[4] V.N. Grigor'ev, B.A. Gulin, B.N. Esel'son, V.D. Korepanov, and V.A. Mikheev, in: Fizika kondensirovannogo sostoyaniya (Physics of the Condensed State), No. 10, 166 (1970).
[5] V.N. Grigor'ev, B.N. Esel'son, and V.A. Mikheev, Zh. Eksp. Teor. Fiz. 64, No. 2 (1973) [Sov. Phys.-JETP 37, No. 2 (1973)].
[6] D.S. Miyoshi, R.M. Cotts, A.S. Greenberg, and R.C. Richardson, Phys. Rev. A2, 870 (1970).
[7] M.G. Richards, J. Pope, and A. Widom, Phys. Rev. Lett. 29, 708 (1972).

FEASIBILITY OF HIGH-PRESSURE NOBLE-GAS LASERS

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We propose here a new type of noble-gas-discharge laser operating at high pressure (on the order of atmospheric) generating ultraviolet radiation, and having a wavelength tunable over a wide range, on the order of 5000 cm^{-1}. To be specific, we use xenon as an example. The proposed working transition is from the $^3\Sigma_u^+$ state of the Xe_2 molecule (corresponding to an internuclear potential with a minimum [3, 4]) into the $^1\Sigma_g^+$ state. The question of the use of these transitions to produce an optically pumped laser was discussed earlier in [1]. Superradiance of condensed xenon was observed in [2] following excitation of excitons, which are analogous in their nature to the Xe_2 molecule in the $^3\Sigma_u^+$ state by an electron beam.

At moderate temperatures, the lower energy states corresponding to transitions from the $^3\Sigma_u^+$ bound state are practically free; population inversion can be therefore attained relatively easily. The problem is to obtain an acceptable gain and consequently a sufficiently high population of the upper states. The excitation mechanism proposed here is based on the following assumptions: 1) At high pressures, the radiation corresponding to the ^3P - $^1S_0$ transitions is dragged, and this contributes to the attainment of a high $Xe\,^3P$ density in the discharge. 2) If the number of excited atoms per unit volume is N^*, then there exist also N_{un} unstabilized Xe_2 $^3\Sigma_u^+$ molecules, with $N_{un} = N^* Z_{bi} \tau_{st}$, where Z_{bi} is the frequency of the collisions of the excited and unexcited atoms, and τ_{st} is the duration of the collision process. 3) Stabilized Xe_2 $^3\Sigma_u^+$ molecules are produced, with high probability, in the triple $Xe\,^3P + Xe\,^1S_0 + Xe\,^1S_0$ collisions. The inverse process of molecule dissociation in collisions with atoms calls for additional energy and has very low probability at low temperatures. Allowance for such a dissociation does not change qualitatively the arguments that follow. The lifetime of the stabilized molecules is the time of the radiative transition τ_{rad}; the rate of their production is $N^* a Z_{tr}$, where $Z_{tr} \approx Z_{bi}^2 \tau_{st}$ is the frequency of the triple collisions of the excited atoms with the unexcited ones, and a is a probability-theory factor close to unity.

Thus, the production of Xe_2 $^3\Sigma_u^+$ molecules proceeds in two stages: the first is excitation of the atom by electron impact, and the second is the formation of a molecule by collision of the atoms. The kinetics of the system is described roughly by the equations

$$\frac{\partial N^*}{\partial t} = -\frac{1}{\tau} N^* + W ,$$

$$\frac{\partial N_{st}}{\partial t} = N^* a Z_{tr} - N_{st} \frac{1}{\tau_{rad}} ,$$

$$\tau^{-1} = a Z_{tr} + Z_{bi} \tau_{st} \tau_{rad}^{-1} . \tag{1}$$

Here N_{st} is the density of the stabilized molecules and W is the summary rate of production of the Xe ^3P atoms. It is natural to assume that the emission bands are the same for the stabilized and unstabilized molecules. The gain is then determined by the sum $N_{st} + N_{un}$.

If either the time of action Δt of the exciting pulse or τ exceeds τ_{rad}, then it follows from the equations above and from the equality $N_{un} = N^* Z_{bi} \tau_{st}$ that $N_{st} + N_{un} = N^* \tau_{rad}/\tau$. The gain is then

$$K = \frac{\lambda^2 N^*}{4 \Delta\omega \tau} ; \text{ if } \quad \Delta t > \tau , \quad K \approx \frac{\lambda^2}{4 \Delta\omega} W . \tag{2}$$

It was tacitly assumed above that $N^* + N_{st} + N_{un} << N$, where N is the density of the unexcited atoms, i.e., $W \min(\Delta t, \tau) << N$. This condition limits from below the working range of pressures if the gain is specified. Using the relations $Z_{bi} = Z_0 N$ and $N = N_0 p$, where p is the pressure (the temperature is assumed constant throughout), we obtain

$$Z_0 \tau_{st} \tau_{rad}^{-1} N_0^2 (1 + a Z_0 \tau_{rad} N_0 p) p^2 >> \frac{4 \Delta\omega}{\lambda^2} K . \tag{3}$$

For numerical estimates we assume $\lambda = 1750$ Å, $\Delta\omega \simeq 5000$ cm^{-1} [4], $\tau_{rad} \simeq 4 \times 10^{-9}$ sec (the time of the radiative $^3P - {}^1S_0$ transition for xenon [5]), $\tau_{st} \simeq 10^{-12}$ sec, $Z_0 \simeq 10^{-10}$ sec^{-1}cm^3, $N_0 \simeq 3 \times 10^{19}$ cm^{-3}atm^{-1}, and $\varepsilon_0 \simeq 10^{-18}$ J (ε_0 is the energy required to excite one atom). We then obtain from (2) and (3)

$$K \approx 10^{-7} W \epsilon_0 \, \text{W}^{-1} \text{cm}^2 ; \; p^2 (1 + 12 a p \, \text{atm}^{-1}) >> 0{,}4 \, K \, \text{atm}^2 \cdot \text{cm} .$$

Using a pulsed discharge, we can apparently get a power input sufficient to obtain a gain on the order of 0.1 cm^{-1} and higher. Then, as follows from our estimate, it is necessary to operate at pressures higher than atmospheric. At such pressures, the principal role is played by triple collisions, and $\tau \simeq 10^{-7} p^2$ atm^{-2}sec.

The maximum pulse duration is limited by the temperature rise, the rate of which is determined by the ratio of $W \varepsilon_0 \eta$ (η is the fraction of energy converted into heat) to the specific heat per unit volume. For example, at $K = 0.1$ cm^{-1}, $p = 1$ atm, and $\eta = 0.5$ the gas temperature rises 100° within 10^{-7} sec (thus, at pressures below atmospheric the time of loss of inversion through heating can be shorter than τ).

Under quasicontinuous or continuous operating conditions, gains of practical use can be obtained by using a discharge in a thin capillary. The capillary diameter can be estimated from a relation obtained by solving the heat conduction equation:

$$\Delta T \approx \frac{W \epsilon_0 \eta}{16 \kappa} d^2 ,$$

where ΔT is the temperature difference between the cylinder axis and its wall, and κ is the thermal conductivity coefficient of the gas. We assume that a mixture of xenon and helium is used to increase the thermal conductivity, with $p_{He} \gg p_{Xe}$, so that $\kappa \simeq \kappa_{He}$ ($\kappa_{He} \simeq 4 \times 10^{-4}$ cal-deg^{-1}sec^{-1}cm^{-1}). The capillary diameter at $\Delta T \simeq 200°K$, $K \simeq 0.05$ cm^{-1} ($W\varepsilon_0 \simeq 5 \times 10^5$ W-cm^{-3}), and $\eta = 0.5$ is then 0.05 mm.

We note that the presence of helium changes the time τ and leads possibly to other effects, for example to the appearance of the $HeXe\,^3\Sigma^+$ molecule and of a new emission band; relations (2) will remain in force, however.

The development of a molecular xenon laser is perfectly realistic. The use of other noble gases for this purpose may encounter serious difficulties due to the rapid increase of τ_{rad} on going to lighter atoms. In principle, one cannot exclude the possibility of lasing with molecules of the type ArXe, KrXe, etc., produced in collisions $Ar\,^3P + Xe\,^1S_0 + M$, $Kr\,^3P + Xe\,^1S_0 + M$, etc. The time τ_{rad} of such molecules may be shorter than the time of the radiative transition $^3P - {}^1S_0$ in atoms, since the presence of xenon should contribute to violation of the Wigner rule. Several elementary processes that lead to the excitation of noble-gas atoms and to the formation of diatomic molecules by passage of an electron beam through a mixture of argon and krypton or xenon were investigated in [6].

We can expect lasers of this type to have high efficiency and power, and to be tunable in a relatively wide frequency range (~5000 cm^{-1}).

[1] B.L. Borovich and V.S. Zuev, Zh. Eksp. Teor. Fiz. 58, 1794 (1970) [Sov. Phys.-JETP 31, 961 (1970)].
[2] N.G. Basov, O.V. Bogdankevich, V.A. Danilychev, G.P. Kashnikov, O.M. Kerimov, and N.P. Lantsov, Kratkie soobshcheniya po fizike (Brief Commun. on Physics), FIAN, No. 7, 68 (1970).
[3] Y. Tanaka, JOSA 45, 710 (1955).
[4] L.W. Sieck, J. Phys. Chem. 72, 3129 (1968).
[5] O. Kent Anderson, Phys. Rev. 137, 21 (1965).
[6] B. Kravets and S.K. Rodes, Abstracts of Third All-union Conf. on Nonlinear Optics (in Russian), Minsk, 1972, p. 134.

OSCILLATIONS OF A TYPE-II SUPERCONDUCTOR IN A MAGNETIC FIELD

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Andronikashvili, Chigvinadze, et al. [1 - 4] have tested in their experiments an original currentless procedure for the investigation of pinning forces and vortex interactions in type-II superconductors. In these experiments, a superconducting cylinder in the mixed state [5] executes small axial oscillations in a magnetic field perpendicular to the cylinder axis, and the dependence of the frequency and the damping decrement of the oscillations on the field, temperature, sample purity, and other factors is measured (Fig. 1, where the curves are taken from [4]).

The author has advanced elementary theoretical considerations that explain the unusual character of these relations (the damping in the superconducting state is larger than in the normal state!). The increase of the oscillation