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Study of Amplifying Characteristics of Copper Bromide Active Media Operating at the Increased Superradiance Pulse Duration Mode

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***Abstract*—Amplifying characteristics of the copper bromide vapor active media with the increased inversion duration are studied using the detailed kinetic modeling. The analysis of the gain radial profile and its time evolution at various points of the GDT profile is presented. The results show the possibility of application such active media to the tasks of the remote object visualization.**

***Keywords*—active medium, brightness amplifier, inversion, kinetic model, gain, active optical system.**

I. Introduction

One of the promising directions of metal vapor active media application is using them in the nondestructive testing. The visual-optical control using active optical systems is based on brightness amplifiers allows diagnostics of processes that occur in extreme conditions [1–7]. In other words, active optical systems allow one to visualize processes that blocked by the intense background light (internal or external). In some real scientific and technical tasks, an observed process or object of diagnostics can be located at a considerable distance (remote object). To visualize such processes it is advisable to use active optical systems with brightness amplifiers operating at increased superradiance pulse duration mode [8]. Alternatively, an active optical system can be based on a bistatic configuration [9]. However, the use of a bistatic configuration requires the development of two active elements (an amplifier and a generator) that significantly complicates the development and increases the size of the system.

The most common active medium in such systems is the active medium on copper bromide vapors. The typical duration of a superradiance pulses in such active media is 30-40 ns. In [8], it was shown that the active optical system with the pulse duration of 40 ns (on the base) does not allow high-quality visualization of objects located at a distance of more than 3 m. It corresponds to a 20-nanosecond travel of light back and forth. It indicates that to estimate the range of the high-quality imaging it is important to know not only the duration of the superradiance pulses but also the spatio-temporal gain profile. Earlier, in [10], the principal possibility of a significant increase in superradiance pulse duration was shown. In particular, the duration of 320 ns on the base was obtained.

The results of development and experimental studies of the copper bromide brightness amplifier with the superradiance pulse duration of 100 ns are presented in [8]. The study made it possible to increase the distance to the object up to 10 m. An increase in the duration of the superradiance pulse was achieved by the reducing the pulse repetition frequency (PRF) and increasing the pulse energy storage. However, there are no detailed studies of the gain characteristics of active media operating in such mode. In particular, the evolution of the gain radial profile during the superradiance pulse is of interest.

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II. Model Description

The study of spatio-temporal gain characteristics of the copper bromide active medium operating at increased superradiance pulse duration mode was performed using the kinetic modeling. A detailed description of the kinetic model is given in [11–14]. The experimental data presented in [8] were chosen as input parameters for the model.

The simulation was carried out for the radiation pulse repetition rate of 3, 10, and 15 kHz. As in the experiment (for 3 and 15 kHz), the energy stored in the capacitor per unit of frequency remained the same in the model. This was achieved by changing the capacity of the storage capacitor in the pump circuit. The simulation parameters of the copper bromide active medium are given in Table I.

TABLE I. The Simulation Parameters

Mode number	Mode 1	Mode 2	Mode 3
Pulse repetition rate, kHz	3	10	15
The buffer gas pressure (Ne), torr	30	30	30
Gas discharge tube (GDT) wall temperature, □C	650	650	650
Active zone diameter, cm	5	5	5
Active zone length, cm	90	90	90
Capacity of the storage capacitor, nF	3.4	1.1	0.75

III. Model Results

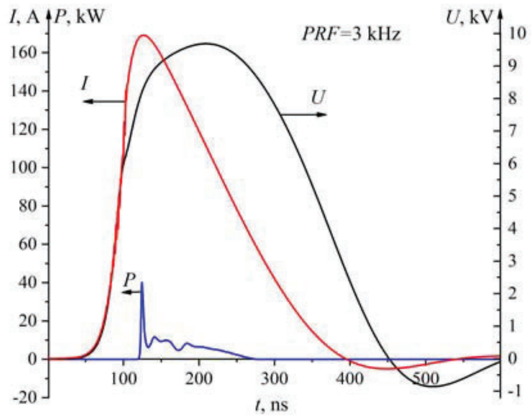
In Fig. 1, amplified spontaneous emission (ASE), GDT voltage and current through the GDT pulses obtained by modelling of active media for different frequencies are shown.

Note that the obtained waveforms of the GDT voltage and current are consistent with the experimental data presented in [8]. As in the experiment, the amplitude of the GDT voltage decreases and the amplitude of the GDT current increases with an increase of the pulse repetition frequency. This is caused by an increase in plasma conductivity due to a decrease in the interpulse period, which leads to a decrease in the time for the plasma relaxation.

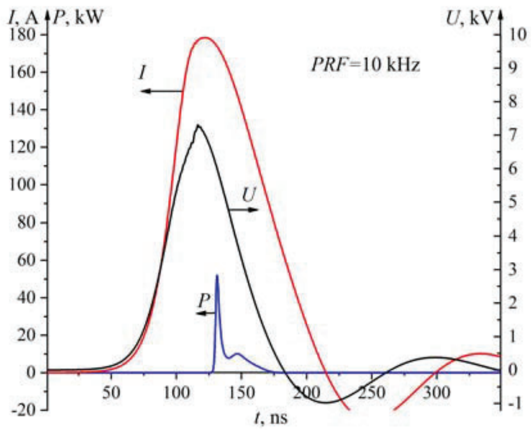
Waveforms in Fig. 1 show that with a decrease of the pulse repetition frequency there is a significant increase in the duration of superradiance pulses in the case of a constant input energy. Thus, at the PRF of 15 kHz in the experiment the duration of the superradiance pulse was about 50 ns (on the base) and at the frequency of 3 kHz – 120 ns. In the model, the pulse durations were 40 and 150 ns, respectively.

To analyze the gain characteristics for different superradiance durations, the spatio-temporal modeling of the gain was performed. Fig. 2 shows the radial dependences of the gain of the active medium at different time points, which correspond to the times in Fig. 1, and Fig. 3 shows the time evolution of the gain coefficients at various radial points of the GDT.

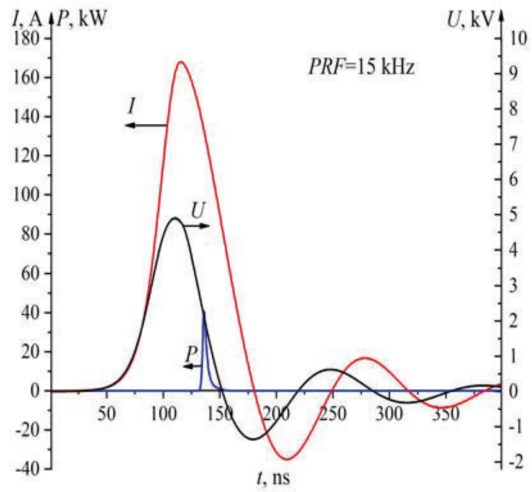
It can be seen from Fig. 2 that the relatively uniform spatio-temporal gain profile is observed only at the beginning of the ASE pulse. Then the gain in the GDT center decreases quite quickly. Thus, it is necessary to take into account the unevenness of the spatio-temporal gain profile for the use of such active medium as a brightness amplifier operating in the long-pulse mode in the visual-optical control of remote objects it is necessary to take into account the unevenness of the spatio-temporal gain profile. Namely, the rapid decrease in the gain in the central region of the GDT and its increase in the wall areas.



(a)



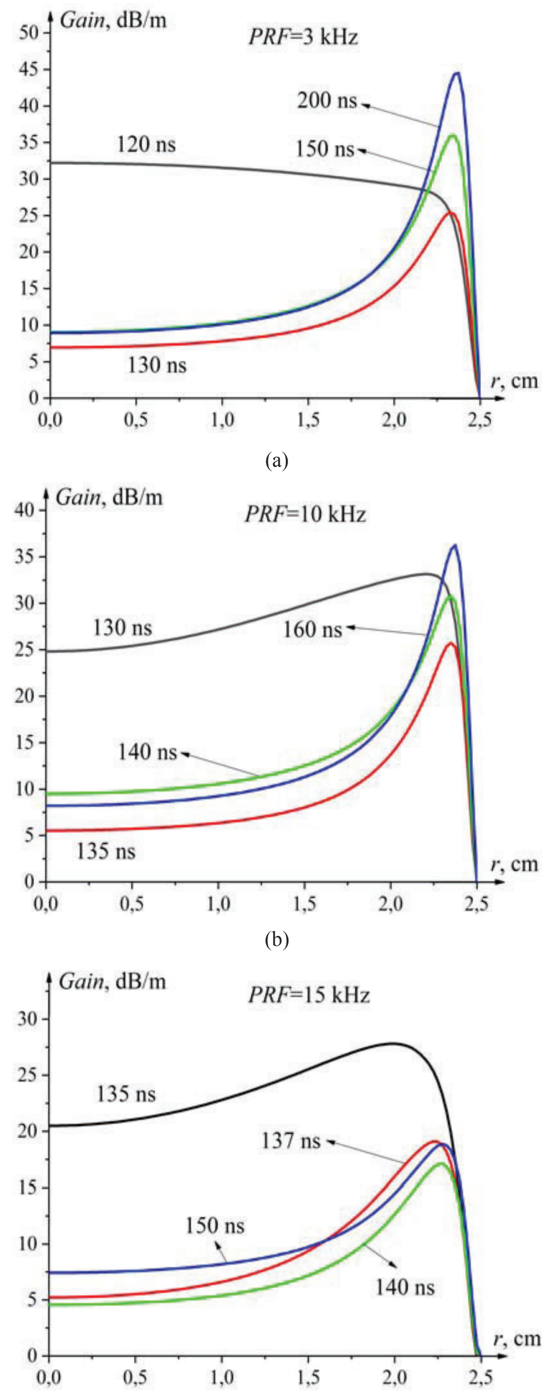
(b)



(c)

Fig. 1. Time dependencies of the volume averaged ASE power (blue line), the GDT voltage (black line) and the current throgh the GDT (red line) at different modes: a – Mode 1, b – Mode 2, c – Mode 3 (Table I).

change in the gain for over 120 ns will allow the effective visualization of remote objects.



(c)

Fig. 2. Radial dependences of the gain of the active medium: a – Mode 1, b – Mode 2, c – Mode 3 (Table I).

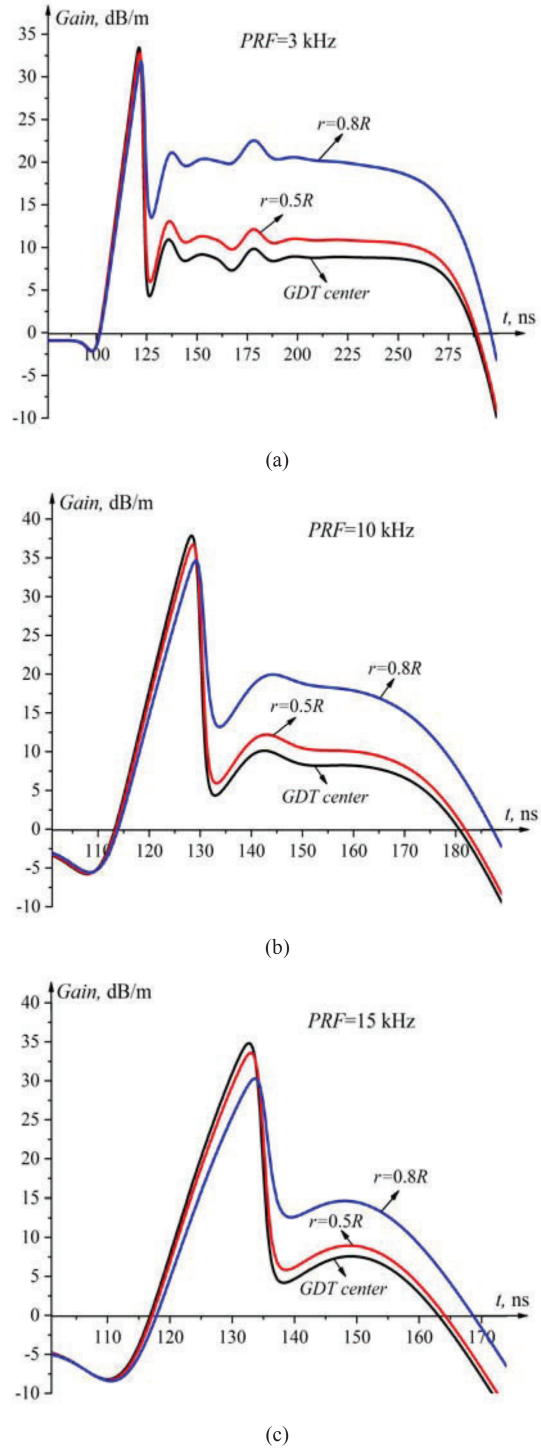


Fig. 3. Time dependencies of the gain of the active medium: a – Mode 1, b – Mode 2, c – Mode 3 (Table I).

At the same time, the results of modeling of the gain time evolution (Fig. 4) show that, in the case of the low PRF (increased duration of the inversion), a quasi-uniform gain is preserved for a long time at various points of the GDT profile. In particular, for the PRF of 3 kHz, the gain has a small change during the inversion time from 130 to 250 ns. Therefore, taking into account the radial unevenness of the profile and a small

This is confirmed by the experimental results on the signal amplification at different distances to the object (3, 6 and 10 m), which are presented in [8]. In particular, at distances of 3 and 6 m the authors obtained similar pulses (in the shape and the amplitude) of the amplified signal. In other words, the relative stability of the gain for some time was observed. At the same time, the removing the object at a distance of 10 m led to the decrease in the amplitude of the amplified signal. This fact is associated with a decrease in the gain at the end of the inversion time since, on its return to the GDT, a significant part of the superradiance fell into the time region of the low gain.

At higher PRFs (10 and 15 kHz) the radial gain profile (Fig. 2) is more uneven. In this case, the time evolution (Fig. 3) of the gain also does not allow you to identify areas of its small change.

IV. Conclusion

The paper presents the results of detailed kinetic modeling of the spatio-temporal gain characteristics of the copper bromide active medium operating at increased superradiance pulse duration mode. The simulation results are in a good agreement with the known work on the obtaining of an increased pulse duration by the reducing the PRF of pumping pulses.

The simulation showed that a decrease in the PRF can lead to a significant increase in the duration of the inversion. At the same time, it is necessary to maintain the stored energy into the active medium. The results of the modeling of the gain profile showed that a uniform radial profile is observed only at the initial moment of inversion. Then the gain shifts to the wall areas. However, when operating at the increased superradiance pulse duration mode, there is a small change in the gain for over 120 ns.

The modeling study together with experimental data [8] show the principal possibility of using the increased superradiance pulse duration mode in metal vapor active media for the use of them in tasks of the remote object visualization. When operating in this mode, the active medium can maintain a relatively stable gain value for a long time. However, you should take into account the significant unevenness of the radial gain profile.

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