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SPONTANEOUS TRANSIENT PROCESSES IN THE EMISSION SPECTRUM OF A SEMICONDUCTOR LASER

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It is known that in semiconductor lasers (SL) transient processes that occur spontaneously or under the influence of controlling signals [1 - 3] are accompanied by changes of the inverted population in the active region of the generator, of the gain, and of the frequency of the maximum gain. By virtue of this, changes in the composition of the generated radiation can also occur in the transient process, besides the changes in the intensity [8].

We report here the preliminary results of the observation of rapid changes in the emission spectrum of a GaAs semiconductor laser. We observed spontaneous changes of the intensity of the spectral components of the radiation. These changes can be called, in analogy with [1], frequency automodulation, to distinguish it from automodulation of the integral light flux.

We used a DFS-12 diffraction spectrograph and a "Kentavr" electron-optical instrument with a time resolution $\sim 10^{-11}$ sec. The injection was by means of current pulses of 100 nsec duration at 78°K.

The entrance slit of the spectrograph separated from the entire p-n junction a section 20 - 50 μ wide, containing one spatial emission channel.

In the observation of fast changes of the emission spectrum, it is necessary to take into account the uncertainty relation for the wave processes. An analysis shows that in the case of spectral resolution with the aid of a diffraction grating, the transient time of the spectrum is close to $1/\Delta\nu$ ($\Delta\nu$ is the frequency interval of the process) and is equal to

$$t_{tr} = kNT, \qquad (1)$$

where k is the order of the spectrum, N is the number of slits participating in the resolution, and T is the period of the light wave. It is seen from (1) that to obtain the necessary temporal resolution it is necessary to restrict the order of kN of the interference, and this leads to a decrease of the spectral resolution. We chose for the experiment a spectrum transient time of $\sim 5 \times 10^{-11}$ sec and a spectral resolution ~ 1.0 Å. The results of the observations are reported below.

a) Generator with spatially uniform injection. Typical photochronograms of the spectrum are shown in Figs. 1a - c for different injection currents. When the threshold current is exceeded by approximately 30%, the width of the spectral band stabilizes at a level 5 - 6 intervals $\Delta\lambda$ between axial modes, and with further increase of the current it remains practically unchanged and does not shift until the threshold is exceeded 3 - 4 times. As a rule, certain modes, which usually constitute a dense group, are intensity-modulated with a period $(1 - 3) \times 10^{-10}$ sec. The modulation period depends little on the injection current. The obtained modulation pictures are quite varied. One encounters periodic synchronous pulsations in a group of modes, non-synchronous pulsations, and more complicated forms of modulation. The period of the modulation does not agree with the period of the intermode beats and is much larger than the latter. At some values of the injection current, the modes spread out and the spectrum acquires a characteristic band structure.

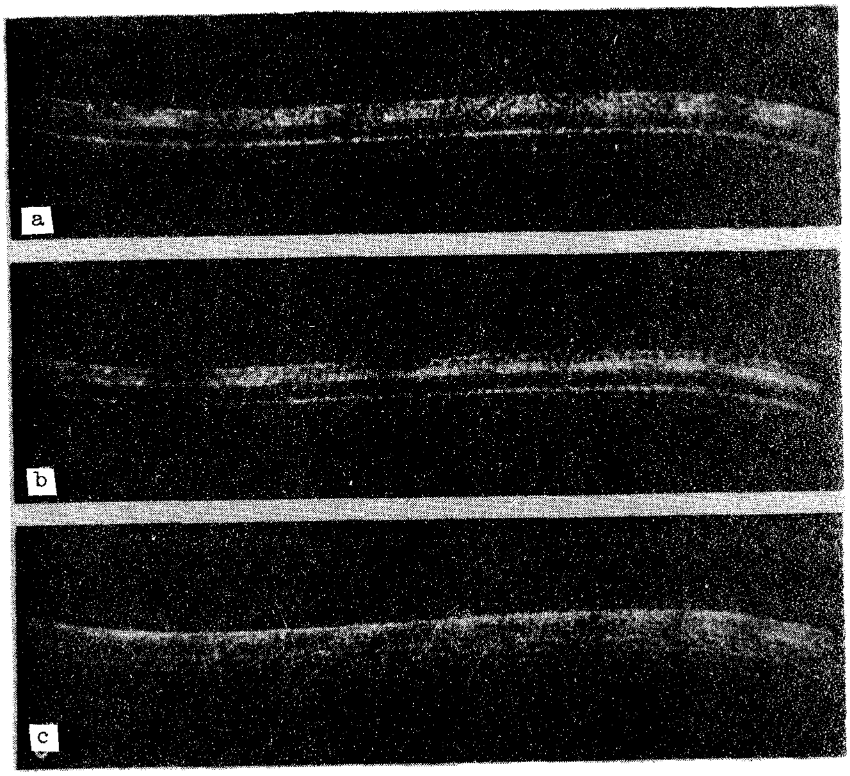

Fig. 1. Chronogram of the spectrum of SL with uniform injection. Sweep 1.2 nsec from right to left. The quantum energy increases in the upward direction. Injection current: a, b - 1.5 A; c - 2.5 A.

b) The generator with non-uniform injection had three injection regions of approximately equal dimensions. Typical photochronograms are shown in Figs. 2a - d. The total width of the band at large injection reaches $8\Delta\lambda$. Just as for the uniformly injected generator, spontaneous changes are observed in the intensities of the individual modes within the band, with a period 10^{-10} - 10^{-9} sec, and these reveal definite tendencies.

Neighboring axial modes, at least for the investigated SL, turn out to have low stability relative to each other. One encounters practically no cases in which they coexist longer than several tenths of a nanosecond. Modes that are separated by 2 - 3 intervals of $\Delta\lambda$ can exist longer and are less dependent on one another. For these modes, switching of intensity to neighboring low-frequency modes was observed (Figs. 2a, b). At a relatively slight excess above threshold, this phenomenon has a regular character and affects mainly the high-frequency modes, while the low-frequency modes can emit without pulsations (Fig. 2c). It must be emphasized that when these regimes were observed without a spectrograph, the integral automodulation could be shallow or completely missing.

At low non-uniformity of the injection, the modulation of the individual spectral components does not vanish, although it does become irregular. Under these conditions, an overall increase of the injection leads to the spreading of the modulation over the entire band, and integral modulation is not observed as a rule. An analysis of the photochronograms shows that, besides the motion of the instantaneous intensity maximum over the neighboring modes, this maximum also shifts along the resonance curve and from mode to mode. The shift within the mode can be particularly clearly traced in regimes with a large modulation period (0.5 nsec) and amounts to $0.6\Delta\lambda$. At a highly non-uniform injection, a distinct integral automodulation appears. In these regimes, a competing interaction of modes takes place within each individual automodulation pulse. This pulse consists frequently of three groups of modes excited in

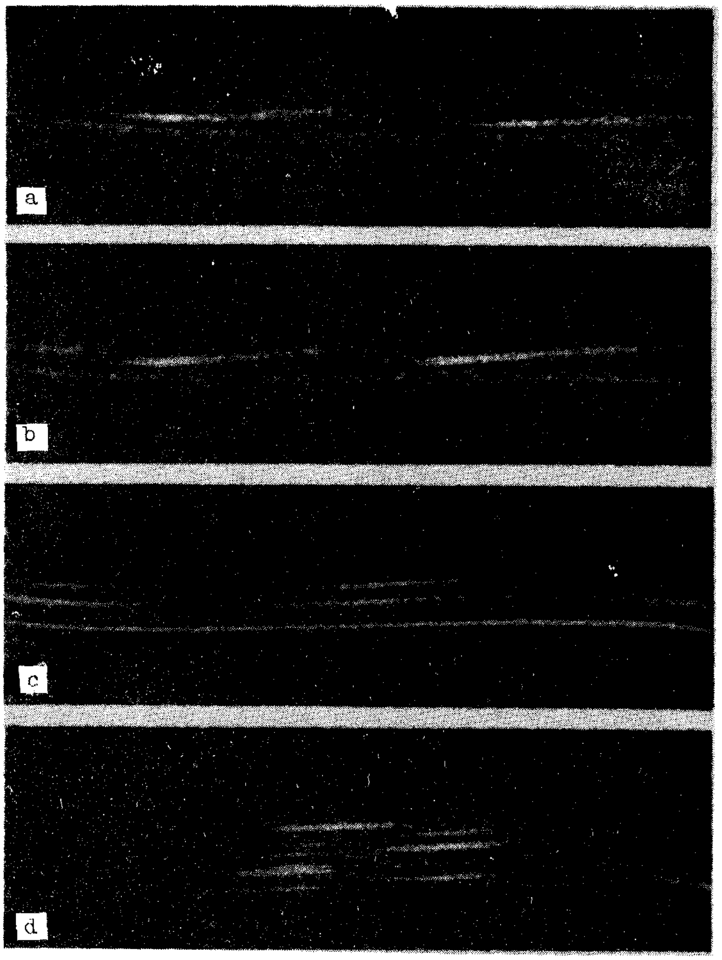

Fig. 2. Chronogram of spectrum for SL with three injection regions. Injection currents (amperes): a - 3, 3, 1; b - 5, 3, 1; c - 5, 3, 1; d - 6, 3, 0.

succession, and the modes generating in the second group are not represented in the first. The time of emission of the modes amounts in this case to (1 - 3) × 10^{-10} sec. In the regime in which the automodulation is synchronized by an external signal [4] one can also observe competition between modes of neighboring frequency and a shift of the intensity maximum along the mode counter, but more closely in synchronism.

Thus, for the investigated cases of the uniform and non-uniform (three regions) injection, we have observed spontaneous modulation of the intensities of the individual modes and groups of modes, with times 10^{-10} - 10^{-9} sec, motion of the maximum of the intensity along the contour of the mode, and successive emission of groups of modes (in the case of deep integral automodulation). These phenomena can apparently not be attributed to heating of the crystal. It is also known that the emission line in semiconductors is homogeneously broadened [5]. These phenomena can be explained by assuming that the gain in a given mode depends on the intensity of the other modes. A similar concept of non-linearity of the mode interaction is used to explain the multimode generation of semiconductor lasers [6], and the same approach possibly explains also the frequency automodulation. The foregoing experimental results demonstrate that the explanation previously proposed for automodulation [7, 8], in which no account is taken of the multimode character of the radiation, calls for further review.

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[1] V.D. Kurnosov, V.I. Magalyas, A.A. Pleshkov, L.A. Rivlin, V.G. Trukhan, and V.V. Tsvetkov, ZhETF Pis. Red. 4, 449 (1966) [JETP Lett. 4, 303 (1966)].
[2] Yu.A. Drozhbin, Yu.P. Zakharov, V.V. Nikitin, A.S. Semenov, and V.A. Yakovlev, ibid. 5, 180 (1967) [5, 143 (1967)].
[3] V.A. Grekhnev, V.D. Kurnosov, A.A. Pleshkov, O.N. Prozorov, L.A. Rivlin, A.T. Semenov, V.V. Tsvetkov, and V.S. Shil'dyaev, Phys. Tekh. Poluprov. (Special Issue), Physics of p-n Junctions in Semiconductor Devices, p. 30, 1969.
[4] V.I. Magalyas, A.A. Pleshkov, L.A. Rivlin, A.T. Semenov, and V.V. Tsvetkov, ZhETF Pis. Red. 6, 550 (1967) [JETP Lett. 6, 68 (1967)].
[5] I.A. Poluektov, Yu.M. Popov, and N.N. Shuikin, Ninth Internat. Conf. on Semiconductor Physics, Abstracts of Papers, 193, 1968.
[6] N.N. Shuikin, Candidate's Dissertation, 1970.
[7] N.G. Basov and V.N. Morozov, Zh. Eksp. Teor. Fiz. 57, 617 (1969) [Sov. Phys.-JETP 30, 338 (1970)].
[8] L.A. Rivlin, Izv. Vuzov Radiofizika 12, 1796 (1969).

LIFETIMES OF EXCITED STATES OF At^{217}

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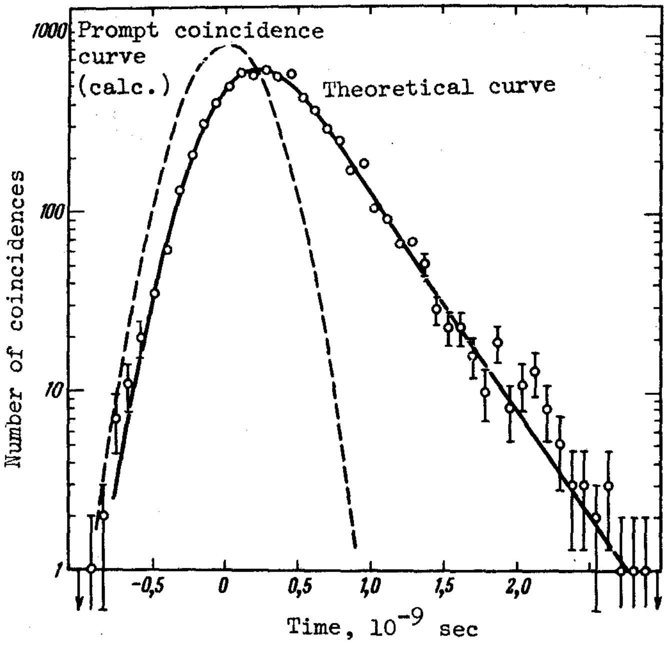
We measured the lifetimes of the 218 and 99 keV levels of At^{217}: $T_{1/2}$(218 keV) = $(2.7 \pm 0.2) \times 10^{-10}$ sec, $T_{1/2}$(99 keV) > 5×10^{-10} sec.

The properties of odd nuclei in the region between the doubly-magic lead Pb^{208} and nuclei having a stable deformation have not yet been thoroughly studied. The measurement of the lifetime of the excited states of such nuclei is of independent interest. In addition, knowledge of the lifetime of nuclear levels is essential for the interpretation of the experimental data of the angular α-γ (α-e) correlations2). We report here the results of the measurement of the lifetime of the excited states of At^{217}. The measurements were performed by the delayed-coincidence method. The α particles produced in the decay of Fr^{221} were registered with a semiconductor surface-barrier silicon detector. The energy resolution of the (FWHM) detector was 25 keV. The conversion electrons were registered with



Spectrum of delayed coincidences of α particles (E_α = 6.124 MeV; Fr^{221}) and conversion electrons (E_γ = 218 keV; At^{217}). The solid curve was calculated from the formula for the delayed-coincidence spectrum, with parameters chosen by least squares.

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2) In particular, we have measured the angular α-γ correlations in the decay of Fr^{221} [1].