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Collisional lasing on a self-terminating transition of a helium atom

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***Abstract*. Laser on a self-terminating transition of a helium atom is studied under excitation of the helium mixture with molecular gases by single long-duration (up to 700 ns) or double nanosecond pulses. In He – H_2O and He – NH_3 mixtures, no limitations were found on the pulse repetition rate and the laser pulse duration obtained was equal to that of the pump pulse.**

Keywords: *collisional lasing, helium laser*.

A promising direction of quantum electronics development is search for new and study of existing gas lasers on atomic media with de-excitation of lower lasing states in inelastic collisions with particles of laser mixtures. Usually, similar collision processes in such lasers are only efficient for a limited number of media and are not general in character (lasers on $n\,^1S_0 - n\,^1D_2$ transitions of the oxygen group [1], inert gas lasers [2, 3], europium- and calcium-vapour lasers [4], etc). In the present study, we try to obtain a collisional lasing on a transition from a resonance state (RS) to metastable state (MS) when lower levels are depopulated through the processes specific for relaxation of almost all levels. Such processes are electron de-excitation and relaxation with the energy transfer to the molecule.

For a test medium we choose a thoroughly studied self-terminating He laser, which operates on the self-terminating transition $2\,^1P_1^0 - 2\,^1S_0$ ($\lambda = 2.06$ μm) with the quantum efficiency reaching 16 % [5]. The rate constant of electron de-excitation from the helium MS $^1S_0$ to the state $^3S_1$ is extremely high $k_e = 4 \times 10^{-7}$ cm^3 s^{-1} [6], which is by an order of magnitude greater than the rate constant of RS on the lasing transition [7]. The helium MS also rapidly relaxes in collisions with various molecules with the rate constants $k_M \approx 10^{-9}$ cm^3 s^{-1} [6].

The He laser was pumped by an electron beam (EB) generated by an open discharge. Such excitation allows one to realise a non-Maxwellian electron energy distribution function needed for lasing by an electron de-excitation mechanism and to obtain lasing in the presence of molecular admixtures [5]. A 12-cm-long laser cell with a diameter of 3.1 cm and radial EB injection was used [5]. The laser was excited by single and double nanosecond pulses from power supplies with a peaking capacitor [5] and by single pulses with the duration of 700 ns generated by a pulse-forming line with an impedance of 4 Ω.

In exciting by single pulses, the lasing duration τ_{max} in pure helium does not exceed 50 ns. For studying the possibility of obtaining a quasi-cw lasing, the active medium was excited by double pulses with the duration of 20 – 30 ns. In Fig. 1, curve (*1*) presents a typical dependence of the lasing energy ratio in the second pulse w_2 to that of first pulse w_1 on the time delay Δt between the pulses in pure helium. One can see that the second pulse lasing starts at $\Delta t \gtrsim \Delta t_{min} \approx 1.25$ μs, which is close to the data for a Pb-laser pumped by an electron beam at $\lambda = 723$ nm [8], the lower level of which is also efficiently depopulated by electrons.

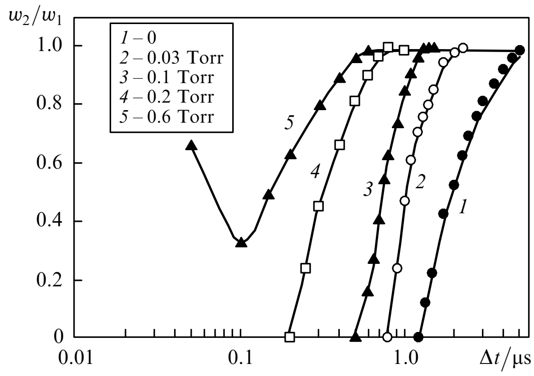

Figure 1. Ratio of the lasing energies in the second (w_2) and first (w_1) pulses versus the delay between the pulses Δt at $p_{He} = 7$ Torr and $p_{H_2O} = 0 - 0.6$ Torr.

Introduction of molecular additives substantially changes the behaviour of lasing in the second pulse. The mixtures of helium with H_2, N_2, O_2, CO_2, H_2O, NH_3, and N_2O were studied. Even a small quantity of these gases reduces Δt_{min}. However, at an increasing pressure of admixtures the lasing in the second pulse exhibits different behaviour in different gases. In the mixtures with dimers, up to the utmost additive pressure at which lasing still occurs we have $\Delta t_{min} \sim 650$ ns (for He – H_2); for CO_2 and N_2O, Δt_{min} is somewhat less. The least value of Δt_{min} is realised in the mixtures with NH_3 (60 ns) and H_2O. In Fig. 1, the

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relative lasing energy in the second pulse w_2/w_1 is presented versus the delay Δt between the pump pulses at various pressures of water vapour. With an increase in p_{H_2O}, the parameter Δt_{min} reduces (an increase in w_2/w_1 at $\Delta t = 60$ ns and $p_{H_2O} = 0.6$ Torr in Fig. 1 is the result of partial overlapping of the first and second pulses at small Δt).

When the mixtures of helium with NH_3 and H_2O were pumped by single pulses, longer lasing pulses were obtained in comparison to the case of pure helium. In the He–H_2O mixtures the lasing pulse is actually symmetric with respect to the rectangular exciting pulse and its duration reaches ~ 600 ns (see Fig. 2). The lasing power in this case compares well with that in the self-terminating regime without H_2O.

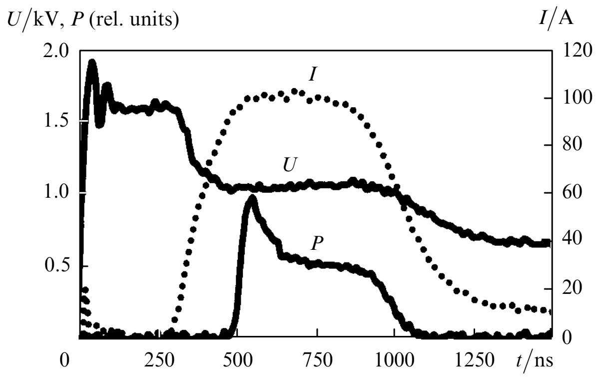

Figure 2. Oscillograms of voltage U, current I, and radiation intensity P in the He–H_2O mixture at $p_{He} = 6$ Torr, $p_{H_2O} = 1.1$ Torr.

The maximal duration of the lasing pulse and electron concentration in the self-terminating regime can be obtained by solving the system of kinetic equations [5] describing populations of RS and MS with cascade transitions taken into account. If the pump power linearly increases with time, the maximal calculated duration of lasing is $\tau_{max} \leqslant 50$ ns and in pumping by a rectangular pulse $\tau_{max} \leqslant 24$ ns, which coincides with the results of the experiment. In the mixtures with NH_3 and H_2O the duration of lasing pulses is by more than an order longer than in pure helium, which proves that the lasing transfers to a collisional quasi-cw operation regime. At the moment of developed lasing the electron concentration n_e reaches 3×10^{13} cm^{-3}, which corresponds to the rate of MS depopulation $k_e n_e = 1.2 \times 10^7$ s^{-1}. If we assume that the rate constant of depopulation for helium MS $^1S_0$ by admixture molecules is $k_M = 10^{-9}$ cm^3 s^{-1} then at their concentration $n \sim 10^{16}$ cm^{-3} the rate of relaxation is $k_M n \approx 10^7$ s^{-1}. Hence, as electrons so and molecular admixtures efficiently depopulate MS. The fact that quasi-cw lasing is only observed in the mixtures of helium with NH_3 and H_2O can be explained by that the vibration states of these polar molecules very quickly relax due to which plasma electrons acquire an efficient cooling channel, which results in quenching the MS helium state $^1S_0$ and obtaining the quasi-cw lasing.

Thus, in the experiments performed, a self-terminating lasing in helium was converted to a quasi-cw regime by using two mechanisms of depopulating a lower lasing state, namely, electron depopulation and quenching of helium metastable states in collisions with molecules.

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