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Strontium vapour laser with a pulse repetition rate of up to 1 MHz

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Abstract. **For the first time it has been shown that the pulse repetition rate of the lasers on the self-terminating transitions of metal atoms may be as high as ~1 MHz. The highest pulse repetition rate equal to ~830 kHz was realised on self-terminating IR transitions in Sr I atoms (λ = 6.456 μm and ~3 μm) and in Sr II ions (λ ~ 1 μm) in a strontium vapour laser operating in a self-heating pulse periodic regime. The energy yield of a Sr laser was found to be proportional to the energy input into the active medium in a wide range of excitation pulse repetition frequencies; in this case, the average total specific output laser power is equal to 30 – 40 mW cm^{-3}.**

Keywords: *strontium vapour laser, pulse periodic regime.*

1. Introduction

A strontium vapour laser (SVL) is a high-efficiency source of IR radiation operating on self-terminating transitions in Sr I atoms with wavelengths λ = 6.456 μm and ~3 μm (2.60, 2.69, 2.92, 3.01, and 3.06 μm) and in Sr II ions with λ ~ 1 μm (1.091 and 1.033 μm) (Fig. 1). The output SVL wavelengths were found to fall within the absorption bands of polymers and biotissues. A high absorption coefficient for laser radiation at these wavelengths ensures efficient ablation, making it possible to employ this laser in medicine as well as in the processing of polymers [1].

Realised to date are an average SVL output power of ~13.5 W and an output power of 22 W in an 'oscillator–amplifier' regime. In this case, the energy yield of the laser rises proportionally with the volume of its active medium. Along with lasing on the self-terminating transitions in strontium atoms and ions, lasing was obtained on the self-terminating transition $2\,^1P_1 - 2\,^1S_0$ in helium atoms (λ = 2058 nm) and on the 2s – 2p transitions in neon atoms in a He – Ne – Sr mixture. An ionisation-recombination SVL regime was realised, whereby there occurred lasing on the λ = 430 nm line in Sr II ions along with the lasing on the self-terminating transitions in strontium atoms and ions [2 – 7]. A laser pulse repetition rate (PRR) of ~100 kHz was achieved in the experiments [2]. In this case, numerical simulations [8] showed that the limiting PRR of a strontium vapour laser may as high as ~1 MHz. This generates the necessity of investigating the output energy characteristics of SVLs at a high excitation PRR.

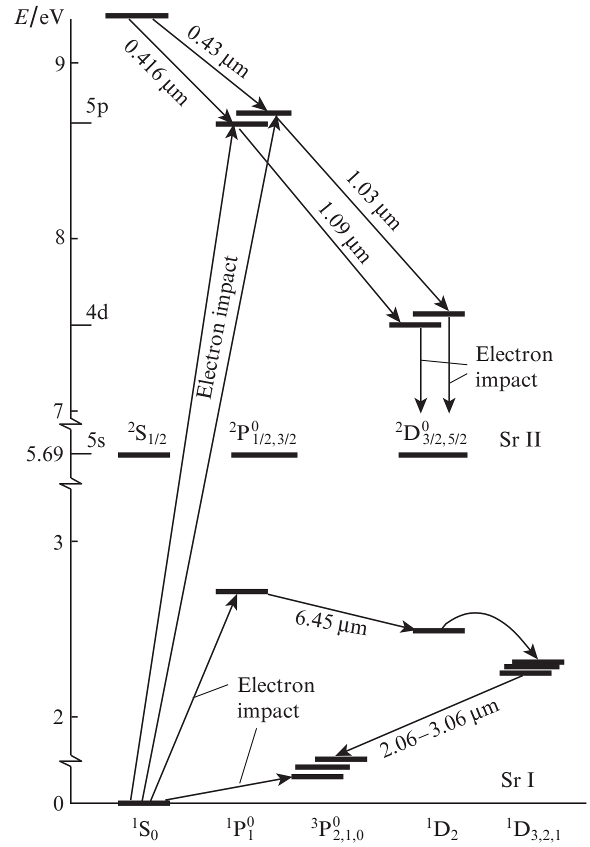

Figure 1. Diagram of laser transitions in atomic and ionic strontium.

In the present work we carried out experiments in the self-heating regime of an SVL with a gas-discharge tube (GDT), in which the discharge channel was made of ceramic BeO tube with an inner diameter of 8 mm and a working volume of 9 cm^3. Helium and neon were employed as buffer gases. The active medium was pumped by a discharge of a storage capacitor with a capacitance of 235 – 470 pF into the GDT [9 – 11]. A TGU1-60/7 tacitron served as a switch. The excitation PRR was equal to 120 – 830 kHz; the voltage of a high-voltage rectifier was U_{hv} = 0.65 – 1.35 kV. The pulses of current, voltage, and lasing were recorded with the help of a Rogowski loop, a Tektronix P6015A voltage-measuring probe, and FEK-24 and FSG photodetectors. The recorded signals were fed to a Tektronix TDS-3034B oscilloscope. The average output power was monitored with a Nova II (OPHIR) power meter. The

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inductance of the charging choke in the charging circuit of the storage capacitor was equal to ~5 mH and was selected on the condition of resonance storage-capacitor charging for an excitation PRR of ~200 kHz.

Simulations of the resonance charging of the storage capacitor via the charging choke show that the high-voltage rectifier charges the storage capacitor in this case to the double voltage $\sim 2U_{hv}$ for an excitation PRR below 200 kHz and that the voltage across the storage capacitor decreases practically linearly by a factor of two as the excitation PRR changes from ~200 to ~800 kHz. Accordingly, the energy stored in the storage capacitor decreases approximately four-fold, which enables us to automatically maintain the self-heating laser mode without changing the capacitance of the storage capacitor and the output voltage of the high-voltage rectifier as the excitation PRR is so changed.

Experimental investigations of SVL energy characteristics performed under the conditions specified above enabled us to raise the lasing PRR to a maximum of 830 kHz. In this case, with increasing excitation PRR we observed a variation of the average output power (Fig. 2) without variations of the spectral composition of the laser radiation. As the excitation PRR was changed from 250 to 830 kHz, the total output laser power in all laser radiation lines lowered by less than 25%. In the investigation of lasing on the self-terminating transitions of Sr II ions, with increase in excitation PRR the half-amplitude duration of laser pulses shortened to several nanoseconds (Fig. 3). At the same time, the lasing in Sr I atoms on $\lambda = 6.456$ μm terminated only on cessation of an excitation pulse (Fig. 4).

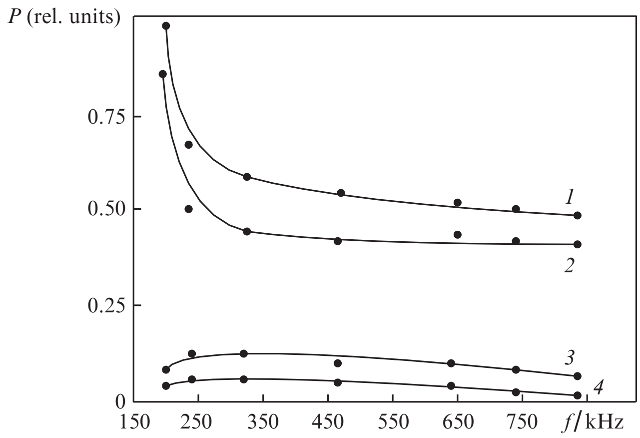

Figure 2. Total average output laser power (*1*) and average output power in the lines with $\lambda = 6.456$ μm in Sr I atoms (*2*), ~1 μm in Sr II ions (*3*), and ~3 μm in Sr I atoms (*4*) as functions of excitation PRR for a buffer gas (a He–Ne mixture) pressure of 60 Torr and a storage capacitor capacitance of 330 pF.

Figure 5 shows the pulsed current–voltage discharge characteristics for different excitation PRRs. With increase in PRR we observed an insignificant efficiency lowering of the energy input into the GDT; its average value was equal to ~45% (relative to the rectifier power takeoff) throughout the interval of PRR variation for a buffer gas (a He–Ne mixture) pressure of approximately 90 Torr. The total output laser power lowered two-fold when the buffer gas pressure was increased by almost a factor of three (Fig. 6). Interestingly, for a helium pressure of ~80 Torr the average output power

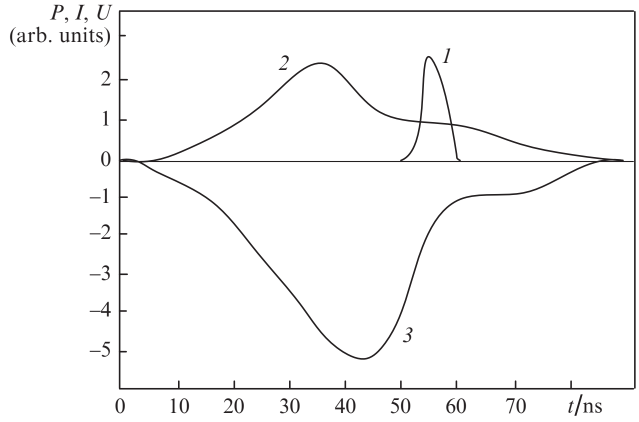

Figure 3. Oscilloscope traces of a laser pulse (*P*) at $\lambda \sim 1$ μm in Sr II ions (*1*), of current *I* (*2*) and voltage *U* (*3*) pulses for a PRR of ~150 kHz, a buffer gas (a He–Ne mixture) of 38 Torr, a storage capacitor capacitance of 330 pF, and a total average output laser power of 335 mW.

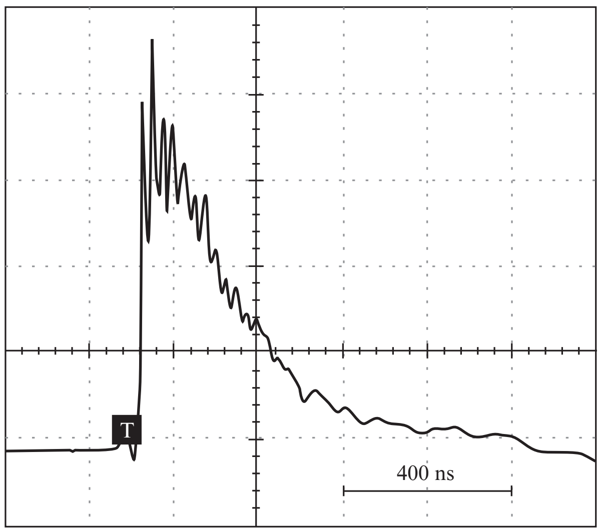

Figure 4. Oscilloscope trace of a laser pulse at $\lambda = 6.456$ μm (because of the photodetector response time, the pulse duration is substantially longer than the true one, which does not exceed the excitation pulse duration).

of the group of Sr II lines with $\lambda \sim 1$ μm was one-and-a-half times the output power at $\lambda = 6.456$ μm in Sr I atoms. The total power of lasing at the $\lambda \sim 3$ μm Sr I line group for a helium pressure up to 100 Torr remained virtually constant and lowered insignificantly on further increase of the pressure. The efficiency of pumping of the active medium substantially lowered with increase in buffer gas pressure: by a factor of two on raising the pressure by almost a factor of three.

The experimental investigations carried out in our work bear out the conclusions drawn from numerical simulations [8] that the lasing PRR in a pulse periodic laser on the self-terminating transitions of strontium may be as high as ~1 MHz. The limiting PRR (830 kHz) of the Sr laser in our experiments was restrained by the resonance charging of the storage capacitor rather than by the processes in the active medium of the laser: all self-terminating IR transitions in Sr I atoms and Sr II ions exhibited lasing up to the values of excitation PRR

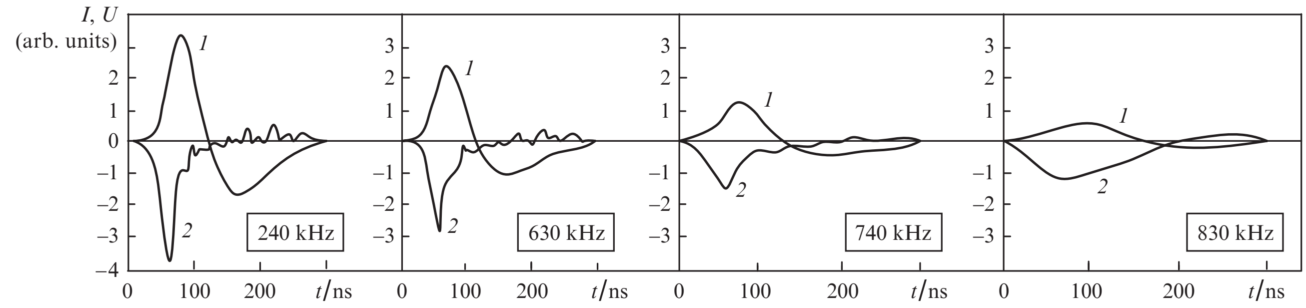

Figure 5. Oscilloscope traces of current (*1*) and voltage (*2*) pulses for different PRRs in the 240–830 kHz range.

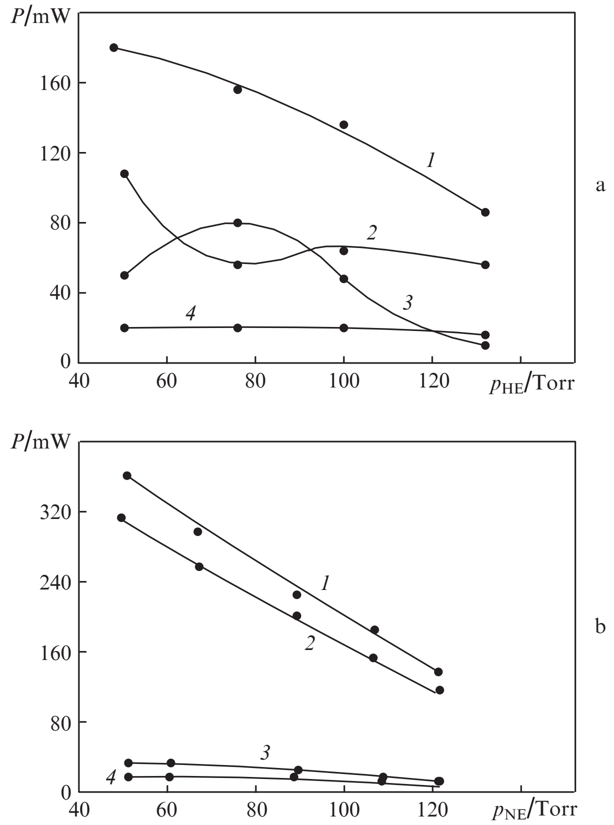

Figure 6. Total average output laser power (*1*) and average output power in the lines with λ = 6.456 μm in Sr I atoms (*2*), ~1 μm in Sr II ions (*3*), and ~3 μm in Sr I atoms (*4*) as functions of helium (a) and neon (b) buffer gas pressures for a lasing PRR of 242 kHz and a storage capacitor capacitance of 470 pF.

whereby the storage capacitor could still be charged to a voltage exceeding the excitation threshold value.

The resultant experimental data suggest that the threshold conditions for the pumping of the active medium of a Sr laser are realised for a field intensity of 30–40 V cm^{-1}, while the optimal field intensity is equal to 100–200 V cm^{-1}. In this case, the energy yield in the Sr vapour laser in proportional to the energy input into the active medium in a wide range of excitation PRRs. The low threshold values of the *E*/*p* ratio (~0.2 V Torr^{-1} cm^{-1}), which make possible the quasi-continuous [12, 13] and cw [14] lasing in alkali-earth metal vapour lasers, underlie the fact that a rather high specific average output power (30–40 mW cm^{-3}) was achieved at high PRRs in our experiments. This value of specific output power corresponds to that obtained previously in an SVL with an active medium volume up to 650 cm^3 for a lasing PRR of 10–20 kHz [7].

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