violation of the condition (1) and confirms our point of view.

4. The results enable us to point to a method of attaining complete ANC. To this end, it is necessary to use the impurity photoconductivity in p-InSb, so as to get rid of the thermalized non-equilibrium holes.

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[1] V. F. Elesin, ZhETF Pis. Red. 7, 229 (1968) [JETP Lett. 7, 176 (1968)]; Zh. Eksp. Teor. Fiz. 55, 792 (1968) [Sov. Phys.-JETP 28, 410 (1969)].

[2] S. Zwerdling, W.H. Kleiner, and I.P. Theriault, J. Appl. Phys. 32, 10 (1961).

[3] R. A. Smith, Semiconductors, Cambridge Univ. Press.

[4] R. Laff and H.Y. Fan, Phys. Rev. 121, 53 (1961).

LINE STRUCTURE OF GENERATION SPECTRA OF LASERS WITH INHOMOGENEOUS BROADENING OF THE AMPLIFICATION LINE

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It is known that the generation spectrum of an Nd^{3+} glass laser has a line structure. Various hypotheses have been advanced to explain this structure, such as the analytic properties of the gain function [1] or the fluctuating character of the emission [2]. In our opinion, the line structure of the generation spectrum of a laser with an inhomogeneously broadened line is due to the high sensitivity of the generation spectrum to the presence of frequency-dependent losses in the resonator. It can be shown that introduction of frequency-dependent losses of the type

$$\frac{1}{T(\omega)} = \frac{1}{T_0} - \Delta\left(\frac{1}{T}\right)\cos\frac{r\pi\omega}{\Delta\omega} \qquad (1)$$

into the resonator leads to the appearance in the laser spectrum of dips with relative intensity

$$\frac{\Delta I}{I_0} = \frac{\Delta(1/T)}{1/T_0}\left(\frac{ST_0}{I_0} + \frac{I_0}{PT_0}e^{-\frac{2\pi\gamma}{\Delta\omega}}\right)^{-1} \qquad (2)$$

where ST_0, I_0, and P are respectively the spontaneous-noise power, the generation power averaged over the frequency, and the pump power in a unit frequency interval. Formula (2) is based on the assumption that the inhomogeneous width is infinite, and that the homogeneous broadening is characterized by a dispersion contour with width γ.

Frequency-dependent losses of type (1) can be produced by placing in the resonator a plane-parallel layer of matter of optical thickness ℓ. The interference of the light reflected from its surfaces causes its transmission to depend on the frequency in accordance with formula (1), where $\Delta\omega = 1/2\ell$.

A cell made up of two wedge-like glass plates with strictly parallel internal surfaces was placed inside a confocal resonator with spherical mirrors (R = 1 m).

It follows from (2) that the sensitivity of the generation spectrum to the presence of losses depends on the ratio $2\pi\gamma/\Delta\omega$.

We used two cells of different thickness, $\ell_1 = 0.45$ cm ($\Delta\omega = 1.1$ cm$^{-1} \ll \gamma$) and $\ell_2 = 0.025$ cm ($\Delta\omega = 20$ cm$^{-1} \sim \gamma$). The loss modulation depth $\Delta(T^{-1})/T_0^{-1}$ depended on the coefficient of reflection from the interface between the glass and the layer of matter in the cell. The matter employed was a mixture of benzene and chlorobenzene, chosen such as to have a minimum reflection coefficient.

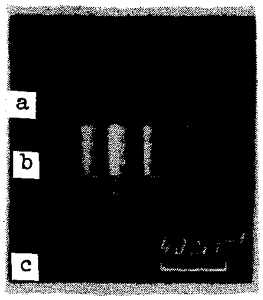

Fig. 1. Generation spectrum of Nd^{3+}-glass laser at different temperatures(a cell with acetone, having an optical thickness 0.025 cm, was placed in the resonator. a) T = 290°K, b) T = 260°K, c) T = 240°K.

We obtained the dependence of the depth of modulation of the emission spectrum on the reflection coefficient.

Even at the minimal reflection coefficient, 2×10^{-7} (measured by an independent method), modulation was noted in the spectrum, with a period $\Delta\omega = 1.1\ cm^{-1}$. In a thin cell with $\Delta\omega \sim \gamma$, the modulation depth was strongly dependent on the ratio $\gamma/\Delta\omega$. The homogeneous width γ varied with the temperature of the active medium.

Figure 1 shows the generation spectra of a neodymium-glass laser with a thin cell inserted in the resonator, at various temperatures. It is clearly seen that when the temperature is decreased and the homogeneous width is decreased, the spectrum becomes smoother, and the modulation with period $\Delta\omega = 20\ cm^{-1}$ decreases noticeably. This obviously explains the continuity of the generation spectrum at helium temperatures, observed in [3].

This dependence of the spectral structure on the value of the homogeneous broadening may permit a determination of the width of the homogeneous line of Nd^{3+} in glass and its temperature dependence.

Our results confirm experimentally the high sensitivity of the generation spectrum of a laser with inhomogeneously broadened amplification line to the frequency-dependent losses in the resonator. Consequently any weak discimінating action leads to a line structure, if the influence of this action exceeds the influence of the spontaneous emission. It is possible that the structure of the spectrum in [2] is due to incomplete elimination of selective losses. A structure is produced in the generation spectrum even by the diffraction of the energy reflected from the tilted back face of the mirror substrate. (In our experiments, the tilt angle was 10° and the substrate was 3 cm thick.)

Such a sensitivity of the generation spectrum to losses makes it possible to use a laser with an inhomogeneously broadened amplification line as a highly sensitive spectrograph. Instead of a cell with a liquid, we placed in the resonator a tube, through which gas was blown. We chose ammonia NH_3 and methane CH_4, which have a transparency window in the vicinity of 1.06 μ and are of great interest in astrophysics. Figures 2 and 3 show the spectra obtained at a tube length of 18 cm. The pump power increases in the downward direction. Figure 4 shows the spectrum obtained at an ammonia layer thickness 0.3 cm, with the spectrum in the absence

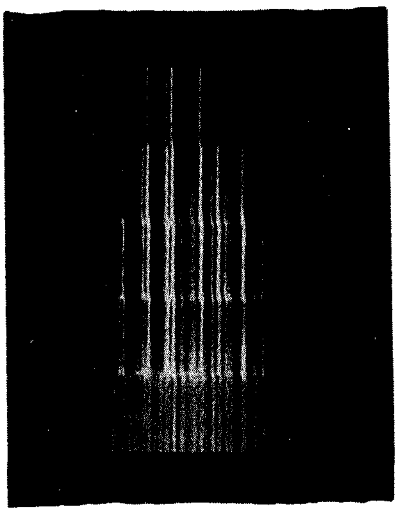

Fig. 2. Generation spectrum with ammonia in resonator, ℓ = 18 cm.

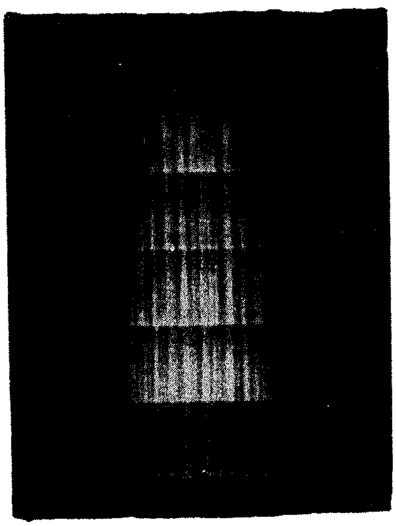

Fig. 3. Generation spectrum with methane in resonator, ℓ = 18 cm.

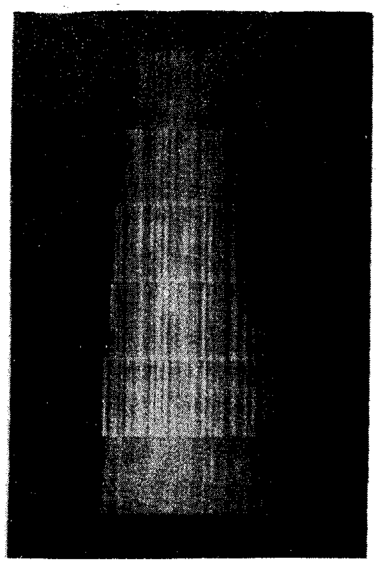

Fig. 4. Generation spectrum with ammonia, ℓ = 0.3 cm. Bottom - without ammonia.

of ammonia shown at the bottom. We see that the reproducibility of the spectrum is high. The spectrum of Fig. 4 is in full accord with the lower spectrum of Fig. 2.

The results show that lasers with inhomogeneously broadened lines can be used as highly sensitive spectrographs. Indeed, to obtain the absorption spectrum of the third harmonic of the H-oscillation, say in NH_3 [5] or in HCN [4], cells several meters long are used at atmospheric pressure, and the spectrum of Fig. 4 reveals absorption lines at the edge of the rotational structure of the third harmonic of the fully-symmetrical vibration of ammonia, $\nu_1 = 3137\ cm^{-1}$, at a layer thickness 0.3 cm. Such a spectrograph also has a high operating speed and is convenient for the investigation of fast processes.

If the absorption line changes the loss in the resonator by an amount $\Delta(1/T)$, then its registration requires a time t_r such that $\Delta(1/T)\cdot t_r \sim 1$. The nonlinearity of the spectrograph apparently does not prevent the performance of quantitative measurements. Its sensitivity can be varied at will by changing the temperature, and hence the homogeneous width γ and the geometry of the resonator and the ratio ST_0/I_0. To vary the working range, dyes can be used as the active media.

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[1] V. S. Mashkevich, Zh. Eksp. Teor. Fiz. 53, 1003 (1967) [Sov. Phys.-JETP 26, 601 (1968)].
[2] V.I. Malyshev, A.V. Masalov, and A.A. Sychov, ZhETF Pis. Red. 11, 324 (1970) [JETP Lett. 11, 215 (1970)].
[3] M. N. Tolstoi and V. N. Shapovalov, Opt. spektrosk. 23, 648 (1967).
[4] G. Herzberg, Vibrational and Rotational Spectra of Polyatomic Molecules (Russ. transl.), IIL, 1949, pp. 320, 332, 485, 412.
[5] Sing-Hung Chao, Phys. Rev. 50, 27 (1936).

EQUILIBRIUM CONCENTRATION OF POSITRONS IN AN OPTICALLY THIN RELATIVISTIC PLASMA

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In a plasma that is opaque to radiation, positron production begins at temperatures $kT \sim 0.1\ mc^2$. Very rapidly (at $kT \sim 0.4\ mc^2$, where m is the electron mass), the pair pressure becomes equal to the radiation pressure, and can greatly exceed the pressure of the initial electrons [1]. In a low-density plasma, when the radiation goes off freely, the positron concentration is determined by the equilibrium between the processes of pair production by collisions of e^- and e^+ with the nuclei and with one another (without participation of the photons), on the one hand, and the annihilation of the electrons and positrons (with emission of photons) on the other. No detailed equilibrium takes place and the equilibrium thermodynamic formulas are not valid. We present in this note the physical picture of the processes in such a plasma.

The main result is the absence of an equilibrium state at temperatures exceeding 20 MeV, thus establishing the upper limit of the temperature of an optically thin relativistic plasma.

Annihilation is a process of second order in the charge, and its cross section is of the order of

$$(\hbar/mc)^2\alpha^2 g(E/mc^2) = r_0^2\, g(E/mc^2)\ ,$$

where $\alpha = e^2/\hbar c = 1/137$ is the fine-structure constant, $r_0 = e^2/mc^2 = 2.8\times10^{-13}$ cm is the classical electron radius, and E is the pair energy in the c.m.s. When $E \gg mc^2$ we have $g \sim E^{-2}$.

The number of annihilations per unit volume and per unit time, obtained by integrating over the maxwellian distributions of the electrons and positrons, is

$$A = \pi n_+ n_- c\, r_0^2\, \psi(\theta)\ , \qquad \theta = kT/mc^2\ ,$$

where

$$\psi(0) = 1 \quad и \quad \psi(\theta) \sim \theta^{-2} \text{ for } \theta \gg 1.$$