Peculiarities in behavior of the 1101 nm transition in the thulium vapor laser

V.A. Gerasimov and A.V. Pavlinskii

Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk

Received December 5, 2003

The 1101-nm thulium atomic transition has been studied. An abnormal behavior of a lasing pulse under changes of the tube temperature and pump voltage is revealed. Lasing pulse properties are found to depend on the form of the optical excitation of the resonance levels.

The thulium gas-discharge laser is known[1] to have more than 15 lasing transitions in the 600–2000 nm region, but only the 589.9 nm transition has the resonance level as an upper one. Upper lasing levels of other transitions have the same parity as in the ground state and cannot be efficiently excited through collisions between unexcited atoms and electrons.

In this case, as the mechanism for production of population inversion, the collisional transfer of excitation from a close resonant level $\Delta E < kT_g$ to the upper laser level was assumed, where ΔE is the energy defect between the levels; k is the Boltzmann constant; T_g is the gas temperature. Consideration was given to collisions of resonantly excited thulium atoms with those in the ground state and with atoms of the buffer gas (helium).[2]

The study of energy characteristics of the laser radiation at different thulium atomic transitions (the experimental setup was described in Ref. 3) has revealed abnormal behavior of the lasing line at $\lambda =$ $= 1101$ nm.

First, as the GDT heated up, the lasing at this transition has appeared at an abnormally low rectifier voltage (~ 1 kV) and low concentration of thulium atoms, whereas the lasing at other transitions was still absent.

Fig. 1. Oscillograms of the pump current pulse and lasing pulses at different rectifier voltages shown as numbers near curves (in kV).

Second, as the rectifier voltage increased, the laser power grew, reached its maximum at the voltage of about 2.5 kV, then decreased, and vanished at the voltage higher than 4 kV. At further heating of GDT and increasing the concentration of metal atoms, the 1101-nm lasing line appeared along with others.

All this is illustrated in Fig. 1, which depicts the oscillograms of the pump current pulse and lasing pulses at different rectifier voltages.

Figure 2 shows the diagrams of the lasing pulse energy and delay (at the maximum) relative to the current pulse beginning.

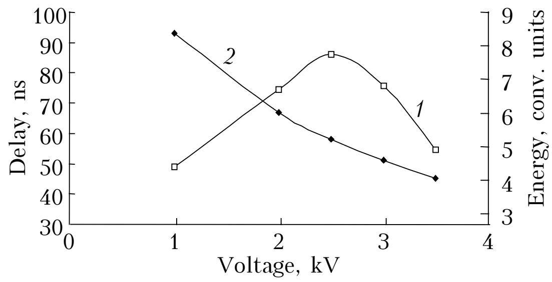

Fig. 2. Energy (*1*) and delay (*2*) of lasing pulses as functions of the rectifier voltage.

Taking into account the fact that the upper lasing level of the 1101-nm transition with the energy $E = 25536$ cm^{-1} lies above the most upper levels of lasing transitions in the thulium atom, the abnormal behavior of the 1101-nm line (lasing at very low pump voltage) puts in doubt the assignment of this transition. In this connection, the assignment was checked as follows. Since the 25536 cm^{-1} level is close to the upper lasing level ($E = 25717$ cm^{-1}) of the self-terminating transition at $\lambda = 589.9$ cm, the correctness of the assignment can be confirmed by the presence of mutual modulation of the lines with $\lambda = 1101$ and 589.9 nm (Fig. 3).

Further study allowed us to find the conditions, under which the visible lasing at $\lambda = 589.9$ nm appeared first during the GDT heating (concentration of thulium atoms $N_{\mathrm{Tm}} = 10^{14}$ cm^{-3}, concentration of helium atoms $N_{\mathrm{He}} = 10^{16}$ cm^{-3}). As the KS-13 filter (opaque at $\lambda < 600$ nm) was inserted in the cavity, the lasing at $\lambda = 1101$ nm (observed in an image-converter tube) appeared, while the visible lasing disappeared. As the concentration of helium atoms was doubled, all other conditions being the same, the 1101-nm line appeared first as the GDT heated up. This fact indicates that the upper lasing level of the 1101 nm transition is populated from the resonant

0235-6880/04/02–03 144-02 $02.00

level, which is simultaneously the upper lasing level for the transition at λ = 589.9 nm, through collisions with helium atoms.

Thus, the experiment has proved the assignment of the transition at λ = 1101 nm.

Fig. 3. Simplified scheme of energy levels for the thulium atomic transitions at λ = 589.9 and 1101 nm.

Having analyzed possible causes of the abnormal behavior of the lasing line under study, we came to the only, from our point of view, explanation. The activity of the lasing transition at very low voltage is caused by the fact that the upper lasing level is populated from three closely located resonance levels: (1) 25656-cm^{-1} level belonging to the configuration $6s6p$ ($^3P_0$) and having the energy defect ΔE = 120 cm^{-1} with respect to the upper level of the 1101-nm transition; (2) 25717-cm^{-1} level ($5d6s^2$) with ΔE = 181 cm^{-1}; (3) 25745-cm^{-1} level ($5d6s^2$), ΔE = 209 cm^{-1}. The oscillator strengths for transitions from these levels, except for the first one, are higher than those for lower-lying transitions.

The relative intensities of the resonance transitions from these levels measured for our excitation conditions turned to be 0.77 for the level of 25717 cm^{-1} and 0.34 for the level of 25656 cm^{-1}. The transition from the resonant level of the 25745 cm^{-1} energy was not observed.

The fact of the lasing disappearance at the transition at λ = 1101 nm with the increasing pump voltage, in our opinion, is connected with the optical excitation function for the resonance levels. As is known, the optical excitation functions of the thulium atom are classified into four types. The excitation function of the type A is depicted in Fig. 4 [Ref. 4].

The excitation functions for the resonance transitions from the levels lying near the upper lasing level with λ = 1101 nm are unknown. But assuming them to correspond to the type A, the behavior of the lasing with the increasing voltage can be explained as follows.

At the beginning of the current pulse, the electron energy at the excitation characteristic of metal vapor lasers is, as is known, 5–10 eV. The excitation function of the type A has the peak before 5 eV. As the electron energy increases above 5 eV, the excitation cross section rapidly decreases. This leads to vanishing of the lasing as the pump voltage and, consequently, the electron energy increase.

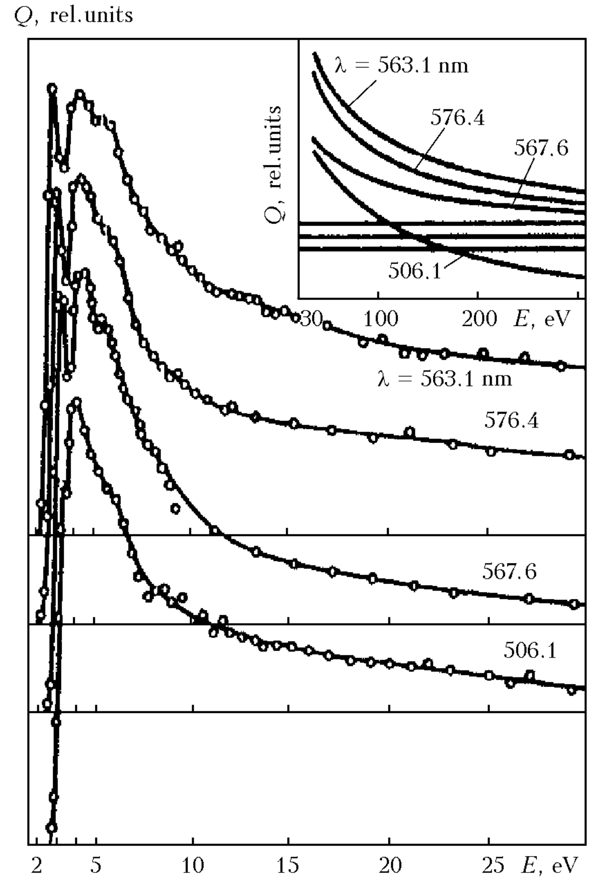

Fig. 4. Optical excitation function of A type.

The subsequent appearance of the lasing with the increasing concentration of thulium atoms also can be explained.

The rate of population of the upper lasing level can be written as

$$V_u = N_{\mathrm{He}} N_i(R_i) \langle \sigma_i(R_i, U_l) v \rangle =$$
$$= N_{\mathrm{He}} N_0 \langle \sigma_i(0, R_i) v_e \rangle \, n_e \langle \sigma_i(R_i, U_l) v \rangle,$$

where v, v_e are the velocities of colliding particles and electrons; N is the concentration of particles; σ_i is the cross section of the corresponding process; R and U are the resonance and upper levels of the lasing.

It is seen from the equation that the decrease of the excitation cross sections can be compensated by the increase of the concentration of thulium atoms, just as observed experimentally.

References

1. V.A. Gerasimov and B.P. Yunzhakov, Sov. J. Quant. Electron. **19**, No. 12, 1532–1536 (1989).
2. V.A. Gerasimov and A.V. Pavlinskii, Atmos. Oceanic Opt. **16**, No. 4, 352–353 (2003).
3. V.A. Gerasimov and L.N. Starkova, Pis'ma Zh. Teor. Fiz. **27**, No. 2, 51–55 (2001).
4. L.L. Shimon, I.I. Garga, V.N. Kachanov, and I.V. Kurta, Opt. Spektrosk. **55**, No. 1, 22–29 (1983).