Ultraviolet high-pressure laser using an $Ar + N_2$ mixture

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Lasing was achieved at a wavelength $\lambda = 3577$ Å by pumping an $Ar + N_2$ laser with an electron beam. The spectral and energy characteristics of the laser are investigated as functions of the mixture composition at pressures 0–20 atm.

1. Generation of ultraviolet radiation on the second positive system of nitrogen $C^3\Pi_u \to B^3\Pi_g$ ($\lambda = 3371$ Å) was obtained by now either by exciting N_2 with short discharge-current pulses or with a beam of fast electrons from an accelerator.[1,2] However, the attained efficiency and the specific generation power are small (0.6%, 2 kW/cm^3 [1]). To improve the energy characteristics of the laser it was proposed to populate the upper laser level of $N_2(C^3\Pi_u)$ by transfering energy from ^3P states of argon excited in the discharge.[3] However, no lasing was obtained with the $Ar + N_2$ mixture. Recent experiments on the excitation of Xe, Kr, and Ar by a high-power electron beam have shown that pumping of the ^3P levels of inert gases has high efficiency, ~20%.[4] We have therefore performed experiments aimed at obtaining laser action in a mixture $Ar + N_2$ excited by an electron beam.

2. An electron beam from a cold-cathode accelerator ($E \approx 600$ keV, $j = 100$ A/cm^2, $\tau = 2 \times 10^{-8}$ sec)[5] was introduced into the chamber with the working mixture through a titanium foil 50 μ thick. The length of the

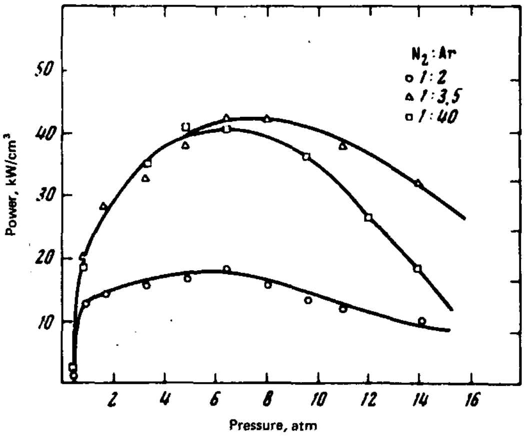

FIG. 1. Dependence of the specific generation power on the pressure and composition of the $Ar + N_2$ mixture.

active region was 4 cm. The laser resonator was made up of a spherical total-reflection mirror ($r = 0.5$ m) and a flat semitransparent aluminum mirror ($T = 8\%$) sputtered on a quartz substrate. The laser-radiation energy was measured with a calorimeter and the power with a high-speed vacuum photocell (resolution not worse than 10^{-9} sec).

The emission spectra were photographed with a VM-1 monochromator (dispersion 18 Å/mm) on the RF-3 film. The spectral and energy characteristics of the laser and spontaneous emission were investigated as functions of the composition of the $Ar + N_2$ mixture at pressures 0—20 atm. In the spectra of the spontaneous emission of pure N_2 and of the mixture $Ar + N_2$, the line of the transition $C^3\Pi_{uv'=0} \rightarrow B^3\Pi_{gv''=1}$ ($\lambda = 3577$ Å) has the highest intensity. The spontaneous-emission power increases approximately by one order of magnitude when argon is added to the nitrogen. This indicates that direct electron-impact excitation of the $C^3\Pi_u$ level is small in comparison with the population by argon. The lasing threshold is not reached in mixtures with more than 50% N_2. Lasing is obtained at a wavelength 3577 Å in mixtures with compositions $Ar:N_2$ from 1:1 to 40:1. The generation threshold was reached at a mixture pressure ~0.4 atm. The efficiency of a laser with an $Ar:N_2$ (3.5:1) mixture at a pressure of 1 atm was 3%. The waveform of the laser-emission pulse at pressures higher than 0.7 atm duplicated in all the investigated mixtures the waveform of the pump pulse. The dependence of the specific generation power on the composition and pressure of the mixture is shown in Fig. 1. The maximal specific generation power reached 45 kW/cm² at a pressure ~7 atm, which is much higher than the values obtained earlier. [1,2]

The spontaneous and laser emission spectra obtained with an $Ar:N_2$ (3.5:1) mixture at 14 atm pressure are shown in Fig. 2.

3. It can be assumed that the formation of inversion and lasing in the $Ar + N_2$ mixture proceeds in accordance with the following scheme:

$$e + Ar(^1S_0) \xrightarrow{k_1} e + Ar(^3P), \qquad (1)$$

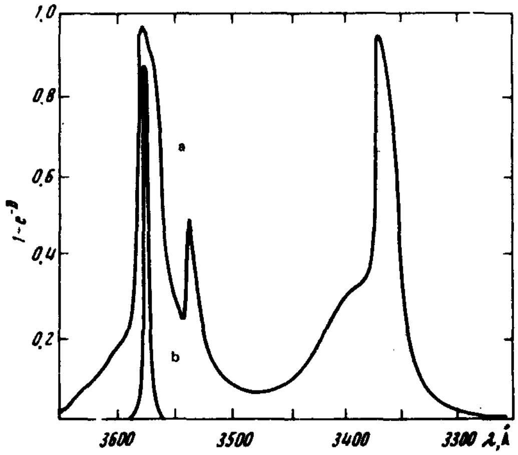

FIG. 2. Microgram of the spectra of spontaneous (a) and laser (b) emission (D_0 is the photographic density of the cell). The generation line width (~2 Å) was determined by the resolution of the monochromator. The intensity of the spectrum (b) has been reduced in comparison with the intensity of the spectrum (a) by an approximate factor of 500.

$$Ar(^3P) + N_2(X^1\Sigma^+_{gv=0}) \xrightarrow{k_2} Ar(^1S_0) + N_2(C^3\Pi_{uv'=0}), \qquad (2)$$

$$N_2(C^3\Pi_{uv'=0}) \xrightarrow{\tau_{21}} N_2(B^3\Pi_{gv''=1}) + h\nu. \qquad (3)$$

The lifetime of the metastable levels ^3P of argon is ~1 sec. [6] As the result of collisions of the second kind, excited $N_2(C^3\Pi_u)$ molecules are produced, predominantly in a state with $v' = 0$. The effective excitation-transfer cross section is ~3.4×10^{-16} cm². [7] At high pressures, a process that competes with (2) is the formation of the Ar^*_2 molecules that emit in the far UV region:

$$Ar(^3P) + 2Ar(^1S_0) \xrightarrow{k_4} Ar_2^* + Ar. \qquad (4)$$

The rate of formation of the Ar^*_2 molecules in triple collisions is $k_4 \sim 10^{-32}$ cm⁶ sec⁻¹. [8]

The stationary solution of the rate equations describing the reaction (1)—(4) shows that the population of the level $C^3\Pi_{uv'=0}$ at the generation threshold is equal to

$$n_2 = A\tau_{21}k_2x(1-x)j/[k_2x + k_4N(1-x)^2], \qquad (5)$$

where τ_{21} is the lifetime of the level relative to (4); k_2 is the rate of energy transfer from $Ar(^3P)$ to $N_2(X^1\Sigma_g^+)$; j is the accelerator current density; x is the fraction of N_2 in the mixture; N is the number of particles of the mixture per cm³; A is a normalization constant. The lower laser level, in accordance with the Franck-Condon principle, has a neglegibly small population, $n_1 \approx 0$. In connection with the collision quenching of the level $C^3\Pi_{uv'=0}$, the value of τ_{21} decreases with increasing N_2 pressure[9]

$$1/\tau_{21} = 1/\tau^0_{21} + 3.3\cdot10^7 px, \qquad (6)$$

where $\tau^0_{21} = 4\times10^{-8}$ sec is the lifetime at $p = 0$, where p is the mixture pressure in atm.

The relations (5)—(6) explain qualitatively the experimental results. The decrease of the gain and of the output power at high pressures is apparently due to collision quenching, to an increase in the rate of the process (4), and also to an increase in the transition line width.

The laser medium considered here is promising for the production of powerful subnanosecond pulses with large contrast and with efficiency ~2—3% in a multistage system with a driving laser generator.

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