Possibility of pumping metal vapor lasers by an electric generator with an inductive energy storage and semiconductor switch

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Received February 21, 2001

Results of experimental investigation into pumping the gas discharge tube by a generator with an inductive energy storage and semiconductor opening switch at a high pulse repetition frequency (PRF) are considered. For the first time, the PRF of 12 kHz has been obtained for such a type of the generators. At a discharge through a 80-cm long tube, current pulses with a pulse leading edge shorter than 10 ns were obtained at the current amplitude of 550 A. It is suggested to use such a generator for pumping metal-vapor repetitively pulsed lasers, including copper-vapor laser, which are widely used in the laser monitoring of the atmosphere.

In our earlier papers,[1–7] it was shown that the inductive energy storage can be successfully used for pumping pulsed dense-gas lasers. Generators with the inductive energy storage allow one to switch readily between pumping modes and pump various-type lasers under optimal conditions. The development of specialized semiconductor opening switches (SOS)[8] extended significantly the range of application of generators with the inductive energy storage. However, in the literature there are no data characterizing various modes of pumping pulsed gas lasers by means of inductive storages at the pulse repetition rates higher than 100 Hz, even for pumping using a longitudinal discharge. At the same time, a wide class of metal-vapor lasers,[9] including the copper-vapor laser, which are extensively used for studying the properties of the atmosphere and ocean, need for efficient pumping generators with the pulse repetition rate of 10 kHz and higher.

In this paper, we consider peculiarities of pumping a gas discharge tube using inductive energy storage and a semiconductor opening switch at high repetition rates. Note that as such pulse generators operated in an active load, the maximum pulse repetition rate in the steady-state mode did not exceed 1 kHz, and in the short-time mode (30–40 s) the pulse repetition rate was 5 kHz (Ref. 8).

The circuitry of our setup was similar to that described in Ref. 7. Power was supplied from a high-voltage rectifier, which charged a capacitor $C = 20$ μF up to the voltage of 1–5 kV. The capacitor C was connected through a throttle and diode with a capacitor $C_0 = 2000$ pF and charged it up to doubled voltage at the pulse repetition rate of 1–12 kHz. After operation of a thyratron (TTI-2500/50 with water cooling), the capacitor C_0 through an inductance $L_0 = 11.3$ mH and a thyratron charged the capacitor $C_1 = 2000$ pF. At roughly maximum voltage across C_1, a water-cooled throttle L_1 made of 175 M100NM 20 × 10 × 5 mm ferrite rings came into action. At charging of the capacitor C_1, the current took a path through SOS diodes in the forward direction, and as the throttle L_1 operated, the direction was changed into the backward one. As a result, SOS diode broke the current, and the energy stored in the inductance came to generation of a high-voltage pulse on the discharge tube, which was connected in parallel with the SOS diodes (Fig. 1). For details of operation of a similar circuit, see Ref. 7.

As circuit breakers, we used specialized silicon diodes of SOS-50-2 or SOS-150-2 type[8] with the maximum reverse voltage of 50 or 150 kV, respectively, and the maximum amplitude of the broken current of 2 kA. The diodes are kept in transformer oil. We have studied two breakers: the first consisting of four SOS-50-2 diodes connected in parallel and the second consisting of two SOS-150-2 diodes also connected in parallel. The parallel connection of diodes was used to decrease the mean current through them at high repetition rates. As a load, we applied a ceramic neon-filled tube 2 cm in diameter with 40 or 80 cm gap between the electrodes. At the voltage of 20–35 kV across the gas discharge tube, neon breakdown occurred. The tube was water-cooled and connected with a minimum inductance in parallel to the SOS diodes. In most experiments, the peaking capacitor $C_2 = 22–100$ pF with minimum inductance was connected in parallel to the tube. The voltages and currents in the setup were measured by ohmic dividers, shunts, or Rogovsky belt, whose signals came to the TDS-220 oscilloscope.

It was of the greatest interest for us to study the possibility of operation of the inductive energy storage at the pulse repetition rate of 10 kHz and higher, therefore Figs. 1 and 2 show oscillograms obtained under these conditions. The studies at lower frequencies

0235-6880/01/08 662-03 $02.00

were performed only to decrease heating of some elements of the circuitry during generator tuning to the operation mode. At optimization of the tube breakdown time lag, the time of operation of our generator in the steady-state mode exceeded 10 min and was limited only by overheating of the ceramic tube.

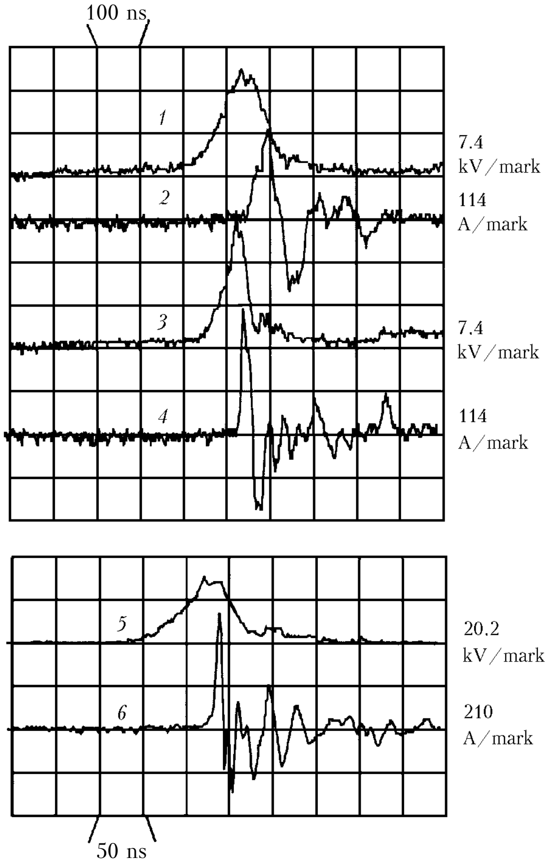

Fig. 1. Oscillograms of current pulses through SOS diodes (*1*), voltage across the tube (*2*, *3*, *5*), and current through the tube (*4*, *6*) at the pulse repetition rate of 10 kHz, discharge gap of 40 cm, and the use of four SOS-50-2 diodes connected in parallel; peaking capacitor of 100 pF (*1*, *2*, *3*, *4*) and 22 pF (*5*, *6*); neon pressure of 300 (*1*, *2*) and 30 Torr (*3*–*6*); rectifier voltage of 3 kV.

Let us analyze the obtained oscillograms. As we decreased the charging voltage and/or increased the discharge gap, the tube breakdown terminated and two voltage pulses were recorded on the load (see Fig. 1, curve *2*). As the voltage was increased, the breakdown (usually, partial) first occurred during the second voltage pulse, and then during the first pulse (see Fig. 1, curves *3*–*6*). The decrease of the capacity of the peaking capacitor led to shortening of the front of the voltage pulse and the current pulse (see Fig. 1, curves *5* and *6*). The shortest front of the current pulse was recorded in the circuit without the peaking capacitor (see Fig. 2). In the tube with the interelectrode separation of 80 cm at the pulse repetition frequency of 12 kHz and the neon pressure of 30 Torr, we have obtained the discharge current amplitude of 550 A and the leading front of the current pulse shorter than 10 ns (see Fig. 2, curves *5* and *6*). The obtained modes of operation of the generator with inductive energy storage are characterized by the pulse repetition frequency corresponding to those used in metal vapor lasers,[9] and in the steepness of the current pulse they exceed the parameters of most known generators based on capacitive energy storages that are used for pumping metal vapor lasers.

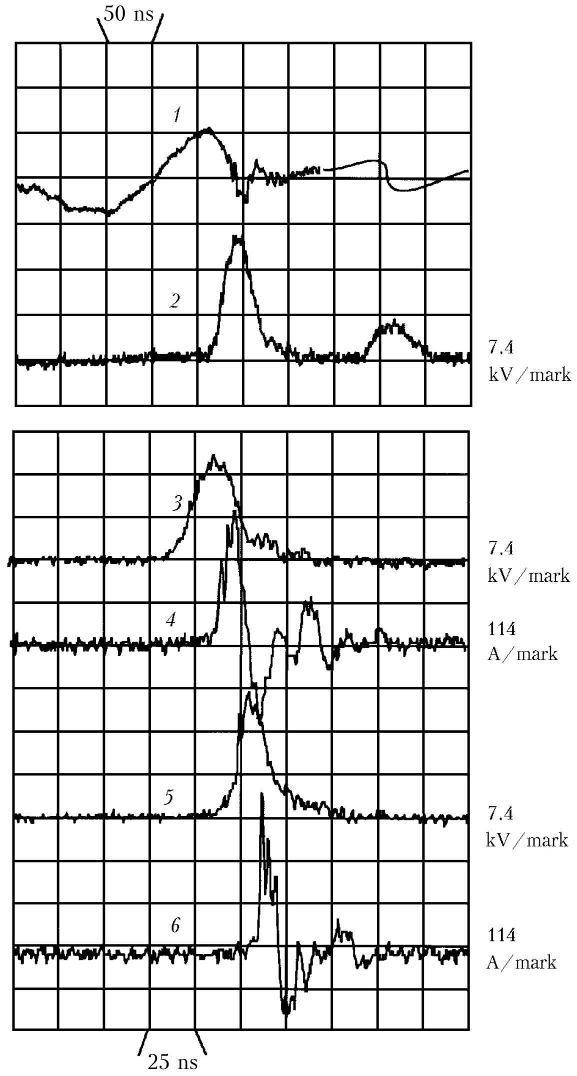

Fig. 2. Oscillograms of voltage pulses across the tube (*1*, *3*, *5*) and current through the tube (*2*, *4*, *6*). Discharge tube length of 40 cm, rectifier voltage of 3 kV, and the pulse repetition rate of 10 kHz (*1*–*4*); discharge tube length of 80 cm, rectifier voltage of 4 kV, and the pulse repetition rate of 12 kHz (*5*, *6*); two SOS-150-2 diodes connected in parallel; peaking capacitor of 100 pF (*1*, *2*) and peaking capacitor turned off (*3*, *4*, *5*, *6*); neon pressure of 30 Torr.

Thus, operation of the pumping generator with the inductive energy storage and semiconductor opening switch at the pulse repetition rate of 12 kHz has been demonstrated for the first time. At the discharge through the 80-cm long tube, the current pulses with the leading front shorter than 10 ns and the amplitude of 550 A have been obtained. In the nearest future, this generator will be applied to pumping repetitively pulsed metal-vapor lasers that are widely used in laser sensing of the atmosphere.

Acknowledgments

The authors are thankful to S.N. Rukin, who kindly gave us SOS (SOS-150-2) diodes, as well as V.A. Vizir and E.Kh. Baksht for their help.

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