture of the superradiance of an epitaxial laser diode, observed with the aid of a P-4 electron-optical converter placed at the output of a DFS-8 spectrograph. The strongly magnified image of the p-n junction was focused on the input slit of the spectragraph parallel to its direction.

In accordance with the idealized models, one should have expected the picture to comprise a set of equidistant vertical lines, i.e., the wavelength of any longitudinal mode of the superradiance should be the same for all the points of the p-n junction.

The experiment revealed, on the other hand, that the wavelength of the superradiance modes varies along the p-n junction. Using the spectral-spatial pictures of the superradiance it is possible to obtain qualitative and quantitative information on the spatial inhomogeneity of the optical characteristics of the p-n junction of a laser diode. We shall assume that the wavelength of the superradiance mode [1, 2] is connected with the refractive index of the medium and with the resonator length by the relation

$$q\lambda_q = 2n\ell, \tag{1}$$

where all the symbols are standard. Simple estimates of the influence of the various parameters contained in (1) on the wavelength of the superradiance mode show that the only real cause of the coordinate dependence of λ_q observed in Fig. 1 is the variation of the refractive index of the medium along the p-n junction.

Taking into account the dispersion of the refractive index at the edge of the absorption edge [3], we put $n = n(\lambda, x)$. We then readily obtain from (1) an expression for the coefficient of proportionality between the change of the mode wavelength, $d\lambda_q/dx$, and the change of the refractive index dn/dx:

$$\frac{dn}{dx} = \frac{n}{\lambda_q}\left[1 - \left(\frac{\lambda_q}{n}\right)\left(\frac{dn}{d\lambda}\right)\right]\frac{d\lambda_q}{dx} \tag{2}$$

The proportionality coefficient can be determined, knowing the interval $\Delta\lambda$ between the neighboring longitudinal modes of the resonator; this interval is connected with the other characteristics of the resonator by the expression

$$\Delta\lambda = \frac{\lambda^2}{2nl}\left[1 - \left(\frac{\lambda}{n}\right)\left(\frac{dn}{d\lambda}\right)\right]^{-1}. \tag{3}$$

for GaAs with $\ell = 260\ \mu$, $\Delta\lambda = 2.5$ Å, and $n = 3.58$ we get

$$\frac{dn/dx}{d\lambda_q/dx} = 6 \cdot 10^{-4}\ \text{Å}^{-1}. \tag{4}$$

For Fig. 1, the maximum change of the mode wavelength, $\Delta\lambda_q$, over a p-n junction length $\Delta x = 110$ is equal to ~ 20 Å, which yields, in accordance with (4), $\Delta n \approx 10^{-2}$.

Stern [3], pointing out the dependence of the refractive index on the width of the forbidden band, presents the following relation for the connection between the change of Δn and the change of ΔE_g in GaAs:

$$\frac{\Delta n}{\Delta E_g} = -0{,}8\ \text{eV}^{-1}. \tag{5}$$

Using this relation and the result shown in Fig. 1, we can obtain the value of Δn by starting from considerations other than those used in the derivation of (4).

It is clearly seen from Fig. 1 that the position of the maximum of the spontaneous-emission spectrum varies along the p-n junction. By determining this shift $\delta\lambda$ of the maximum in the section Δx under consideration and using the usual relation for the connection of $\delta\lambda$ with ΔE_g, we obtain with the aid of (5) $\Delta n \approx 10^{-2}$.

These results allow us to assume that the reason for the variation of the superradiance

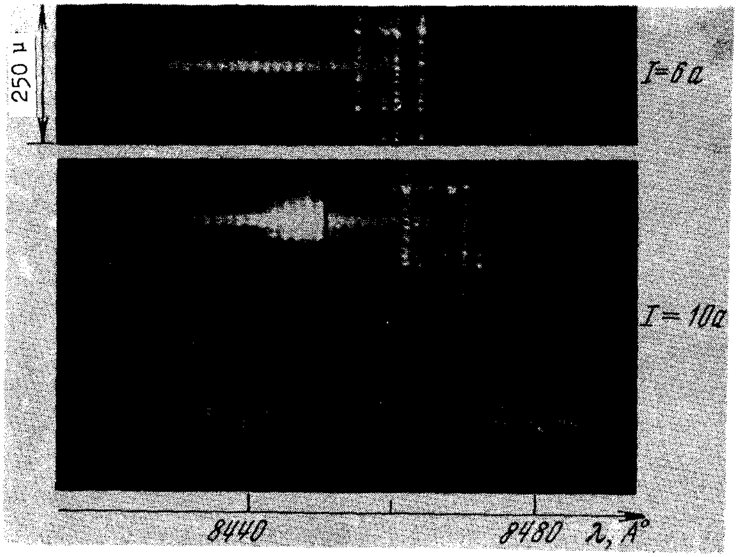

Fig. 2. Spectral-spatial picture of radiation of a diffusion laser diode.

along the p-n junction in a superconducting structure is the change of the refractive index, due to the uneven width of the forbidden band.

This conclusion is of practical interest because it suggests a procedure for the investigation of optical inhomogeneities in p-n junctions. Furthermore, by investigating the refractive-index gradient along the p-n junction, we can advance a hypothesis explaining the formation of the generation channels in injection lasers.

The refractive-index gradient calculated on the basis of Fig. 1, $dn/dx = 10^{-4}\ \mu^{-1}$, is quite sufficient to bend appreciably the trajectory of a light beam propagating perpendicular to the refractive-index gradient. The presence of a maximum of the function $n(x)$ should lead in this case to focusing of the radiation and to formation of a generation channel in the vicinity of this maximum, as is indeed seen from Fig. 2. The occurrence of generation channels is observed also in regions with minimum refractive-index gradients, as is clearly seen in Fig. 1.

The observed regularities of the channeling of radiation in p-n junctions of laser diodes confirm the hypothesis that the presence of the refractive-index gradients along the p-n junction leads to the formation of generation channels in injection lasers.

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ERRATA

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First line: "in a superconducting structure...." should read " in a semiconductor structure..."