SPACE-TIME CHARACTERISTICS OF THE RADIATION OF A SEMICONDUCTOR LASER WITH ELECTRONIC EXCITATION

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Results are presented of an investigation of the influence exerted on the generation regime of a semiconductor laser with electronic excitation by the resonator length, by the electron energy, and by the excess of the pump level over the generation threshold. To check on the possibility of controlling the generation regime and obtaining the desired radiation characteristics, we investigated also a semiconductor laser with unstable resonator and a semiconductor laser in which the electron-bombarded face was doped with zinc to a depth 5–7 μ.

THE spatial and temporal characteristics of the radiation generated by laser are among the main characteristics determining their practical applications. The generation regimes of different types of solid-state lasers have many properties in common. For example, the spike generation regime is observed in most of them. But there are also many significant differences, connected with the excitation methods, the working-level properties, the active-medium optical properties, and the resonator geometry and dimensions.

Although the investigation of the dynamics of the electromagnetic field in resonators of different types of solid-state lasers have by now been the subject of a large number of papers, the generation dynamics of solid-state lasers with electronic excitation has remained practically uninvestigated. An investigation of the dynamics of semiconductor lasers with electronic excitation is of interest in view of their possible use in optical electronics and optical information processing.

Observation of the nonstationary character of the generation regime of semiconductor lasers with electronic excitations was first reported in[1]. In the present paper we report the results of an investigation of the influence exerted on the generation regime by the resonator length, the electron energy, and the pump to threshold ratio. To assess the possibility of controlling the generation regime so as to obtain the desired radiation characteristics, we investigated also a semiconductor laser with an unstable resonator and a semiconductor laser in which the electron-bombarded face was doped with zinc to a depth 5–7 μ.

The semiconductor laser was excited with an electron beam at a pulse duration 150 nsec and an electron energy from 50 to 150 keV. The radiation was registered with a high-speed photoelectronic recorded FÉR-2 with a time resolution limit 0.05 nsec[2]. The investigated samples were made of n-GaAs doped with tellurium to a concentration $n = 2 \times 10^{18}\ cm^{-3}$. The samples were in the form of rectangular parallelepipeds. The distance between the faces forming the optical resonator ranged from 0.625 to 10.9 mm. All the measurements were made at liquid-nitrogen temperature, to which end the samples were soldered to the cold finger of a nitrogen cryostat. The transverse dimension of the excited region was 0.5 mm and was determined by the dimension of the gap in the copper screen placed in the path of the electron beam ahead of the sample.

1. DYNAMICS OF FIELD IN THE NEAR ZONE

In the investigation of the dynamics of the field in the near zone, the image of the radiating face of the resonator was focused on the cathode of the photorecorder. The slit of the photorecorder subtended the radiating part of the end face, and the time sweep was perpendicular to the slit. The observations have shown that at all the investigated electron energies, resonator lengths, and at different pump to threshold ratios, a spiked generation regime is observed.

The depth of modulation of the radiation near the threshold was small and increases first with increasing pump-current density. However, starting with a certain excess of pump current over threshold ($j/j_0 \approx 3$), the depth of modulation again begins to decrease.

The dependence of the spike periods ΔT on the pump to threshold ratio at different resonator lengths is shown in Fig. 1. As seen from the figure, the spike period decreases rapidly near the threshold. At $j/j_0 \gtrsim 3$, the dependence becomes weaker and the curves flatten out. The obtained dependence of the spike repetition period on the pump to threshold ratio is in good agreement with the well known formula[3]:

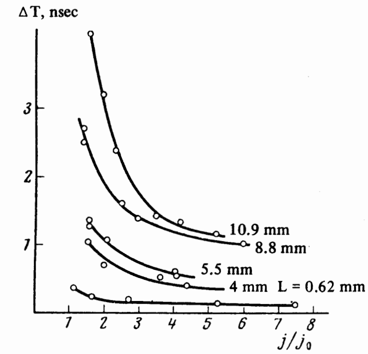

FIG. 1. Dependence of the spike period ΔT on the excess above threshold.

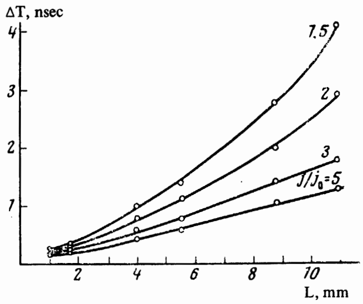

FIG. 2. Dependence of the spike period ΔT on the resonator length.

$$\Delta T = [T_1 T_2/(n-1)]^{1/2},$$

where T_1 is the spontaneous lifetime, T_2 is the lifetime of the photon in the resonator, and n is the excess of the pump over generation threshold.

Figure 2 shows the dependence of the spike repetition period on the resonator length at different pump to threshold ratios. As seen from this figure, the dependence is practically linear for large pump to threshold ratios and becomes stronger with decreasing pump current.

It follows from the presented formula that the spike period should increase with increasing resonator length like $\sqrt{L}$ at small lengths, and then exhibit saturation. Experiment reveals a stronger dependence of ΔT on L, and in particular the period is $\Delta T \sim L^{4/3}$ at $j/j_0 = 2$. It should be noted that in injection lasers[4] the dependence of the spike period on the resonator length is of similar character.

Apparently, the stronger dependence of ΔT on L is due to the increase of the depth of modulation (in our experiments, up to 80–90%) with increasing length L. Indeed, the formula for the spike period was obtained by linearizing the balance equations near the stationary solution, i.e., at a low depth of modulation, and as shown in[5], the spike repetition period increases with increasing depth of modulation.

To determine the influence exerted by the passive part of the resonator on the generation regime, we performed experiments in which one third of the resonator length was covered with a metallic plate. In this case, the spike repetition period remained unchanged, within the accuracy of our measurements, and the depth of modulation decreased.

To determine the influence exerted on the generation dynamics by the electron energy, we performed an experiment with a resonator of L = 8.8 mm at energies 50 and 140 keV (with the same excess over the generation threshold). It was observed that with increasing electron energy, both the spike repetition period and the depth of modulation increased. The increase of the spike period is apparently the consequence of the decrease of the threshold gain with increasing electron energy[6]. The increase of the electron energy leads to a broadening of the active region in the direction of the electron beam, and consequently to a decrease of the diffraction losses and to an increase of the photon lifetime in the resonator T_1.

In[7] there were investigated the radiation characteristics of an injection semiconductor laser, one of the resonator faces of which was doped with zinc, leading to a change in the spectral characteristics and in the distribution of the field in the near and far zones. We investigated the generation regime of a semiconductor laser with electron excitation, in which the electron-bombarded face was doped with zinc to a depth 5–7 μ. The investigations were performed on two samples 4 and 8.2 mm long, and showed that in such a generator there is a sharp decrease of the depth of modulation of the radiation, while the spike period remains unchanged. It is possible that by choosing the depth of the doping and of the doping impurity (particularly, doping with manganese) it is possible to control effectively the dynamic radiation characteristics of a semiconductor laser with electron excitation.

The influence of the resonator geometry on the formation of the field was investigated by us in an unstable resonator[8]. In this case one of the resonator faces of the sample was made concave with a curvature radius 3 cm at a sample length 0.5 cm. An investigation of the near zone in this case has shown that, unlike with a flat resonator, the generation begins immediately, almost over the entire face, and with a much higher degree of field homogeneity. However, the depth of modulation of the radiation increased. The influence of the resonator geometry calls for further research.

2. FIELD DYNAMICS IN THE FAR ZONE

The behavior of the directivity pattern of the radiation was investigated in the direction of the electron beam and in a direction perpendicular to it. To this end, a screen located at a distance 400 mm from the sample was projected on the photocathode of the high-speed photorecorder. The slit of the photorecorder was made to pass one of the indicated directions.

Figure 3 shows the dynamics of the directivity pattern in the direction of the electron beam. As seen from the figure, the form of the directivity pattern changes from spike to spike, and at individual instants of time the width of the directivity pattern is smaller than the width of the diagram averaged over the entire pump pulse. The more complicated behavior of the directivity pattern (angle scanning) in the central part of the picture is apparently due to beats of non-axial modes. In the direction perpendicular to the electron beam, the change of the directivity pattern was much smaller, this being connected with the larger number of excited non-axial modes.

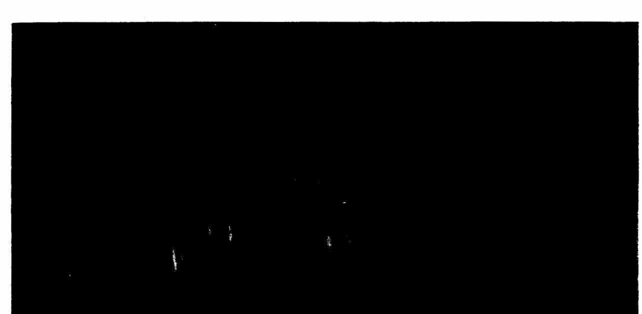

FIG. 3. Scanned directivity patterns in the direction of the electron beam at L = 8.8 mm; total sweep duration 60 nsec.

A similar behavior of the field in the resonator was observed also when the active medium was a CdS single crystal, whose radiative-transition mechanism is different from that in gallium arsenide. It can therefore be concluded that the observed effects are apparently common to lasers of this type.

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