STUDY OF A COPPER-VAPOR LASER WITH A LARGE ACTIVE VOLUME PUMPED WITH A THYRISTOR OR THYRATRON POWER SUPPLY

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In this paper we present some results of experimental investigation into the performance characteristics of a copper-vapor laser with the aperture of 60 mm *in diameter and volume about* 2.5 liter *having an indirectly heated active element and pumped with a thyristor and a thyratron power supply. It is shown that the thyristor source having less weight and smaller size is as efficient as a standard thyratron source. The optimal voltage and power of a pump source have been found, at which the efficiency of both a pump source and a laser as a whole is maximum for a given pump power density. It has been revealed that the dependence of the optimal (with respect to the average output power of the laser) repetition frequency of pumping pulses on the wall temperature of indirectly heated active volume of a laser gas-discharge tube has a maximum.*

At present metal-vapor lasers are widely used in such important branches, as laser industrial technologies, laser separation of isotopes, laser medicine, as well as in a wide variety of scientific studies, among them, in atmospheric optics studies.

Improvement of efficiency, reliability and service life of pump sources of such a laser widens the possibilities of its application. One direction in the development of new power supply sources is the use of high-power solid-state semiconductor controlled devices as commutators in the circuits of pump pulse generation. Such commutators are more economic and have longer service life as compared to now traditional gas-discharge and electrovacuum commutators that require additional power for heating cathodes, cooling anode, triggering losses, etc.

A need in high-voltage high-power anode supply of such commutators requires a high-voltage high-power rectifier, that along with a big size of a commutator results in a large size and heavy weight of a power supply.

Reference 1 describes a high-power high-voltage magneto-thyristor pulse generator, whose performance characteristics meet the conditions of generation excitation in the active volume of a gas-discharge tube (GDT) of a copper-vapor laser. Such a source needs no high-voltage rectifier, because thyristor commutators supply the rectified voltage directly from the line without a transformer. Pump pulses with the necessary amplitude and duration are generated in such a source with the help of a pulse transformer (PT) (Fig. 1*a*) with succeeding compression of a pulse with a sequence of L–C circuits of a generating line (inductors $L_3 - L_8$, capacitors $C_3 - C_9$).

In Fig. 1 L_{sh} is the inductor whose inductance is much greater than the inductance of a discharge circuit with GDT that allows shunting of the GDT resistance in pauses between the pumping pulses.

In such a generating line, the nonlinear inductors $L_3 - L_8$ (Fig. 1*a*) with ferromagnetic cores play a part of gates that switch the discharge of preceding capacitors to the following ones at the moment of core saturation when the voltage at the preceding capacitor reaches its amplitude value.

In this case the capacitance of the capacitors $C_3 - C_9$ is the same in all cells and equal to 3.3 nF, while the inductance of inductors $L_3 - L_8$, at saturated cores, decreases from L_3 to L_8, that leads to the effect of a successive compression of a pulse from the output of a pulse transformer (PT) to the end generating line. The cells $L_8 - C_9$ (Fig. 1*a*) and $L_2 - C_3$ (Fig. 1*b*) additionally play the part of load matching element (in our case the laser GDT is considered as a load), whose resistance varies in time (decreases from maximum to minimum during the gas discharge pulse).

Reference 2 presents the first results of experimental study of a copper-vapor laser with a 2.5-liter active volume and an aperture of 60 mm when pumping from a magneto-thyristor source.

In this paper we present some results of the further experimental study of a copper-vapor laser pumped with a thyristor (Fig. 1*a*) or thyratron source (Fig. 1*b*). The GDT design was a vacuum-tight quartz housing water cooled from outside. A ceramic tube of beryllium oxide coated with a thermal insulator layer of zirconium oxide powder was placed inside the housing. Powerful copper electrodes were at the ends of the ceramic tube. The tube has 60 mm inner diameter and

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about 900 mm length. Its volume was 2.5 liter. The above parameters of the magneto-thyristor source generally match elements and parameters of the source described in Ref. 1. The capacitors $C_3 - C_9$ match the value C_3 in the "compression" cell of the thyristor source and equal 3 nF. As a commutator (Fig. 1*b*), the hydrogen thyratron of TGI1–2500/50 class was used in the circuit. The pumping pulse repetition frequency for both sources can be continuously varied within 0–3 kHz.

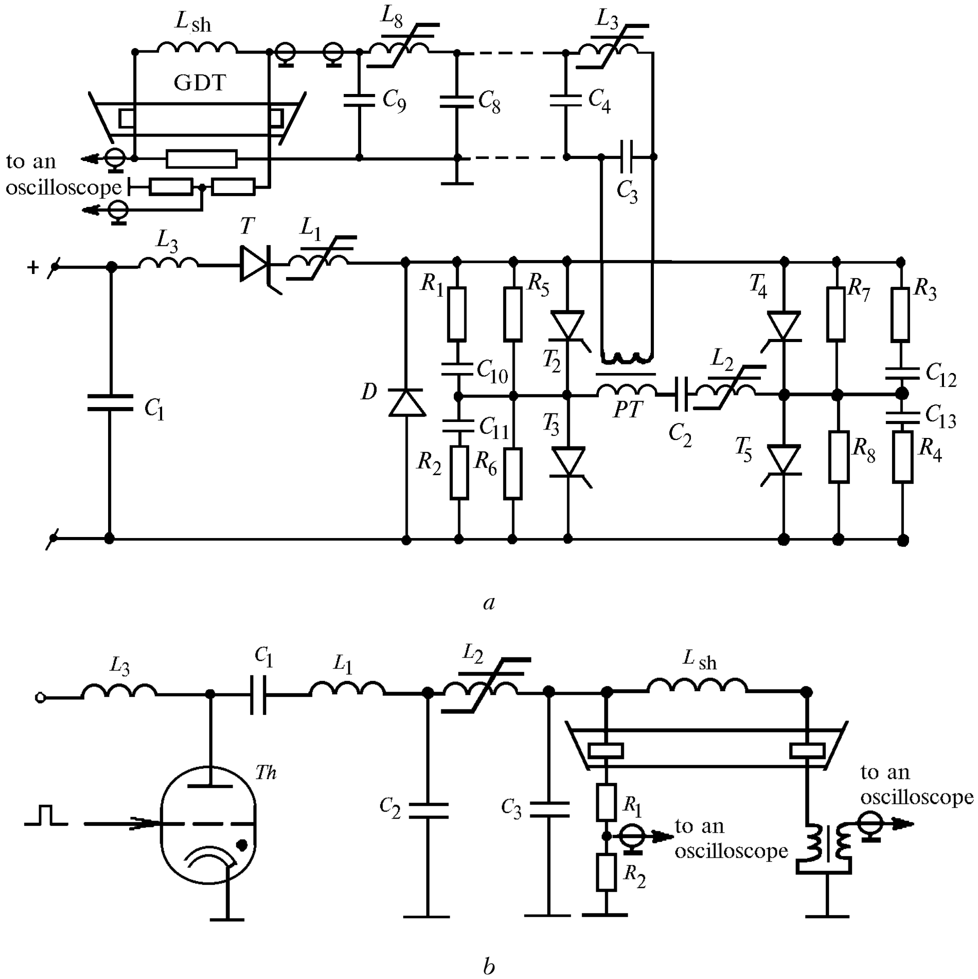


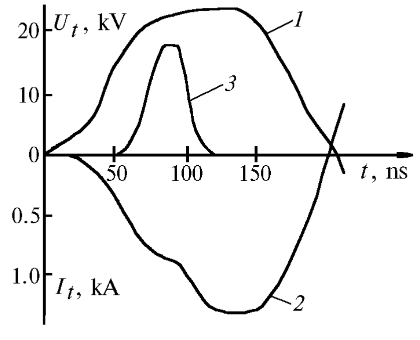
FIG. 1. Circuitry of two power supply sources for a copper-vapor laser: a) simplified circuitry of magnetothyristor power supply source of a laser GDT, $C_3 - C_9$ = 3.3 nF; *b) circuitry of a thyratron power supply source of a laser GDT,* C_1 = 6.0 nF, C_2 = 4.0 nF, C_3 = 3.08 nF.

The GDT active zone was heated up to the working temperature using a coil heater made of molybdenum wire wound directly on the ceramic tube of beryllium oxide. Ends of the coil heater were connected with the GDT electrodes and through them to a separate heater. The saturation choke coil L_l (Fig. 1*b*) or the so-called "compression line" was assembled from K17×8.2×5 ferrite rings of 1000NN mark as in Ref. 3. The ferrite assembly was 830 mm long. The "compression" line was in the metal cylinder. The inner part of ferrites was cooled by water through a brass tube.[3]

The circuitry for recording electric parameters is shown in Fig. 1. Pumping pulses were recorded with an FK–19 coaxial photoelement. Signals from dividers, current shunt (Fig. 1*a*), measuring transformer (Fig. 1*b*) and photoelement were recorded with a C1–75 oscilloscope, located in a screened room. Mean laser output power was measured with an IMO–2 power meter. Wall temperature in the laser active volume was measured through a transparent window at the GDT ends with an optical pyrometer.

Figures 2*a* and *b* show pumping and generation pulses for both types of sources. One can see that the use of thyristor source yields pumping and lasing pulses close, in their amplitude-time characteristics, to pulses resulting from pumping of GDT active volume with a thyratron source.

Higher amplitude and shorter length of a current pulse from a thyratron source as compared to those for thyristor source (neon pressure in GDT about 110 Torr), can be explained by lower neon pressure in GDT (75 Torr) when pumping with a thyratron source. Such an explanation is supported by empirical relationships presented in Ref. 4. It follows from them that in the area of working pressure and voltage, as the gas pressure increases and the voltage in gas-discharge gap of the GDT also increases pumping pulse duration, $\tau_{p.p}$, decreases and the amplitude of current pulse increases. In that case the pumping pulse power, $P_{p.p.}$, increases, as the laser output energy per pulse, E_g. The abovesaid is supported by experimental curves *4, 5* and *6* in Fig. 3*b*.



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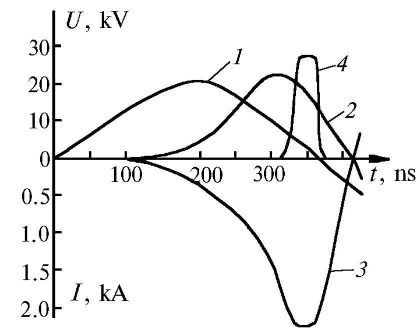
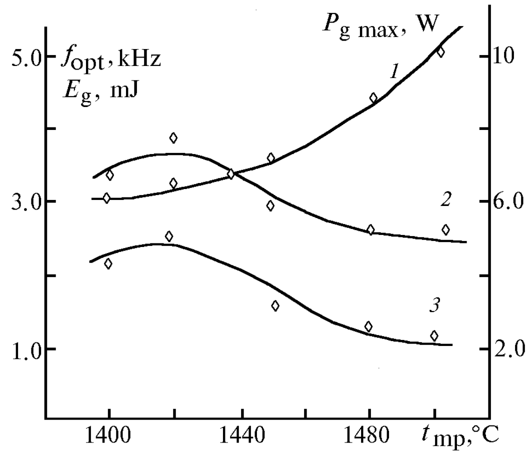


b

FIG. 2. Oscillograms of pumping pulses and laser output for two types of power sources: a) oscillogram of pulses of voltage at the tube, U_t, (curve 1) and current (2) in GDT laser with magnetothyristor source and laser radiation pulse (3), P_{Ne} = 110 Torr; *b) oscillograms of pulses of voltage at C_2 (curve 1), C_3 and GDT (2), current in GDT (3) and laser radiation pulse (4) for a laser with thyratron source* P_{Ne} = 75 Torr.

Figure 3*a* shows the characteristics of a laser with the thyristor source as functions of wall temperature in the working zone of the laser GDT. Figure 2*a* shows the pulse pumping parameters for all conditions of experiments with the thyristor source. Neon pressure, P_{Ne}, in GDT was about 70 Torr in this case. Experiment revealed the following regularities.



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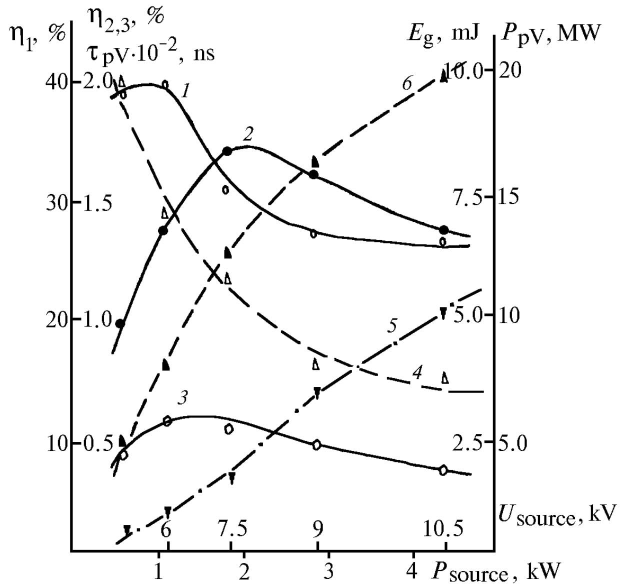

b

FIG. 3. Experimental characteristics for two types of the laser power sources: a) laser output energy per pulse (1), maximum mean output power (2) and optimal pumping pulse repetition freCuency (3) against the wall temperature of GDT of a laser with a thyristor source; b) efficiency of thyratron power source of a laser in energy contribution into GDT, η_1, *(1), in laser radiation as a result of energy contribution into GDT,* η_2, (2), *in laser radiation against pumping source power,* η_3, *(3); FWHM duration of pumping pulse* τ_{pp}, *(4); pulse pumping power,* P_{pp}, *(5); laser output energy per pulse,* E_g, *(6) as functions of voltage at a source,* U_{sour}, *and mean power of a source,* P_{sour}. *Pumping pulse repetition freCuency is* 1.5 kHz.

At any temperature of the active volume wall of the gas discharge tube (t_{mp}), as the pumping pulse repetition frequency deviates from the optimal frequency toward lower values (curve *3*, Fig. 3*a*), the mean generation power decreases as compared to the maximum value (curve 2). In this case, laser output energy per pulse (E_g) increases against the value given by the dependence shown by curve *1* and reaches the value, constant for all lower repetition frequencies. Let us explain that E_g dependence (curve *1*) was found from the relation

$$E_g(t_{mp}) = \frac{P_{g\,max}(t_{mp})}{f_{opt}(t_{mp})} .$$

As the pumping pulse repetition frequency increases from f_{opt} (curve *3*), both the mean power of laser radiation (P_g) and the laser output energy per pulse (E_g) decrease monotonically. Taking into account that f_{opt} increases with decreasing density of residual electrons (ions) and copper metastable atoms, all other conditions being the same,[5] generation energy per pulse increases with increasing density of copper vapor at GDT heating, and the pumping efficiency decreases at thermal population of the lower metastable lasing level of copper atoms with increasing GDT temperature, than for a wide-aperture laser operating at low pulse repetition frequency the presence of maximum in the experimental dependence (curve *3*, Fig. 3*a*) is due to competition among these three processes.

Figure 3*b* shows the experimental characteristics of a laser with thyratron source. It should be noted that for a pumping system in which the laser GDT, hydrogen thyratron, working capacitor and other elements are connected in series in the same gas discharge circuit, the source efficiency (η_1) decreases monotonically as the power supply voltage increases.[4]

" ut at low source voltage η_1 reaches much higher values (~70%, Ref. 4) than in our case (41%, see below) neglecting the losses for filament heating of cathode and hydrogen generator in thyratron.

This means that "compression cells" decrease the efficiency of thyratron sources in comparison with the sources containing only a GDT and thyratron as energy absorbers in the gas discharge circuit. It is clear that the use of "compression cells" in thyratron sources in justified mainly by the necessity to maintain stable operation of a thyratron[3] at increased anode voltage used to increase the laser output energy per pulse (curve *6*, Fig 3*b*).

For a thyristor source η_1 reached ~64% (see below), that is indicative of higher efficiency of the thyristor source against a thyratron one (η_1 = 41%).

Asymptotic approach of η_1, η_2, η_3 and τ_{pp} to some constants in the area of high U_{sour} and P_{sour} causes a growth of pumping pulse power and laser output energy per pulse in proportion to voltage (U_{sour}) and mean power of the pumping source (P_{sour}), starting from some values of U_{sour} and P_{sour} (curves *5* and *6*, Fig. 3*b*).

Such a proportionality holds until a sufficiently high concentration of neutral copper atoms in the GDT, minor thermal population of metastable levels and low concentration of residual electrons and ions are sustained between pulses. Experiment shows that an excess over certain values of U_{sour} and P_{sour} (different for different t_t) leads to a decrease in E_g along with the decrease in η_2 and η_3.

Optimization of pumping parameters of thyristor and thyratron sources yielded the following parameters:

for a thyristor power supply

η_1 = 64%, η_2 = 0.31%, η_3 = 0.2%, E_g = 10 mJ;

for a thyratron power supply

η_1 = 41%, η_2 = 0.9%, η_3 = 0.37%, E_g = 15 mJ.

These results allow one to conclude that in the efficiency of pumping the thyristor source is close to the traditional thyratron source.

So the development of light, reliable and small-size laser sources built around solid-state semiconductor commutators shows promise for industry, medicine and science. One of promising directions is development of mobile laser complexes for environmental monitoring.

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