On the mechanism of formation of the population inversion in pulsed rare-earth lasers

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The processes of populating the upper non-resonant laser levels were studied experimentally. It was shown that such levels are populated through collisional transfer of excitation. Both thulium and helium atoms can be collisional partners in excitation transfer.

Lasing is now obtained at six elements of the lanthanide group, namely, samarium, europium, ytterbium, thulium,[1,2] holmium, and dysprosium.[3,4] For the first four elements, the number of lasing transitions was increased in Refs. 5–9. The laser radiation wavelengths mostly lie in the near IR spectral region. A peculiar feature of the rare-earth-vapor lasers is that only in five of almost 40 laser transitions the upper laser level is resonant. In the rest transitions, the upper laser levels have the same parity as the ground state, and they cannot be efficiently populated by direct electron impact in a gas discharge. In Refs. 3–8 it was supposed that the main mechanism for formation of population inversion in this case is collisional transfer of excitation from closely located resonant levels. In this case, collisional partners may be atoms of both the metal and a buffer gas:

$$M^*(R) + M(0) \to M^*(L) + M(0) \pm \Delta E, \qquad (1)$$

$$M^*(R) + R_g \to M^*(L) + R_g \pm \Delta E. \qquad (2)$$

Here $M^*(R)$, $M(L)$, $M(0)$ are metal atoms at the excited resonant level, upper laser level, and the ground state, respectively; R_g are atoms of the buffer gas.

The levels are thought to be closely located, if the energy difference between them $\Delta E < kT_g$, where k is the Boltzmann constant, T_g is the gas temperature.

The objective of this paper was to experimentally check whether the above assumptions are justified or not.

The thulium vapor laser was chosen for this study by two reasons: rather low working temperatures (the pressure of saturated vapor achieves 1 mm Hg at the temperature of 1100°C) and the large number of laser transitions (about 20) having the defect of energy in reactions (1) and (2) $\Delta E = 27–500$ cm^{-1}.

The behavior of laser pulses at variation of the concentrations of thulium n_{Tm} and helium n_{He} (buffer gas) atoms was analyzed in Ref. 8. Based on this analysis, laser transitions can be divided into three groups according to the shape of the lasing pulse and its position with respect to the current pulse. The corresponding oscillograms are depicted in Fig. 1.

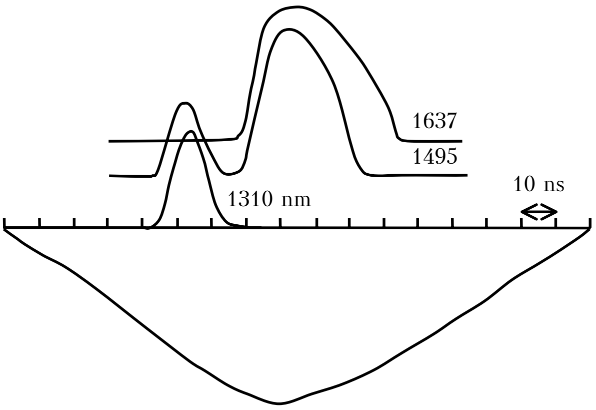

Fig. 1. Shape of laser pulses and their position with respect to the pumping current pulse. The values to the right of the laser pulses show their wavelength in nm.

The first group represented by the transition with the wavelength λ = 1310 nm is distinguished by sensitivity to the concentration of helium; the lasing pulse lies on the leading edge of the current pulse. The second group, for which the lasing pulse lies on the trailing edge of the current pulse, is characterized by operation at very low helium pressure ($P_{\text{He}} < 0.5$ mm Hg). In the third group (λ = 1495 nm) the lasing pulse has two peaks – on the leading and trailing edges of the current pulse.

In this paper, we study the dependence of the laser output power on the concentration of thulium atoms for transitions of the first and second groups. Such information will allow us to judge more certainly on the mechanism of formation of the population inversion.

The experimental setup used is similar to that described in Ref. 9. It included an externally heated gas-discharge tube. The diameter of the gas-discharge channel made of aluminum oxide was equal to 15 mm, and the active zone was 400 mm long. Weighted samples of the working metal were placed directly on the inner surface of the gas-discharge channel all over its length. The temperature in the tube was measured with a Tungsten–Rhenium thermocouple, and the helium pressure was monitored with a VDG-1 vacuometer.

The excitation system was made using the scheme with direct discharge of a reservoir capacitor through the gas-discharge tube. A Model TGI1-1000/25 hydrogen thyratron was used as a switch. The capacitance of the reservoir capacitor was 2.35 nF, and the voltage across it was changed from 2 to 15 kV. The pump pulse repetition frequency was chosen based on the requirement of low energy contribution to heating of the gas-discharge channel due to dissipation of the discharge energy and was 50 Hz. The discharge current was measured with a Rogowski loop. The system for recording of laser radiation consisted of an MDR-23 monochromator, a S7-17 stroboscopic oscilloscope, and a FEU-62 photomultiplier tube. The presence of laser radiation was controlled visually with an image converter.

The laser output power was measured from reflection in the second order of a diffraction grating, which served one of the cavity mirrors. Another (plane) mirror had aluminum coating. A needed laser transition was selected by turning the grating. The power of the laser radiation was measured with an IMO-2N calorimetric detector.

Figure 2 depicts the dependence of the laser radiation power on the concentration of thulium atoms for the lasing lines with $\lambda = 1310$ and 1637 nm. The data were obtained at the buffer gas (helium) pressure of 1 mm Hg and the voltage at the reservoir capacitor of 8 kV.

It can be seen from Fig. 2 that the dependence of laser radiation power on the concentration of thulium atoms is functionally different for the two transitions analyzed: it is linear for the line with $\lambda = 1310$ nm and square for the line with $\lambda = 1637$ nm. This indicates that the population inversion is formed by the reaction (2) at one transition ($\lambda = 1310$ nm) and by the reaction (1) at another one ($\lambda = 1637$ nm). The deviation from the functional dependence for both lines in the upper part is likely caused by the decrease in the electron temperature with the increasing concentration of thulium atoms.

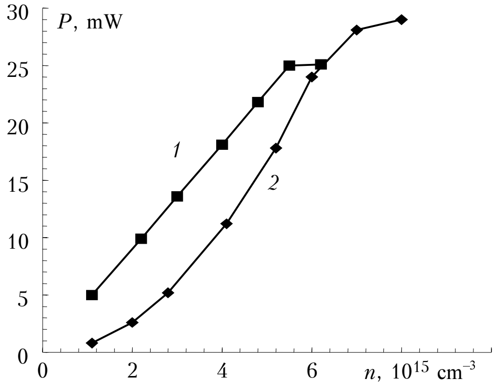

Fig. 2. Dependence of laser output power on the concentration of thulium atoms: $\lambda = 1310$ (curve *1*) and 1637 nm (curve *2*).

Thus, it has been shown that formation of population inversion in lasers with indirect population of the upper lasing levels is caused by collisional transfer of excitation with participation of both thulium and helium atoms.

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