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Experimental study of multipass copper vapour laser amplifiers

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***Abstract*.** **Repetitively pulsed multipass copper vapour amplifiers are studied experimentally. A considerable increase in the peak power of laser pulses was achieved by using a special scheme of the amplifier. It is found that the main reasons preventing an increase in the peak power during many passages of the beam are the competitive development of lasing from spontaneous seeds in a parasitic resonator formed by the fold mirrors of a multipass amplifier, a decrease in the amplification during the last passages, and an increase in the pulse width at the amplifier output.**

Keywords: *copper vapour laser, multipass amplifier, peak radiation power.*

1. Introduction

Double- and four-pass amplifiers [1 – 4] assembled by using a special scheme [5, 6] can provide a considerable increase in the peak power of laser pulses by preserving the average output and pump powers at a previous level. Such amplifiers can be employed in many technological applications requiring high peak powers at low average powers. The increase in the peak power in multipass copper vapour amplifiers (MCVAs) is achieved after the multipass propagation of a laser pulse from a master oscillator (MO) through the active medium of the amplifier, the laser pulse duration τ_{os} being two – four times shorter than the inversion lifetime τ_{inv} in the active medium. It is assumed that a short input pulse acquires from the active medium and accumulates energy approximately equal to that accumulated by a long input pulse with $\tau_{os} \geqslant \tau_{inv}$ in a single-pass scheme (with the same active medium volume) and, therefore, its amplitude is approximately greater by a factor of τ_{inv}/τ_{os}. Indeed, this assumption was confirmed in experiments with a double-pass amplifier [2, 3].

Below, we present the results of experiments with a four-pass copper vapour amplifier. We also compared and analysed amplification processes in double- and four-pass amplifiers. In the case of a four-pass amplifier, we encountered effects that were difficult to estimate quantitatively beforehand. As a result, increase in the peak power under our experimental conditions proved to be considerably smaller than the expected fourfold increase. Detailed studies revealed the main factors restricting the increase in the peak power and indicated the methods of their elimination. The results obtained in the paper can be used to analyse physical processes proceeding in MCVAs and to develop further these amplifiers.

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2. Experimental

Figure 1 shows the scheme of a four-pass copper vapour amplifier with counterpropagating polarisation-decoupled beams. The amplifier consisted of master oscillator (MO) (*1*), spatial filter (*2*), polarisation beamsplitters (*3*) and (*5*), Faraday rotator (*4*), amplifying stage (AS) (*6*), and laser-beam retroreflector units (*7*) and (*8*). Retroreflector unit (*7*) (reflecting the laser beam after the first and third passages) consisted of phase quarter-wave plate (*9*) and plane mirror (*10*), while retroreflector unit (*8*) (reflecting the laser beam after the second passage) consisted of one plane mirror. Polarisation beamsplitter (*5*) was rotated through 45° with respect to beamsplitter (*3*) in the direction of optical rotation by the Faraday rotator.

The master oscillator based on a LT-4 Cu laser tube and an unstable resonator with a magnification of 200 was equipped with a polariser. It generated radiation pulses at 0.51 and 0.578 μm with the electric vector $\boldsymbol{E}$ in the horizontal plane. Telescopic collimator (*2*) (also used as a spatial filter) expanded the laser beam diameter up to 20 mm and separated the part of the beam with divergence equal approximately to four diffraction divergences. Amplifying stage (*6*) was based on a GL-201 tube of diameter 20 mm with the working chamber length $L_{amp} = 80$ cm.

The direction of the first and third passages of the laser beam in the AS is denoted by J^+, and of the second and fourth – by J^- (Fig. 1). Each of the beams occupied the entire cross section of the AS tube.

The output pulse from the MO passed through beamsplitter (*3*), Faraday rotator (*4*) (rotating the vector $\boldsymbol{E}$ by 45°), second beamsplitter (*5*), AS (*6*), and entered retroreflector unit (*7*). The back reflected radiation beam acquired the orthogonal initial polarisation, passed backward again through AS (*6*) and was deflected in beamsplitter (*5*) to plane mirror (*8*). After reflection from this mirror (without changing polarisation), the beam passed through amplifier (*6*) and again entered retroreflector unit (*7*), where it acquired the initial polarisation of the first beam (passage). As a result, the beam

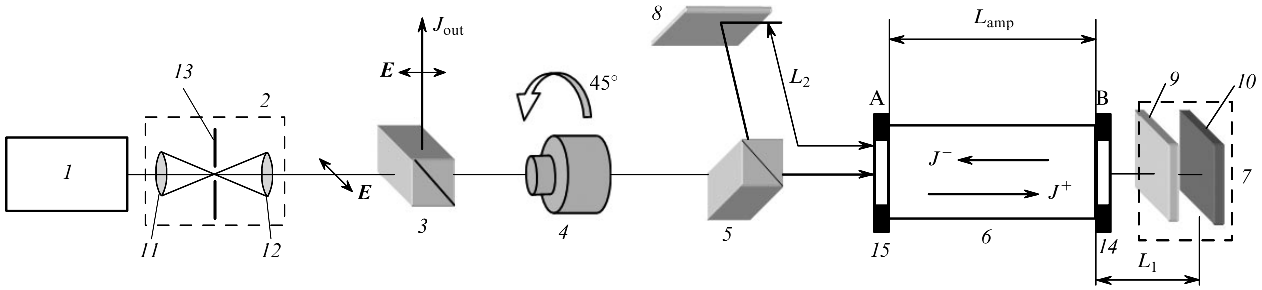

Figure 1. Scheme of a four-pass copper vapour amplifier: (*1*) master oscillator; (*2*) spatial filter; (*3, 5*) polarisation beamsplitters; (*4*) Faraday rotator; (*6*) amplifying stage; (*7, 8*) beam retroreflector units; (*9*) phase quarter-wave plate; (*10*) plane mirror; (*11, 12*) lenses; (*13*) aperture of the MO spatial filter; (*14, 15*) amplifying stage windows; (A, B) discharge chamber sections.

propagated backward during the fourth passage through prism (*5*) and Faraday rotator (*4*), which again rotated the polarisation plane through 45°. The polarisation of the radiation beam became orthogonal to that of the initial MO beam and the beam was coupled out from the amplifier with the help of beamsplitter (*3*).

Note that the optical rotation of a Faraday rotator considerably depends on the radiation wavelength. Because of this, a Faraday rotator was developed and manufactured to our order which had the parameters of a magnetooptical medium specially selected to provide optical rotations at two laser wavelengths that were only slightly differed from 45° (by $+7°$ for the green line and $-7°$ for the yellow line). Polarisation losses of the radiation energy of the amplifier in elements (*3*), (*4*), and (*5*) (Fig. 1) did not exceed 2 %. The same loss was introduced by the phase quarter-wave plate used to operate at the two radiation lines of the amplifier.

To increase the peak power, the values of τ_{os}, τ_{inv}, the total delay τ_{del} of the laser pulse in retroreflector units, the active medium length L_{amp} in the amplifier, and the number N of passes should be connected by certain relations obtained in [2, 5, 6]. For the same pulse delays in both retroreflector units ($L_1 = L_2$), we have

$$\tau_{os} \approx \tau_{inv} - \frac{NL_{amp}}{c} - \tau_{del}, \tag{1}$$

$$\tau_{os} \geqslant \left(\frac{2L_{amp}}{c} + \tau\right), \tag{2}$$

where $\tau_{del} = \tau(N-1)$; $\tau = 2L_1/c$; and c is the speed of light.

Expression (1) was obtained from the requirement that one MO pulse completely covers (during N passages) the time interval equal to the inverse-population lifetime in the AS. Condition (2) provides the complete filling of the working volume by one MO pulse during the inversion lifetime (see [2]). The delays τ_{del} and τ of the radiation pulse in retroreflector units and, correspondingly, distances L_1 and L_2 from sections A or B of a discharge chamber with the active medium to mirrors (*8*) or (*10*) were chosen to satisfy the above relations for a four-pass scheme for $N = 4$ and the specified value of τ_{os}. A double-pass amplifier scheme differs from the scheme in Fig. 1 by the absence of elements (*4*), (*5*), and (*8*).

The average radiation power W_{in} incident on AS (*6*) and the average amplified radiation power W_{out} were measured with an IMO-4S calorimeter. The shapes of radiation pulses $U_{in}(t)$ and $U_{out}(t)$ and the superradiance pulse $U_s(t)$ of the AS were recorded with FEK-22spu photocells and a 3.7-GHz stroboscopic oscilloscope. The oscillograms of the radiation pulses were connected to the time axis taking into account delays in optical measurement paths and in the four-pass variant they corresponded to the position of pulses $U_{in}(t)$, $U_{out}(t)$, and $U_s(t)$ in section A. All these quantities were measured separately at the green and yellow emission lines.

3. Experimental results and discussion

The MO pulse duration was reduced down to the value $\tau_{os} \approx 8 - 10$ ns determined by conditions (1) and (2) by increasing the distance between the highly reflecting resonator mirror and the MO tube, as was done in [7]. Figure 2a presents the shape of MO pulses at the AS input. The ratio of the MO pulse amplitudes for the yellow and

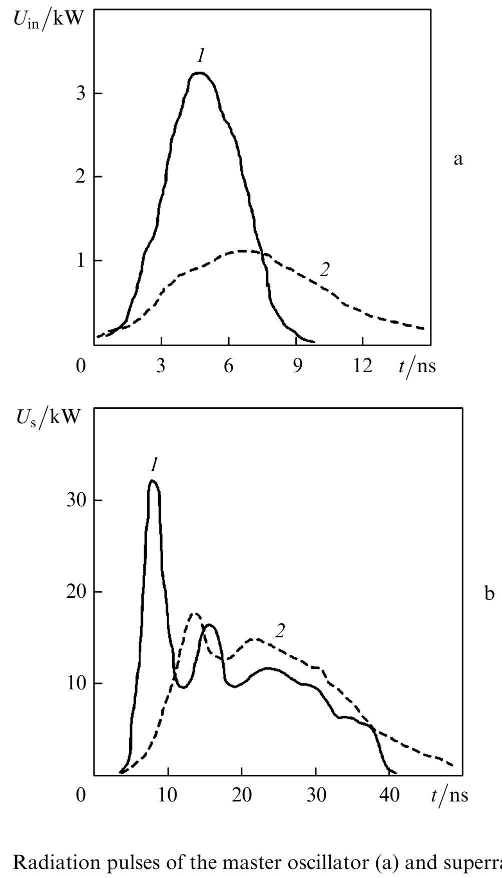

Figure 2. Radiation pulses of the master oscillator (a) and superradiance of the amplifying stage (b) for $\lambda_1 = 0.51$ μm (*1*) and $\lambda_2 = 0.578$ μm (*2*).

green lines was $\sim 1/3$. The base duration of pulses for the green and yellow lines was 8–9 ns and 14–15 ns, respectively. The average (total over wavelengths) MO radiation power at the AS input was $W_{in} \approx 0.25$ W at a pulse repetition rate of 10 kHz. The inversion lifetime τ_{inv} in the amplifier was assumed equal to the AS superradiance pulse duration measured from oscillograms (Fig. 2b) obtained in the absence of the MO signal and for covered mirrors (*8*) and (*10*) (see Fig. 1). The inversion lifetime τ_{inv} in the AS for the green and yellow lines was ~ 35 and ~ 45 ns, respectively, for a typical electrical pump power of 3.0–3.2 kW. The best ratio $\tau_{inv}/\tau_{os} \approx 4$ for the four-pass amplifier was achieved for the green line, while this ratio for the yellow line was only $\tau_{inv}/\tau_{os} \approx 3$.

Figure 3a shows the output pulse (total over wavelengths) of the four-pass amplifier for the optimal delay between the MO and AS pump pulses. The central peak is the MO pulse amplified after four passages. This pulse disappears in the absence of the MO pulse, whereas the amplitudes of side peaks noticeably increase in this case and merge to one pulse. The divergence of the radiation beam measured in this case proved to be very large (7–10 mrad) and its duration was ~ 30 ns, which is typical for plane–parallel cavity copper vapour lasers. If mirror (*10*) is covered or mirrors (*8*) and (*10*) are misaligned, the merged peaks will also disappear. All this suggests that side emission peaks are related to the development of lasing (from spontaneous seeds) in a 'parasitic' resonator, which is formed by the same fold mirrors of the multipass amplifier. In this case, a competition takes place between this lasing and amplification of the input MO pulse.

Special measurements showed that approximately 50 % of the output energy of the four-pass amplifier is emitted in the form of parasitic lasing. This part of radiation (with a high divergence) can be filtered at the AS output with the help of an additional spatial filter. The filtered radiation pulse is shown in Fig. 3b. One can see that its peak power did not increase (cf. Fig. 3a) because upon filtration at the AS output, parasitic lasing inside the AS cavity is preserved and still reduces the useful pulse energy. Note that the base duration τ_{out} of the central peak noticeably exceeds the MO pulse duration τ_{os} (see Table 1).

To observe the evolution of amplification of the MO pulse successively passing through the AS, we used a simple method by mounting weakly transmitting ($\sim 1\%$) mirrors (*8*) and (*10*) (Fig. 1). The radiation transmitted by the mirrors was detected with photocells placed behind them. Because the laser beam is directed to mirror (*10*) only after the first and third passages, while to mirror (*8*) – only after the second passage, the radiation pulses detected behind the mirrors are well separated in time in oscillograms.

Figure 4a shows the oscillograms of 0.51-μm radiation pulses obtained by the method described above, which demonstrate the amplification of pulses after each passage in the four-pass amplifier. The oscillogram of radiation transmitted through mirror (*10*) (heavy curve) contains not only radiation peaks observed after the first and third passages (1B and 3B, respectively) but also additional

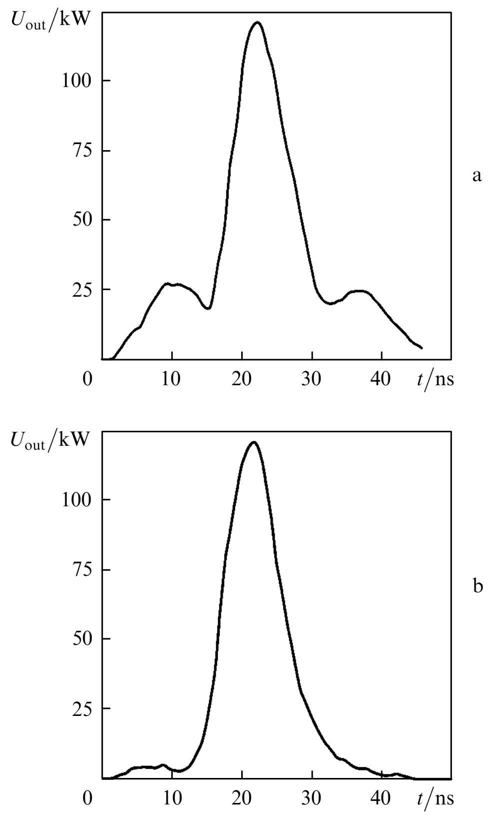

Figure 3. Output pulse (total over the wavelengths) of the four-pass amplifier (a) and the same pulse transmitted through a spatial filter (b).

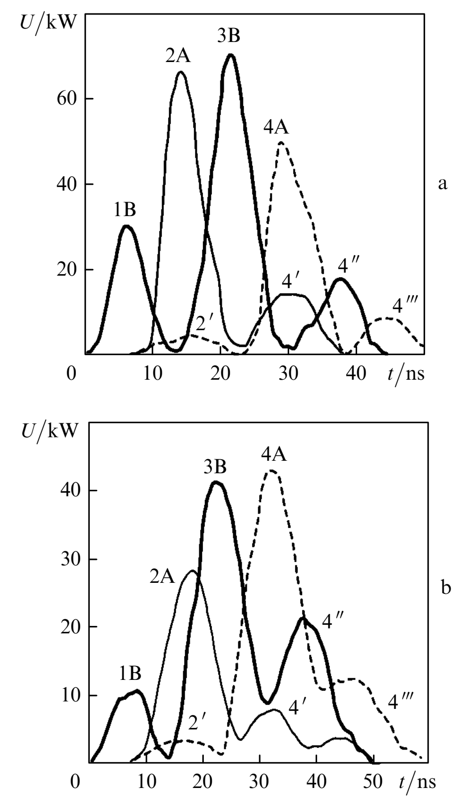

Figure 4. Oscillograms of the 0.51-μm green radiation amplified in the AS and recorded behind mirror (*10*) (heavy curve), mirror (*8*) (thin curve), and at the amplifier output J_{out} (dashed curve) (see Fig. 1) (a) and the same for the 0.578-μm yellow line (b); 1B, 2A, 3B, and 4A are radiation peaks observed after the first, second, third, and fourth passes of radiation in the AS, respectively; 2′, 4′, 4″, and 4‴ are additional peaks in oscillograms.

weak peak $4''$ in the 'tail' of the curve. Similarly, the oscillogram of radiation transmitted through mirror (*8*) (thin curve) contains peak 2A observed after the second passage and additional peak $4'$. In addition, the dashed curve in Fig. 4a presents the oscillogram recorded at the amplifier output (J_{out} in Fig. 1). This oscillogram demonstrates peak 4a observed after the last (fourth passage) and additional peaks – leading peak $2'$ and delayed peak $4'''$. Letters A and B at peaks denote the position of radiation pulses in the corresponding sections of the discharge chamber. The divergence of radiation corresponding to individual peaks in oscillograms in Fig. 4a was measured with a spatial filter mounted in front of the photocell. We found that the divergence of radiation in main peaks 1B, 2A, 3B, and 4A of the amplified signal was $(1.5-2)\times10^{-3}$ rad, while the divergence of radiation in additional peaks $2'$, $4'$, $4''$, and $4'''$ was considerably greater $[(5-10)\times10^{-3}$ rad]. The divergence of radiation in the main and additional peaks increases slightly during successive passages of the laser beam through the AS. Note that peak $2'$ is located exactly under peak 2A, while peak $4'$ is located under peak 4A. This allows us to interpret the observed picture in the following way.

In the case of the optimal delay between the AS pump pulse and the MO pulse in our experiments, the leading edge of the latter enters the active medium of the amplifier at the instant of the inversion onset. The MO pulse has a small duration (8 – 10 ns) and its power is probably not high enough. During the first 5 – 10 ns, the small-signal amplification occurs in self-contained lasers ($\sim10^3-10^4$ [1, 2, 8]). As a result, simultaneously with amplification of the MO radiation, superradiance is developed from spontaneous seeds, which has random polarisation and large divergence determined by the discharge tube aperture. During the backward (second) passage, the mixed radiation is amplified and polarisation beamsplitter (*5*) selects two orthogonally polarised components from the beam after the second passage. One of the components 2A is incident on mirror (*8*) and takes part in the formation of beams for the next passages through the AS. The second component passes through beamsplitter (*5*) to the amplifier output, resulting in the appearance of peak $2'$ preceding main peak 4A in the output pulse oscillogram of the amplifier. After the third passage at the AS input (in section A) the random polarisation of the beam is eliminated because the beam passed twice through polariser (*5*). However, if the gain in the active medium by the beginning of the third passage is still high enough, spontaneous seeds can be amplified and randomly polarised superradiance will be again mixed in to the linearly polarised 3B beam. In addition, after the double passage of the MO pulse through discharge-chamber mirrors (*14*) and (*15*) oriented at an angle of 10° to the AS optical axis, weak optical rotation occurs due to Fresnel reflection losses. As a result, beamsplitter (*5*), which transmits the greater part of radiation after the fourth passage to the amplifier output, directs a noticeable part of radiation to mirror (*8*), leading to the formation of peak $4'$ in the 'tail' of the oscillogram of pulse 2A. Then, peak $4'$ is successively transformed to peaks $4''$ and $4'''$.

Note that no such competition between the development of 'parasitic' lasing and useful amplification of the MO pulse was observed in a double-pass amplifier. This is apparently explained by the fact that in the case of a double-pass amplifier only one beam retroreflector (*7*) was used and it was located at a considerably greater distance from the discharge chamber end, which reduced feedback.

Thus, all the experimental results presented above demonstrate a competition between amplification of the input MO pulse and development of lasing in a 'parasitic' resonator, which is formed by the same fold mirrors of the four-pass amplifier. In addition, the output parameters of the amplifier can be adversely affected by technical factors such as a large tilt angle of the AS chamber to its axis, radiation loses at windows and other optical elements, the quality of polarisation elements of the scheme, reflection of radiation from the chamber walls, etc. The increase in the beam divergence observed with increasing the number of passages is probably caused to some extent by the action of a thermal lens, which is typical for copper vapour lasers [8].

Consider now changes in the pulse peak power after each passage in the amplifier. One can see from Fig. 4a that the increase in the pulse peak power for the green line per pass decreases with increasing the number of passes (cf. the amplitudes of peaks 1B, 2A, and 3B). After the fourth pass, the peak power even noticeably decreases (peak 4A is weaker than peak 3B). This suggests that the gain during the last passage decreases down to the level lower than the total losses in optical elements in the amplifier or even that amplification changes to absorption in the active medium. The evolution of amplification of the radiation pulse for the yellow 0.578-μm line is similar as a whole (Fig. 4b). However, one can see that the decrease in amplification (from pass to pass) is noticeably weaker. After the fourth passage, the 4A pulse still increases. This is probably explained by the lower rates of kinetic processes for the yellow line populating the lower level and depleting the upper operating level, which provides the longer lifetime of inversion.

Note that the peak powers U_{1B}, U_{2A}, U_{3B}, and U_{4A} of the 1B, 2A, 3B, and 4A bands in Fig. 4 and the dynamics of their variation depend not only on amplification in the active medium but also on radiation losses in optical elements, a set of these elements and related losses being different for different passages of the beam (Fig. 1). Therefore, the gain per pass in the active medium was determined by recalculating the peak powers U_{1B}, U_{2A}, U_{3B}, and U_{4A} taking into account the transmission and reflection coefficients of the corresponding optical elements, i.e. they were reduced to the values inside the AS in sections A or B. In our case, the transmission of radiation for polarisation beamsplitters (*3*), (*5*) was 99 %, Faraday rotators (*4*) – 97 %,, the plate (*9*) – 98 %, and walls (*14*), (*15*) – $\sim$ 0.92 %. The reflectance of mirrors (*8*), (*10*) was $\sim$ 99 %.

The ratios of the recalculated pulse peak powers at the output and input of the active medium for the first, second, third, and fourth passes are presented in Table 1 along with similar ratios for a double-pass amplifier taken from [1 – 3]. For comparison we present the results of experiments with a single-pass amplifier obtained for the same AS at the same pump powers. Note that after the fourth pass in our experiment (for the green line), we have $U_{4A}/U_{3B}<1$. Because absorption in optical elements is taken into account, this result means that amplification in the active medium by the instant of the fourth pass changed to weak absorption. Note that $U_{4A}/U_{3B}\gtrsim1$ for the yellow emission line. In this case, the gain per pass slightly exceeded losses in optical elements of the amplifier.

Table 1. Comparative parameters of 0.510-μm copper vapour laser amplifiers.

AS type	τ_{os}/ns	U_{in}^{peak}/kW	U_{out}^{peak}/kW	W_{in}/W	W_{out}/W	δ	τ_{out}/ns	U_{1B}/U_{in}^{peak}	U_{2A}/U_{1B}	U_{3B}/U_{2A}	U_{4A}/U_{3B}	τ_{del}^{opt}/ns
Single-pass												
[1]	35	3.7	90	0.7	15.3	2:1	35	14	–	–	–	–
Double-pass												
[1, 2]	10 – 12	~ 4.0	200	0.2	16.7	2:1	15	35	1.9	–	–	~ 10
[3]	17	6.0	150	0.47	9	1:1	20	55	2.2	–	–	~ 15
Four-pass												
(this paper)	8 – 10	3.2	50	0.17	6	1:1	14	12	2.5	1.4	0.9	~ 5

N o t e : δ is the ratio of energies of the 0.510-μm green line and 0.578-μm yellow line pulses at the output of amplifiers ($\delta \approx 2 - 1.5$ for MO pulses); the AS pump power is 3.1 – 3.3 kW, the pulse repetition rate is 10 kHz, the working volume is 250 cm^3, and $\tau_{inv} \approx 30 - 40$ ns.

It follows from Table 1 that the maximum increase in the peak power was obtained in a double-pass amplifier [3]. The pulse peak power was 305 kW (in all lines), which is 2.2 times higher than in the case of usual single-pass amplification at the same pump power (Fig. 5). The average radiation power remained at the same level (22 – 25 W).

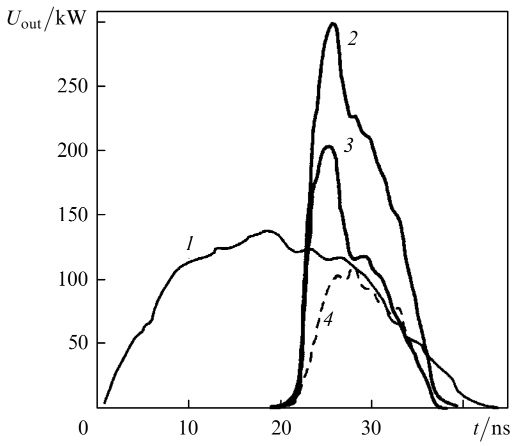

Figure 5. Output radiation pulses (total over the wavelengths) of copper vapour amplifiers for the average radiation power ~ 22 W and a pulse repetition rate of 10 kHz for the single-pass AS for $\tau_{os} \approx \tau_{inv}$ (*1*), double-pass AS for $\tau_{os} \approx 0.4\tau_{inv}$ (*2*), and double-pass AS with $\lambda_1 = 0.51$ μm (*3*) and $\lambda_2 = 0.578$ μm (*4*).

We also investigated in detail the dependence of amplification of the radiation beam in double- and four-pass amplifiers on parameters entering relations (1) and (2) and also on the MO pulse power in a double-pass amplifier [1, 2]. One of the important results is presented in Fig. 6. One can see that the increase in the peak power is maximal for the optimal values of τ_{os} and τ_{del}, which corresponds to the meaning of optimising relations (1) and (2). Indeed, for the specified value of τ_{os} and the value of τ_{del} that is considerably lower than the values satisfying these relations, the amplified radiation pulse will escape from the AS before the end of the inverse population. As a result, a part of the pump energy will not be used. For the values of τ_{del} considerably exceeding the optimal value, the amplified pulse has no time to escape completely from the channel by the instant of the end of inversion and a part of its energy will be absorbed. In both cases, the pulse energy and amplitude at the output of a multipass amplifier decrease. The maxima of the curves in Fig. 6 correspond to the optimal values of τ_{del}. On the other hand, when shorter MO pulses are used, it is necessary, according to (2), to decrease the optimal value of τ_{del}, which is confirmed experimentally (the maxima of the curves in Fig. 6a shift to the left). This confirms the validity of the qualitative model [2] on which the proposed method for increasing the peak power is based.

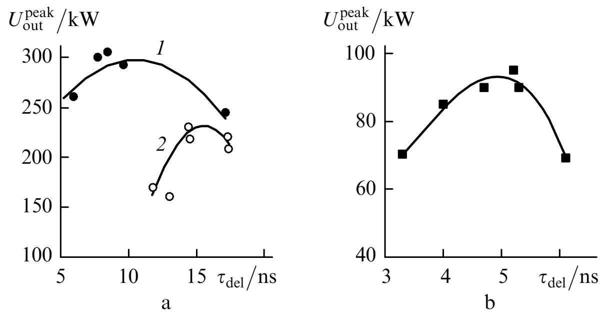

Figure 6. Dependences of the peak power U_{out}^{peak} (total over the wavelengths) of output pulses of amplifiers on the delay τ_{del} and duration τ_{os} of the MO pulse for the double-pass AS [(*1*): $\tau_{os} \approx 12.5$ ns, $U_{in}^{peak} = 5.7$ kW; (*2*): $\tau_{os} \approx 17$ ns, $U_{in}^{peak} = 3$ kW] (a) and the four-pass AS ($\tau_{os} \approx 8$ ns, $U_{in}^{peak} = 3.3$ kW, $\lambda_1 = 0.51$ μm and $\tau_{os} \approx 15$ ns, $U_{in}^{peak} = 1.1$ kW, $\lambda_2 = 0.578$ μm) (b).

Note that the choice of the value of τ_{inv} in (1) is quite uncertain because it depends on the gain dynamics and laser radiation energy density in the active medium of self-contained lasers. In addition, relations (1) and (2) neglect an increase in the pulse duration at the amplifier output (see Table 1). The duration of a superradiance pulse (35 – 40 ns in our case) can be probably considered as the maximum value of τ_{inv}. In the case of well developed induced radiation with the energy density in the active medium exceeding that of superradiance energy by an order of magnitude and more, one should be most likely oriented to the pulse duration in a plane resonator laser (25 – 30 ns in our case). The radiation energy density at a point in the active medium of a multipass amplifier is determined by a sum of intensities of counterpropagating beams and increases nonmonotonically in time (beams J^+ and J^- periodically meet and come apart). It is known [9] that the pulse energy at the output of multipass amplifiers can increase nonmonotonically with the input pulse energy. To describe the behaviour of the pulse peak power and energy in the multipass amplifier more accurately, it is necessary to solve self-consistently nonstationary kinetic equations for level populations and energy balance in the plasma, and nonstationary amplified emission transfer equations taking into account conditions determined by relations (1) and

(2). We are not aware of such studies for multipass copper vapour amplifiers.

As for the competitive development of superradiance with respect to 'useful' lasing, such a process was considered in detail in numerical calculations of plane resonator copper vapour lasers [10, 11]. It was shown that competing amplified spontaneous emission (ASE) in nonaxial beams can carry to the side walls of a discharge chamber up to half the total energy, which is confirmed by numerous experiments. The competition between ASE and amplification of a high-quality MO beam in a copper-vapour active medium was considered in [12] by using zero-dimensional radiation transfer equations and level population kinetics. It was shown that in the case of high enough input MO radiation intensities, lower or comparable with the saturation intensity, a fraction of high-quality radiation in the output beam of the amplifier can achieve 90 % – 100 %. The best result in our experiments with a double-pass amplifier was obtained for high intensities of input MO pulses [2]. However, in experiments with the four-pass amplifier we could not vary the MO pulse amplitude and, therefore, the input intensity could be insufficient for strong amplification of the high-quality input radiation.

4. Conclusions

We have proposed and studied special MCVA schemes with the aim of increasing the peak power of laser pulses by retaining their energy. The double-pass copper vapour amplifier providing the twofold increase in the peak power has been manufactured.

The four-pass copper vapour amplifier has been developed and fabricated. The type of amplification of radiation in this amplifier has been elucidated. First, the competitive development of lasing from spontaneous 'seeds' in a 'parasitic' resonator formed by the fold mirrors of the four-pass amplifier plays a very important role. The fraction of energy corresponding to this lasing amounts to more than half the total energy of the radiation pulse. Second, as the number of passes increases, the gain per pass noticeably decreases and changes in the last pass to small absorption (for the green line). Third, the duration of output radiation pulses considerably increases, which is probably caused by the insufficient steepness of the MO pulse fronts. These factors, however, do not affect strongly the operation of a double-pass amplifier.

In our opinion, parasitic lasing can be reduced by technical methods by using the difference between the divergences of this lasing and the amplified MO beam, as a well as the difference between their polarisations. The amplification of spontaneous seeds can be reduced by varying the amplitude and shape of the MO pulse, optimising excitation regimes, parameters of the active medium, and geometrical dimensions of the AS. In our opinion, these measures will provide the increase in the output power of a four-pass copper vapour amplifier.

The results obtained in our paper confirm the validity of the qualitative physical model [2] describing the method [5] of increasing the amplitude of the MCVA pulse without considerable changes in the specific average power.

To refine the outlook for MCVAs considered in the paper, it is necessary to perform further both experiments and calculations. These MCVAs can find applications in technological problems requiring high radiation pulse peak intensities, for example, in systems for nonlinear radiation frequency conversion, laser isotope separation, pumping of dye lasers, etc.

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