INVESTIGATION INTO THE BEHAVIOR OF THE CONDUCTION OF A COPPER VAPOR LASER PLASMA

V.F. Elaev, A.N. Soldatov, and N.A. Yudin

Tomsk State University
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The parameters of an inductor connected in parallel with a gas-discharge tube (GDT) into an excitation circuit of a copper vapor laser (CVL) have been optimized. The processes resulting in lower output power characteristics of the CVL are shown to occur at some inductance. After an excitation pulse, in case of inductive reactance being of the order of plasma resistance, at resonant frequency of charging of an accumulating capacitor the inductor stores a considerable part of the accumulating capacitor power that is injected into the GDT plasma. This leads to secondary ionization of the CVL plasma and reduces the rate of recombination processes in it.

The self-heating method for producing a vapor of working substance in a copper vapor laser (CVL) proposed in 1972 proved to be not only the simplest and most efficient technique for pumping of an active medium, but also predetermined a choice of an excitation circuit.[1] The circuit of the CVL active medium excitation with resonant charging of an accumulating capacitor and its complete discharging through a gas-discharge tube (GDT) with a thyratron commutator is most widely used up to now. For such an excitation circuit the main output power characteristics as functions of excitation conditions, GDT geometry, and active medium parameters have been studied fairly well. The main mechanisms limiting the output power characteristics also have been elucidated.

Parametric optimization of CVL excitation conditions is carried out through the choice of the optimal parameters of an active medium (its temperature and buffer gas pressure) and pumping (accumulating capacitance, voltage across a rectifier of an excitation source, and excitation pulse repetition rate).

An inductance L of an inductor connected in parallel with the GDT and used for charging of the accumulating capacitor, as a rule, is not specified in references when the main trends in the behavior of output power characteristics are investigated and optimized. A role of the inductor L reduces to shunting of the GDT when charging the accumulating capacitor.

It was shown in Ref. 2 that when charging the accumulating capacitor, the GDT plasma experiences interpulse currents leading to a decrease of the output power characteristics. It was noted in Ref. 3 that the interpulse currents were caused by the choice of too high inductance L in Ref. 2 and to remove this effect, the inductance L should be decreased. It follows from the above that a role of the inductor L in the CVL excitation circuit is not so simple as it seems. Therefore, its role in limiting of the output power characteristics should be studied additionally. This problem is the goal of our investigations.

An analysis of the results reported in Ref. 2 showed that the reactance of the inductor L at the resonant frequency of charging of the accumulating capacitor was about 200 Ω, which was comparable to resistance of a resistor used in excitation circuits instead of the inductor. To remove the effect of interpulse currents, the inductive reactance at the resonant frequency of charging of the accumulating capacitor should be comparable to a plasma resistance of about 10 Ω after the excitation pulse.

Simple estimates show that for a 50-μs charge time of the accumulating capacitor an inductance of about 100 μH has such resistance. The investigations were carried out for the GDT with working channel made of a BeO-ceramic tube with a diameter of 10 mm and a length of 40 cm. Neon was used as a buffer gas. The TGI1–1000/25 thyratron was used as a commutator. The current through GDT, inductance L, and voltage across these devices were measured in the experiments. The inductance L varied within the limits 100–260 μH.

Our studies have shown that for these values of L the interpulse currents caused by charging of the accumulating capacitor do not flow through the plasma. The accumulating capacitor is charged through the inductor L. This inductor completely shunts the GDT during charging. But a part of the power is stored in the inductor L when discharging the accumulating capacitor. The power stored in the inductor L depends on the excitation pulse parameters as well as on the buffer gas pressure and the excitation pulse repetition

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rate. After the excitation pulse, the power stored in L is dissipated by the GDT active medium. The power stored in the inductor can be determined if the inductance L and the amplitude of peak current passing through L are known. The powers P_L stored in L for various experimental conditions are presented in Table I, where $P_{\rm Ne}$ is the buffer gas pressure, $P_{\rm R}$ is the power extracted from the rectifier, f is the pulse repetition rate, $I_{\rm max}$ is the amplitude of inductor current, and $U_{\rm R}$ is the rectifier voltage.

TABLE I.

Serial number	$P_{\rm Ne}$, kPa	L, μH	$P_{\rm R}$, W	f, kHz	$I_{\rm max}$, A	P_L, W	$U_{\rm R}$, kW
1	27.8	100	640	10	11.4	65	4
2	27.8	100	1050	10	12.5	78	5
3	27.8	260	640	10	9.0	105	4
4	27.8	260	500	5	8.0	42	5
5	27.8	260	1000	10	7.0	64	5
6	13.2	260	800	10	5.5	40	4
7	13.2	260	1400	10	8.4	92	5
8	13.2	100	550	5	8.0	16	5
9	13.2	100	1400	10	12.4	77	5
10	13.2	100	800	10	11.0	60	4
11	13.2	100	230	10	18.0	162	1

As one can see from the measurement results presented in Table I, a considerable part of the power of the accumulating capacitor is stored in the inductor L. Such an additional power injection to the plasma after the excitation pulse may heat the plasma in the interpulse interval and moderate the recombination processes. Taking into account that the inductance L is higher than the GDT self-inductance at least by a factor of 10^2, we can consider that the power stored in L is completely dissipated by the plasma active component.

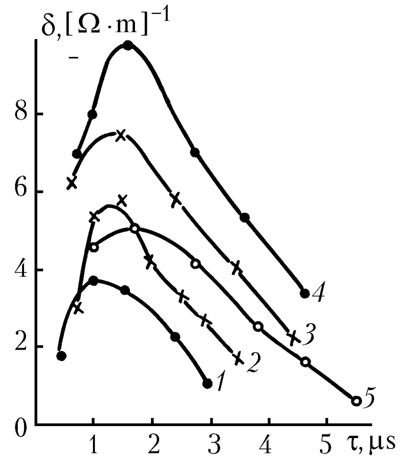

FIG. 1. Time dePendence of CVL Plasma conduction after the excitation Pulse for the cases enumerated in Table I: 1) 1, 2) 2, 3) 10, 4) 9, and 5) 8.

The behavior of the plasma conduction can be judged from oscillograms of pulses of the current and voltage across GDT (after the excitation pulse). Based on this behavior, the recombination processes in the CVL plasma can be studied. Figures 1 and 2 show the plasma conduction as a function of excitation conditions for various L. Additional injection of the power stored in the inductor L leads not only to moderation of the recombination process, but also to the increase in the plasma conduction in this time. The behavior of the plasma conduction after the excitation pulse coincides with the time dependence of the electron concentration measured from the Stark profile[4] of the hydrogen line H_β.

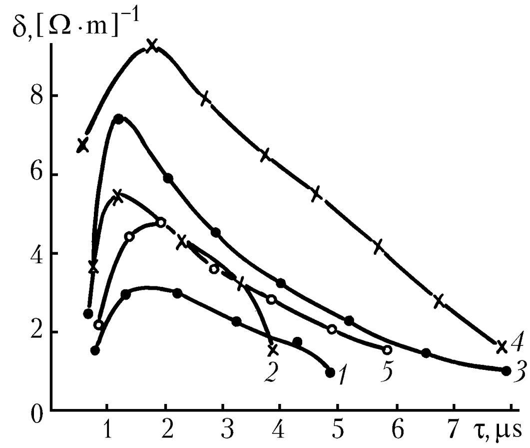

FIG. 2. Time dePendence of CVL Plasma conduction after the excitation Pulse for the cases enumerated in Table I: 1) 3, 2) 5, 3) 6, 4) 7, and 5) 4.

It should be noted that the time dependence of the electron concentration measured in Ref. 4 at the initial stage after the excitation pulse does not agree with the electron concentration measured in Ref. 5. Proceeding from our investigations, we may assume that the inductances L differed significantly in these papers. Unfortunately, as noted above, these inductances were not specified in the papers.

The electron concentration was measured from the Stark profile of the hydrogen line in the Milan CVL where the inductances L of the order of 60–300 μH were used[6] for charging of the accumulating capacitor. Such a value of L coincides with that used in our experiments. Figure 3 shows the behavior of the electron concentration n_e in the interpulse interval of discharging for two cases.

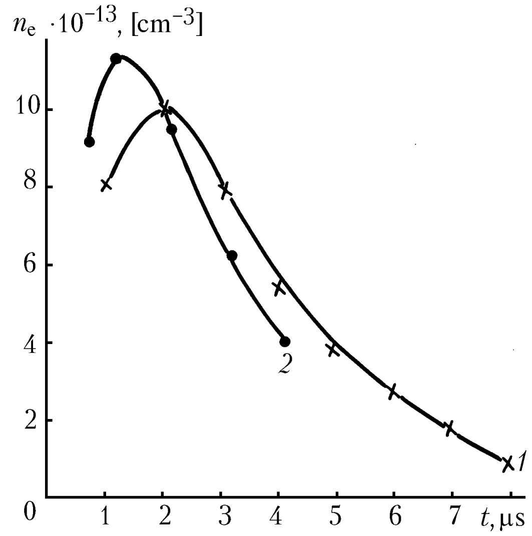

FIG. 3. Time dePendence of the electron concentration for the cases enumerated in Table I: 1) 7 and 2) 9.

The concentration n_e was calculated based on the measurement of the plasma conduction in the interpulse interval under assumption of homogeneous distribution of n_e across the radius of the discharge tube. The total cross section of elastic collision of electrons with neon atoms was borrowed from Refs. 7 and 8 and was assumed constant ($1.1\cdot10^{-16}$ cm^{-2}). The electron temperature T_e in the interpulse interval was borrowed from Ref. 9 and was assumed constant during the measurements and equal to 2500 K.

Our investigations have shown that the inductor L connected in parallel with the GDT influences the plasma processes leading to a decrease of the output power characteristics of the CVL. When a 200-Ω resistor is connected instead of the inductor L, the interpulse currents will pass through the GDT plasma as in the circuit described in Ref. 2.

However, these excitation circuits also differ. When the resistor is connected in parallel with the GDT, the power stored in the accumulating capacitor will be dissipated by the resistor unless the voltage across the GDT attains its breakdown threshold for the GDT active medium. When the inductor is connected in parallel with the GDT, the damped oscillations of current will be observed at the inductor L and GDT unless the voltage across the GDT attains its breakdown threshold for the GDT discharge gap.

Such behavior is caused by the fact that the power stored in the accumulating capacitor passes to the parallel circuit formed by the GDT resistor, inductor L, and GDT self-capacitance. This self-capacitance is 250 pF for the observed period of oscillations.

To increase the output power characteristics, a peaking capacitor connected in parallel with the GDT is commonly used in the above-described excitation circuit. It is clear from the above that the peaking capacitor shunts the inductor L when discharging the accumulating capacitor. The optimal peaking capacitance is adjusted experimentally through optimization of the CVL. However, the peaking and accumulating capacitances must be larger than the GDT self-capacitance.

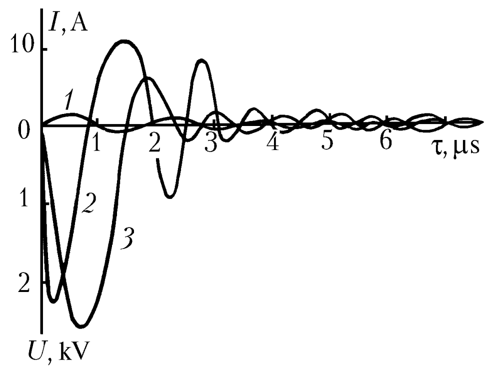

FIG. 4. Oscillograms of Pulses of current Passing through the GDT (1), the inductance L (2), and the voltage (3) across these units for case 11 of Table I.

Our investigations with the investigations reported in Ref. 2 have shown that the inductor L connected in parallel with the GDT for charging of the accumulating capacitor has a parasitic influence on the GDT plasma processes leading to the decrease of the output power characteristics.

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