Superradiance on the 2^+ and 1^- bands of nitrogen in a discharge at pressures above 10 atm

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We obtained intense superradiance on the 1^- bands of nitrogen ($\lambda=3914$ and $\lambda=4278$ Å) by using a double-pulsed transverse discharge in an He-N_2 mixture at a pressure higher than 10 atm. The emission spectrum of the 2^+ system ($\lambda=3371$ Å) at a pressure higher than 4 atm consists of one vibrational-rotational component.

We report here obtaining inversion and intense superradiance on ionic molecular transitions in a pulsed gas discharge at high pressure. The new superradiance lines in the visible band terminate at the lower electronic state of the molecular ion, and the principal mechanism that produces the inversion is direct electron impact with ionization and excitation of the molecules. This mechanism is promising for the development of short-wave lasers, and also for obtaining high-power generation in a high-pressure plasma.

The problem of exciting high-pressure gases arises in many scientific and applied projects, and is usually solved by using electron beams. Among these projects are tunable lasers,[1] high-power molecular lasers, including those with mode locking,[2] excitation of inversion on transitions between coupled and repulsive states of molecules,[3] and others. We developed for the excitation of gas mixtures, at pressures up to 11 atm, a relatively simple laser construction with a double transverse discharge. As seen from Fig. 1, the laser cell with an active volume $0.5\times3\times300$ mm had, besides the main electrodes, additional electrodes located on the external sides of the glass walls. The preliminary high-voltage (~150 kV) discharge of low energy preceded the main discharge by 0.1–1 μsec and produced an initial homogeneous ionization in the volume of the gap. This ensured the development of a spatially homogeneous exciting current pulse with amplitude 10^4 A and a rise time 3–5 nsec. The cell was sealed hermetically with quartz windows and filled with a mixture of He-N_2 in a ratio 100: (1–10). The laser operated in the superradiance regime; the presence of one mirror increased the radiation power and decreased the fluctuations of the pulse amplitude from flash to flash. By superradiance we mean here a regime of sharply directional stimulated emission in the absence of a resonator.

We obtained in this system the well-known superradiance at 3371 Å with a power 20 kW, in a wide range of gas-mixture pressures (Fig. 2). A slight decrease of the power and a reduction of the duration from 2.5 to 1.5 nsec are observed when the pressure is changed from 1 to 10 atm. Of greatest interest is here perhaps the spectral composition of the radiation. At pressures on the order of atmospheric there appears in the superradiance a rotational structure of the (0,0) vibrational band, consisting of approximately 10 lines. With increasing pressure, the number of generating lines decreases rapidly, and starting with 4 atm there remains in the superradiance in practice one line $P_1 10$; $P_1 11$. Inasmuch as the possibility of controlling the radiation spectrum with the aid of a selective resonator is extremely limited, owing to the small lifetime of the inversion (~10^{-9} sec), the most realistic method of increasing the spectral density of the pulsed superradiance is to increase the gas pressure in this case. In our experiments, the spectral width measured with a Fabry-Perot interferometer amounted to < 1 cm^{-1}. Within this width, we observed a sharp structure that was unstable from flash to flash.

New superradiance lines in the visible band, with wavelengths 3914 and 4278 Å were observed when the partial pressure of the nitrogen was decreased by approximately one order of magnitude in the range of summary pressures above 3 atm, in the same laser setup. The measurement accuracy, $\Delta\lambda \lesssim 0.1$ Å makes it possible to ascribe these lines to the bands (0,0) and (0,1) of the first negative system of nitrogen bands, the transition $B^2\Sigma_u^+ - X^2\Sigma_g^+$ of the molecular ion N_2^+. The spectral width of the superradiance in each of these bands was 0.2–0.3 cm^{-1}, and within this width there was also observed an unstable sharp structure. The absence of rotational components is apparently due to pressure effects, just as for the 3371 Å line. It is typical that the lower state for these laser transitions is the electronic state of the ion. The ratio of the superradiance amplitudes in the bands (0,0) and (0,1) is the inverse of that for the spontaneous spectrum.[4] Under our conditions, consequently, the rate of population of the first vibrational level of the state $X^2\Sigma_g^+$ is much lower than for the zeroth level. The duration of the super-

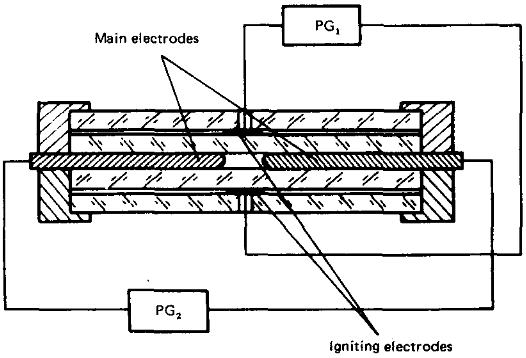

FIG. 1. Diagram of laser cell with double transverse discharge: PG_1—pulsed-voltage generator for pre-ionization, PG_2—generator for the main excitation pulse, working voltage 10–40 kV.

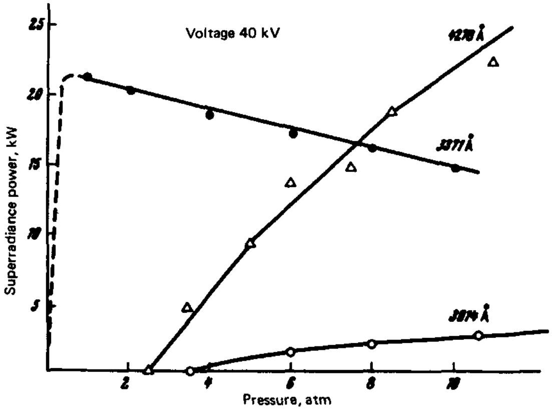

FIG. 2. Superradiance power vs. the mixture pressure.

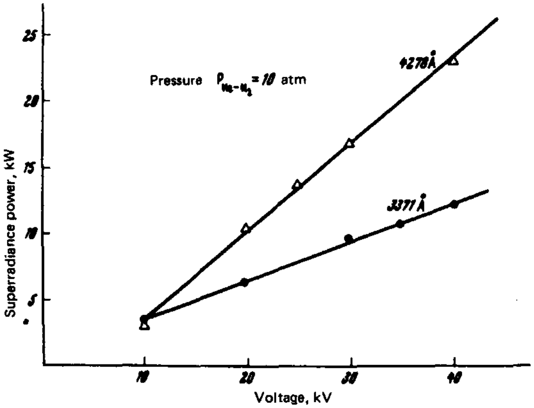

FIG. 3. Dependence of the superradiance power on the working voltage on GP_2.

radiance pulse for both lines was 2.5 nsec and was practically independent of the working pressure. It is interesting that within the limits of the measurement accuracy no delay between the radiation pulse and the current front was observed. Thus, there are all grounds for assuming that the main mechanism for the excitation of the inversion is direct electron impact, which transfers the molecule from the ground neutral state to an excited ionic state:

$$N_2(X^1\Sigma_g^+) + e \rightarrow N_2^+(B^2\Sigma_u^+) + 2e\,.$$

An analogous "instantaneous perturbation" process was observed by Bennett[5] in an analysis of the operation of ionic lasers.

We take particular notice of the almost linear dependence of the radiation power P_{4278} on the mixture pressure P_{He-N_2} in the entire investigated range (Fig. 2). For all the superradiance lines we observe a linear dependence of the intensity on the voltage of the pulse-shaping circuit (Fig. 3). These data should stimulate research on the optimization of the obtained generation processes. For a detailed description of all the features of the mechanism of production of inversion in molecular ionic transitions by a discharge in a compressed gas it is necessary to carry out additional measurements, primarily the parameters of a pulsed plasma. It is also important to determine the influence of the gas pressure on the rates of processes of excitation with ionization.

The considered mechanism for the excitation of inversion in ionic transitions should operate also for other molecules having a sufficient binding energy. The described method of exciting an active medium can be used to construct molecular high-pressure lasers of the type considered in[3,6].

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