An experimental investigation of a high PRR strontium-vapor laser

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A self-terminating laser operation in strontium atoms (SrI) at 6.45 μm and singly-charged ions (SrII) at 1.03 and 1.09 μm producing light over a wide range of pulse repetition rates is investigated. The record pulse repetition rate obtained experimentally is 100 kHz.

Self-terminating metal-vapor lasers (MVLs) occupy a special place in a wide class of currently available coherent light sources. This is due to a unique combination of the laser output parameters: high peak and average power, nanosecond pulse duration, diffraction-limited beam divergence, and high pulse repetition rate (PRR).

A promising field of MVL application is atmospheric optics, including the spectroscopy and analysis of atmospheric gases, remote sensing of the atmosphere, etc. Since MVLs are typical representatives of repetitively pulsed lasers, the feasibility of improving their output characteristics is primarily associated with an increase in the lasing PRR.[1] High PRR laser operation (tens and hundreds of kilohertz) opens up fundamentally new possibilities for practical MVL application, among which is the use of systems for atmospheric optics (side-looking radars, visual navigation devices, computer-based laser graphics in the atmosphere, etc.) However, operation of high PRR pump MVLs has not been adequately studied. To realize this operating mode is of great importance not only for applied research but also for gaining insight into the physical processes that limit the PRR and energy performance of the lasers in question. It is the aim of this work to study experimentally a strontium-vapor laser (SrVL) operated at high PRRs.

1. Experimental setup and technique

The experiments under consideration were performed with the use of a 5 mm diameter 150 mm active length gas-discharge tube. The SrVL active volume is confined by BeO tube walls and end electrodes. The vacuum housing was made from fused quartz and the windows were fabricated from Ba_2F. Pellets of solid strontium were uniformly distributed over the gas-discharge channel. The buffer gas was neon at a pressure of 60 Torr. The block diagram of the experimental arrangement is shown in Fig. 1.

The plane-parallel laser cavity was formed from a totally reflecting Al mirror *1* and a transparent BaF_2 plate *2*. A power supply provides pulse voltage across the gas-discharge tube (GDT). The pump circuit incorporated a tacitron TGU1-5/12 that served as a switch. The current and voltage waveforms, amplitudes, and duration were recorded by means of an oscilloscope S1-75.

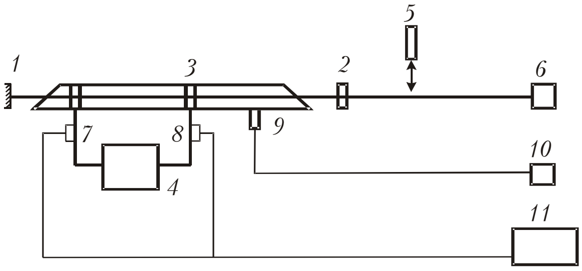

Fig. 1. Block diagram of the experimental setup: totally reflecting mirror *1*; transparent Ba_2F plate *2*; gas discharge tube *3*; power supply *4*; light filter *5*; calorimetric power meter *6*; voltage and current meters *7* and *8*; thermocouple *9*; millivoltmeter *10*; oscilloscope S1-75 *11*.

The latter received signals from a Rogowsky coil and a voltage divider. The power delivered to the GDT was kept constant, the rectified voltage was 3 kV, and the current was 150 mA. The average lasing power was taken by a calorimetric power meter IMO-2N. The spectral content of the laser radiation was investigated, using light filters that passed radiation in two lasing lines near 3 μm (SZS-8) and in ionic lines at λ = 1.03 and 1.09 μm (SZS-20).

2. Gas temperature calculation

The gas temperature T_g is an important gas-discharge plasma parameter. In particular, T_g in MVLs governs the thermal population of metastable states responsible for the inversion in the active medium and in its turn depends on average energy deposition in the discharge chamber, its design features, and thermal conductivity of the buffer gas.

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The gas temperature distribution along the GDT axis for uniform heat release along the discharge channel as a function of time can be written as[2]:

$$T_\mathrm{g}(0) = \left[T_\mathrm{wall}^{B+1} + \frac{3\delta W_\mathrm{n}(B+1)}{8\pi A}\right]^{1/(B+1)}.$$

Here the thermal conductivity of the buffer gas is approximated by the expression $K = AT_\mathrm{g}^B$ (for neon $A = 8.96 \cdot 10^{-6}$ W/(cm · $\mathrm{K}^{1.683}$), $B = 0.683$); T_wall is the GDT wall temperature; W_n is the power deposited per unit length of the tube; δ is the fraction of $P_\mathrm{u.l}$ expended for heating the gas. Based on the experimental data, the calculations assumed that δ decreased as the PRR was increased, whereas T_wall decreased but slightly with increase in the PRR.

The gas temperature was calculated for constant power delivered to the GDT and varying PRRs. Figure 2 shows variations of the gas temperature with PRRs. As PRR is increased, the gas temperature along the GDT axis is seen to decrease. While the input power is fixed, the energy deposition per pulse is decreased with increase in the PRR.

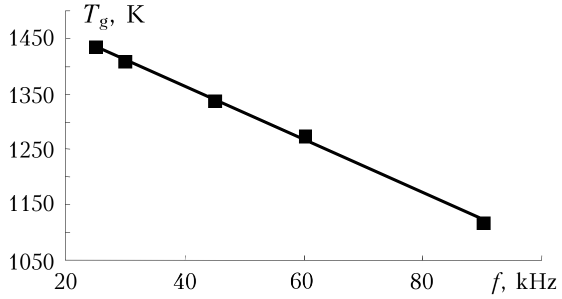

Fig. 2. Gas temperature along the GDT axis versus pulse repetition rate.

The calculated results suggest that the transverse nonuniformity of the gas and Sr-vapor temperature distributions is reduced with increase in the pump PRR. This improves the transverse discharge uniformity and decreases the prepulse plasma microcharacteristics, other things being equal.

3. Basic results

In the course of the experiments, Sr-vapor laser action was obtained in the atomic line at 6.4567 μm ($5p^1P_1^0 - 4d^1D_2$) and in the ionic lines at 1.0917 μm ($4p^65p^2P_{1/2}^0 - 4p^64d^2D_{3/2}$) and at 1.0330 μm ($4p^65p^2P_{3/2}^0 - 4p^64d^2D_{5/2}$). No laser action was observed at 3.0665 μm ($4d^3D_1 - 5p^3P_2^0$) or at 3.0111 μm ($4d^3D_2 - 5p^3P_2^0$). According to Ref. 4, this fact may be accounted for in the following way. The $5p^3P_2^0$ metastable level (λ ~ 3 μm) lies much lower in the energy level diagram than the $4d^1D_2$ metastable level (λ ~ 6.45 μm). As a consequence, the thermal population of the lower $5p^3P_2^0$ laser level is higher than that of the $4d^1D_2$ level. This increases the lasing threshold for λ ~ 3 μm. As the GDT wall temperature is increased, the fractions of the laser radiation at λ = 3.01 and 3.06 μm are reduced substantially. For a wall temperature above T_wall = 700°C the laser action disappears. No distinct peaks are observed on the plots of the average lasing power versus excitation PRR in the 20–100 kHz range (Fig. 3). The estimated data show that PRRs above 100 kHz are feasible.

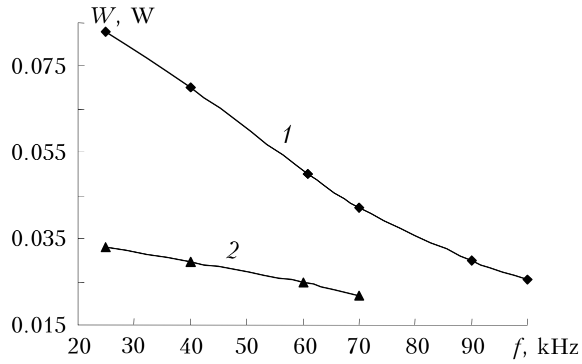

Fig. 3. Total average lasing power for all laser transitions (*1*) and at λ ~ 1 μm (*2*) versus excitation pulse repetition rate.

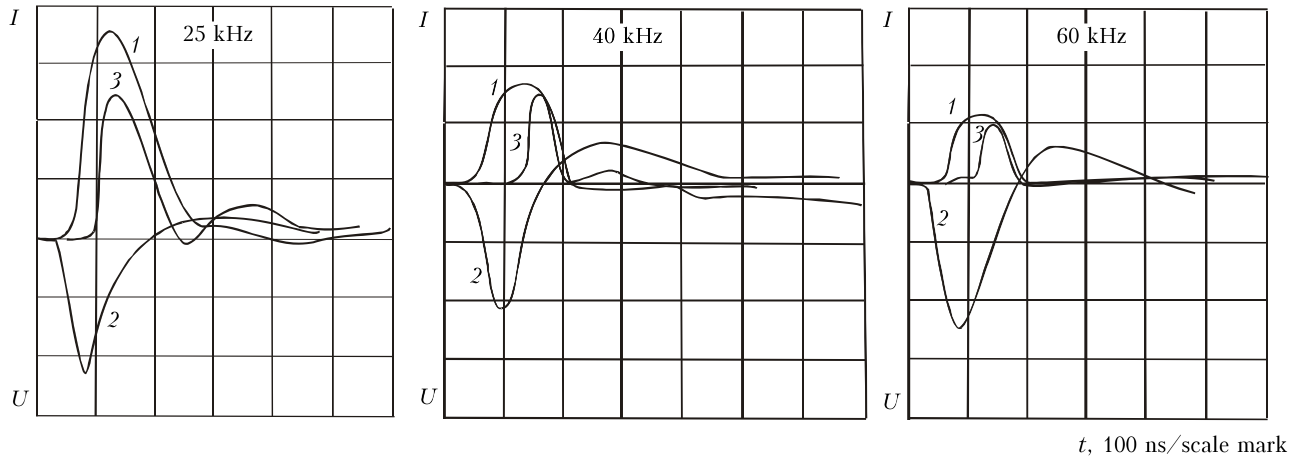

Fig. 4. Oscilloscope traces of current (*1*), voltage (*2*), and lasing pulse waveforms (*3*) for varying excitation pulse repetition rate.

It is shown in our earlier paper[3] for a copper-vapor laser that deleterious influence of cumulative effects in the repetitively pulsed discharge plasma must be lessened if the lasing PRR is to be increased. For the SrVL under consideration, this is accomplished by decreasing the deposited energy per pulse for the same average pump power. It takes a longer time to produce a population inversion needed for exceeding the lasing threshold at high PRRs and the lasing pulse is shifted to the trailing edge of the current pulse (Fig. 4).

Increasing the excitation PRR not only shortens the laser pulse but also reduces the pulse energy. For an excitation PRR of 25 kHz, the lasing pulse duration (FWHM) was 70 ns, whereas for 60 kHz, it was 35 ns. The highest lasing PRR realized in our SrVL experiments was 100 kHz.

Summary

A Sr-vapor laser with a gas-discharge channel diameter of 5 mm and an active length of 150 mm operated at PRRs in the 20–100 kHz range was investigated experimentally.

The gas temperature as a function of the excitation pulse repetition rate was calculated. As the pulse repetition rate was increased, the neon buffer gas temperature was decreased and the transverse nonuniformity of the temperature distribution was reduced.

A record lasing pulse repetition rate for the Sr-vapor laser as high as 100 kHz was obtained in the early stage of the experiments. The laser source under consideration holds much promise for higher pulse repetition rate operation.

Outstanding energy characteristics realized in the laser (total lasing power of 13.5 W and pulse energy of 1.16 mJ, Ref. 5) lead us to suggest that improvements in the energy performance of the SrI and SrII laser at high pulse repetition rates are feasible and further investigations along these lines are warranted.

References

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