Quantum Electronics **31** (10) 864 – 866 (2001)

PACS numbers: 42.55.Lt; 42.60.Lh
DOI: 10.1070/QE2001v031n10ABEH002065

Copper vapour laser with an inductive energy storage and a semiconductor current interrupter

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***Abstract*. A copper vapour laser is built in which a pump generator uses an inductive energy storage and a semiconductor current interrupter. Lasing was obtained in the stationary mode, using a self-heating active element 36 cm^3 in volume, at a pulse repetition rate of 10 kHz and an average output power of 3.3 W. The use of the inductive energy storage in this laser resulted in a 20 % increase in the average output power compared to that for a conventional pump circuit.**

Keywords: *copper vapour laser, generator with an inductive energy storage and a semiconductor current interrupter*

1. Introduction

We showed in papers [1 – 4] that an inductive energy storage (IES) can be used to pump pulsed dense-gas lasers at low pulse repetition rates. IES-pumped generators enable an easy change of the pumping regime and the excitation of lasers of different types under optimal conditions.

The advent of special semiconductor current interrupters (SOS diodes) [5] significantly broadened the possibilities for employing IES-pumped generators and, in particular, allowed the production of generators with a high pulse repetition rate f. When generators of this type were operated with an active load, the maximum f in the stationary regime was 1 kHz, and 5 kHz in the regime of short runs (30 – 40 s) [5]. In Ref. [6] it was shown that an IES with a semiconductor current interrupter can be operated at $f = 12$ kHz.

However, data that would characterise different regimes of pumping pulsed gas lasers by inductive storage devices for $f > 100$ Hz are not available in the literature, even for lasers with a longitudinal discharge pumping. At the same time, there is a need for new pump generators with $f \gtrsim 10$ Hz for the entire class of metal vapour lasers [7 – 9], including the most efficient of them – a copper vapour laser.

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Received 14 May 2001
Kvantovaya Elektronika **31** (10) 864 – 866 (2001)
Translated by E N Ragozin

In this paper, we studied for the first time a self-heating copper vapour laser ($\lambda = 510.5$ and 578.2 nm) pumped by a generator with an inductive energy storage, which is promising for pumping metal vapour lasers with a high pulse repetition rate.

2. Experimental

The electric circuit of the setup was similar to that used in Refs [3, 6]. The power supply was a high-voltage rectifier, which charged a capacitor with a capacitance of 20 μF to a voltage of 1 – 5 kV. This capacitor was connected to a 2000-pF capacitor via a choke and a diode and charged it to the double voltage at $f \sim 1 - 12$ kHz. Upon actuation of the thyratron (a water-cooled TGI-2500/50), the 2000-pF capacitor charged the capacitor $C_1 = 2000$ pF (Fig. 1) via an 11.3 μH inductance and the thyratron. When the voltage across C_1 was about its maximum, a water-cooled magnetic choke L_1 assembled of 175 M1000NM ferrite rings of size 20/10/5 mm was actuated.

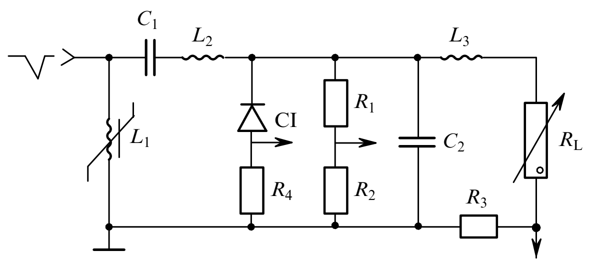

Figure 1. Schematic diagram of the inductive pump generator of the copper vapour laser with a semiconductor current interrupter: (C_1) storage capacitors; (C_2) peaking capacitor; (L_1) magnetic switch; (R_L) load resistance (for a laser tube); ($R_1 - R_4$) voltage dividers and current shunts; (CI) semiconductor current interrupter.

Upon charging the C_1 capacitor, the current through the SOS diodes was flowing in the forward direction, and upon actuation of the L_1 choke, in the backward direction. As a result, the SOS diode interrupted the current, and the energy stored in the inductance was spent to form a pulse of high-voltage across the active element connected in parallel with the SOS diodes. The operation of a similar circuit was described in greater detail elsewhere [3]. Note that the power extracted from the rectifier and commuted by the thyratron in these experiments was significantly lower than the maximum power and exceeded by an order of magnitude the power of the rectifier used in Ref. [3].

The current interrupters were special silicon SOS-25-2, SOS-50-2, or SOS-150-2 diodes [9] with maximum reverse voltages of 25, 50, and 150 kV, respectively, and a maximum amplitude of the interrupted current of 2 kA, which were immersed in transformer oil. We studied three assemblies of SOS diodes connected in parallel: the first one consisted of four SOS-25-2 diodes, the second one of four SOS-50-2 diodes, and the third one of two SOS-150-2 diodes. We used the parallel connection of the diodes to reduce the average current through them at high repetition rates.

As a load, we used an air-cooled sealed-off copper vapour element. The diameter of a discharge channel was 1 cm and the interelectrode distance was 46 cm. A ceramic tube with a discharge channel was placed in a quartz tube; mounted at the ends of the tube were the elements of a confocal unstable resonator. The buffer gas was neon at a pressure of 30 Torr. A voltage applied across the active element caused a breakdown of neon and, after the tube heating, of the mixture of neon and copper vapour.

The active element was air-cooled and was connected in parallel with the SOS diodes. In most experiments, peaking capacitors $C_2 = 22$, 100, 200, or 330 pF were connected in parallel with the active element. The active element was pumped using a conventional circuit with capacitive storage devices and switching accomplished by a TGI1-1000/25 thyratron. The oscilloscope traces of the voltage and the current were measured with ohmic dividers, shunts, or a Rogowski loop, whose signals were fed to a TDS-220 oscilloscope.

3. Results and discussion

As shown in Ref. [6], an IES with a semiconductor current interrupter can be operated at high (up to 12 kHz) pulse repetition rates. A pump generator for metal vapour self-heating lasers should fulfil two functions: first, it should heat the active element up to the working temperature and provide the required concentration of copper vapour and, second, it should provide efficient pumping of the active medium.

Figs 2–4 show typical oscilloscope traces of the voltage pulses across the active element, including the inductance of connecting buses, of the current through the active element, and of the output radiation. The radiation was recorded simultaneously at the yellow and green lines. In experiments, we varied the current interrupter assemblies, the capacity of the peaking capacitor, and the rectifier voltage. The pump generator could operate at $f = 1 - 12$ kHz, the experiments were conducted at $f = 10$ kHz.

Varying the current interrupter assemblies showed that the best results were achieved for the best matching between the reverse SOS-diode voltage and the pulsed voltage across the active element. As the difference of these voltages increases, the losses in the SOS diode also increase, which hampers heating the active element to the working temperature. Thus, for a 100-pF peaking capacitor and 150-kV SOS diodes, the lasing threshold was not reached because of the low temperature of the active element; with 50-kV SOS diodes, the output power was 1.5 W (Fig. 2); and with 25-kV SOS diodes, it exceeded 2 W.

Variation of the capacity of the peaking capacitor C_2 showed that the use of small or zero C_2 values provides the maximum voltage across the active element and shortens the duration of the current pulse, however, the efficiency of heating of the active element lowers. In particular, with 50-kV SOS diodes and $C_2 = 22$ pF, the voltage across the active element amounted to 26 kV and the current was 590 A (Fig. 3), but because the temperature of the active element was not high enough, the output laser power was very low and was not measured. As C_2 was increased to 100 pF, the average output power increased to 1.5 W, and for $C_2 = 200$ pF it amounted to 2.1 W. The highest average output power equal to 3.3 W (Fig. 4) was obtained for $C_2 = 200 - 300$ pF and 25-kV SOS diodes.

The total radiation divergence obtained from far-field measurements was within 3 mrad. In this case, the laser continuosly operated for 8 h (longer times were not explored), and the temperature of oil that cooled the SOS diodes remained unchanged after the first 10 min of laser operation and did not exceed 45 °C for the SOS-25-2 diodes, and 63 °C for the SOS-50-2 diodes. The rectifier voltage was 4.8–5 kV in the optimal regimes.

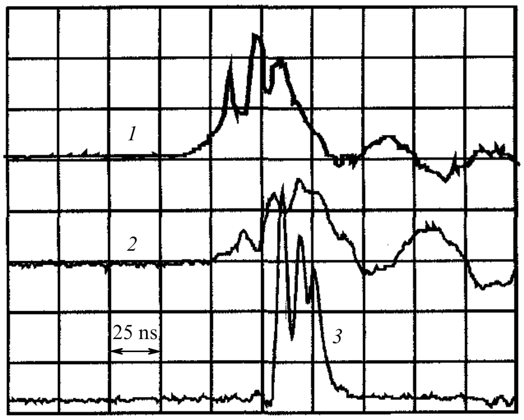

Figure 2. Oscilloscope traces of the voltage pulses across the active element and the inductance of connecting buses (*1*), the current through the active element (*2*), and the output laser pulses at the yellow and green lines (*3*) for a pulse repetition rate of 10 kHz and four SOS-50-2 diodes connected in parallel; the capacity of the peaking capacitor is 200 pF, the rectifier voltage is 5 kV, the average laser power is 2.1 W, the value of the vertical scale division is 6.5 kV (*1*) or 215 A (*2*).

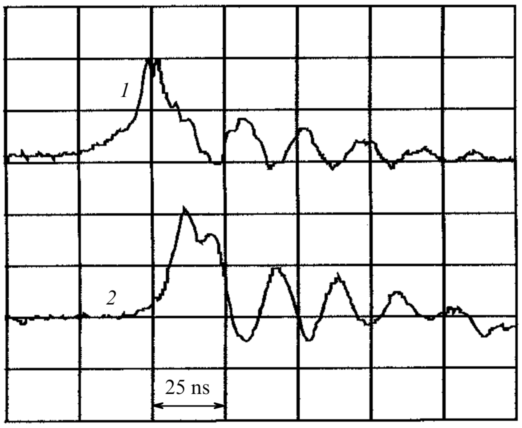

Figure 3. Oscilloscope traces of the voltage pulses across the active element and the inductance of connecting buses (*1*) and of the current through the active element (*2*) for a pulse repetition rate of 10 kHz and four SOS-50-2 diodes connected in parallel; the capacity of the peaking capacitor is 22 pF, the rectifier voltage is 5 kV, the value of the vertical scale division is 6.5 kV (*1*) or 215 A (*2*).

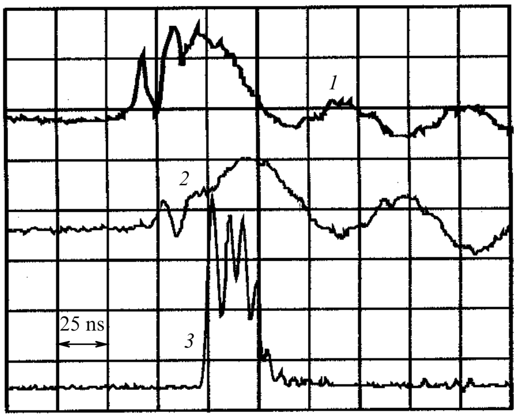

Figure 4. Oscilloscope traces of the voltage pulses across the active element and the inductance of connecting buses (*1*), the current through the active element (*2*), and the output laser pulses at the yellow and green lines (*3*) for a pulse repetition rate of 10 kHz and four SOS-25-2 diodes connected in parallel; the capacity of the peaking capacitor is 330 pF, the rectifier voltage is 4.85 kV, the average laser power is 3.3 W, the value of the vertical scale division is 6.5 kV (*1*) or 215 A (*2*).

We also pumped the active element using a conventional generator with a capacitive storage and a thyratron switch. The average output laser power obtained in this case was 2.7 W, which is 20 % below the output power of the new laser. We plan to analyse in detail the energy losses in different elements of the pump generator with an IES and a semiconductor current interrupter and to study metal vapour lasers which require shorter pump pulses of higher power, allowing a reduction of the working temperature of the active element.

4. Conclusions

Therefore, the use of an IES and a semiconductor current interrupter to pump a copper vapour laser allows increasing the amplitude of the voltage across the active element and the discharge current through it. An average output laser power of 3.3 W was extracted from an active element with a discharge volume of 36 cm^3 at $f = 10$ kHz. A comparison of the average output laser power extracted from the given active element using the conventional and new schemes showed that use of the inductive energy storage resulted in a 20 % increase in the average output power.

Acknowledgements. The authors thank S N Rukin for providing SOS-150-2 diodes, and V B Sukhanov for providing the active element of a copper vapour laser.

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