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Quantitative Effect of Initial Current Rise on Pumping the Double-Pulsed Copper Chloride Laser

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Abstract—**The laser energy output of a double-pulsed copper chloride laser has been found to be a logarithmic function of the circuit inductance over the range of 1 to 12 μH. The initial current rise was inversely proportional to the circuit inductance so that the laser energy was also a logarithmic function of the initial current rise.**

Introduction

SELF-TERMINATING pulsed lasers require fast rising pumping pulses for efficient operation [1]-[3]. Although the relationship between efficiency and steep leading edges of the current pulses is well known for copper lasers, the experimental evidence has only been qualitative [4]-[5]. This work provides quantitative relationships between the initial rate of current increase and the laser energy for a double-pulsed CuCl laser.

The double-pulsed CuCl laser [5]-[8] uses two consecutive electrical discharges to produce laser action from copper atoms. The first discharge (dissociation pulse) dissociates the molecular CuCl into atomic parts and the second discharge (pumping pulse) forms the population inversion between levels in the copper atoms. There is a minimum time required between pulses before laser output is observed (minimum delay) and there is also a maximum time between the pulses, beyond which no laser action is observed (maximum delay). The delay which yields the largest output for the particular condition is termed the optimum delay.

In high repetition rate copper compound lasers [9]-[13] a single pulse provides both pumping for that pulse and dissociation for the next. Thus the pumping cannot be separated from the dissociation in that type of copper laser. A double-pulsed laser is suited for study of the effect of the initial shape of the discharge on pumping copper atoms because the dissociation pulse can be kept constant and the temperature and copper density are controlled independently from the pulsing rate. In this study, inductance was added to the transmission line of the second pulse of the double-pulse CuCl laser in order to decrease the initial current rise of the discharge. The laser energy was obtained as a function of the time delay between the dissociation and pumping pulses. The laser energy and two characteristic time delays are correlated with the initial current rise to determine a quantitative functional relationship.

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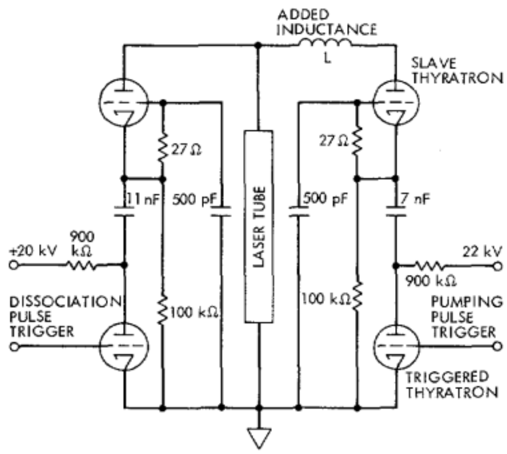

Fig. 1. Schematic diagram of the double-pulse dual thyratron circuit.

Apparatus

Two dual thyratron circuits, as shown schematically in Fig. 1, were connected in parallel to the laser tube. The dissociation pulse of 2.3 J was supplied from three 3.6-nF capacitors in parallel charged to 20 kV. The pumping pulse of 1.7 J was supplied from two 3.6-nF capacitors in parallel, charged to 22 kV. The double pulses were repeated at 2 Hz.

The laser was a Pyrex tube with a 12-mm diameter and was inserted inside an oven. The anode and cathode consisted of p-i-n electrodes and were separated by 300 mm. Thermocouples were placed along the tube to measure the temperature profile which had a maximum of 676 K and a minimum of 664 K. The temperature at each point along the tube varied less than 5 K throughout the data acquisition. The laser tube extended outside the oven so that the Brewster-angle windows were at ambient temperature. Neon gas, at a pressure of 0.49 kPa, flowed across the windows at both ends of the tube. CuCl was supplied by evaporation from two tubes which were attached to and lie below the laser tube between the electrodes.

The optical cavity consisted of a maximum reflecting mirror with a 2-m radius of curvature and a nominally 80 percent transmitting mirror with a 4-m radius curvature. The distance between the mirrors was 0.75 m.

The laser energy was measured with a Korad KDI photomultiplier and a neutral density filter. The laser energy was displayed on a Tektronix 7704 oscilloscope and recorded on Polaroid film. The current pulse was measured on the ground return from the laser tube with a Pearson model 411 current transformer. The current pulse was displayed on a Tektronix 7633 storage oscilloscope and recorded on Polaroid film. For each inductor (and for no inductor) added to the transmission line of the second pulse, the laser energy was obtained as a function of delay time and the shape of the current pulse was also obtained. The rate of current rise was determined from the first 50 ns of the current pulse in which the current increased nearly linearly with time. The laser pulse, with FWHM of 20-25 ns, occurred during this initial portion of the current pulse.

The inductors were placed in the line between the thyratron circuit and the laser tube electrodes of the pumping pulse as shown in Fig. 1. The 35 inductors were air core coils wound from 18 gauge enameled magnet wire. The inductances of these coils were calculated from Wheeler's formula [14] and ranged from 0.13 to 11 μH.

Initial Current Rise and Circuit Inductance

For an ideal switching circuit the initial current rise $\dot{I}$ is equal to the initial voltage V divided by total circuit inductance. This relation can be arranged in the form

$$L = V/\dot{I} - L_0 \tag{1}$$

where the total circuit inductance has been broken into two parts: the inductances of the switching circuit plus the laser tube L_0 and the inductance added to the circuit L. A least-squares fit [15] of the data to (1) yields a circuit inductance of 0.998 ± 0.071 μH and an implied voltage of 20.54 ± 0.35 kV. The coefficient of regression for this fit is 0.989.

With the knowledge of the circuit inductance, the hyperbolic relationship between the total circuit inductance and the initial current rise can be displayed. Such a plot is given in Fig. 2. A power curve fit [15] to the form

$$\dot{I} = a\,(L + L_0)^b \tag{2}$$

on the data yields an implied voltage of 20.56 kV and a power of -1.01 with a coefficient of regression of 0.98. The applicability of the simple analysis of (1) to this CuCl laser is adequately shown with the data in Fig. 2.

Laser Energy

The laser energy at the optimum time delay (termed the optimum laser energy) decreases monotonically with in-

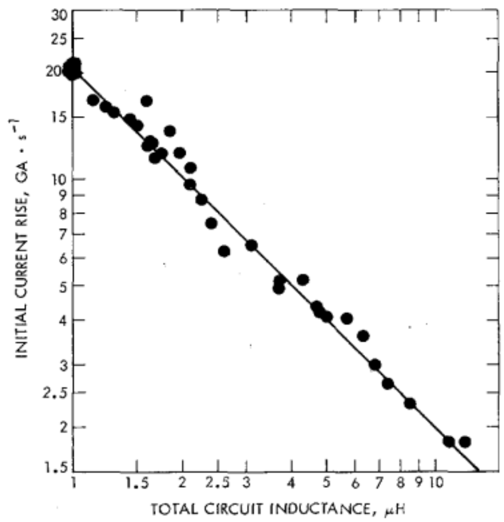

Fig. 2. Initial current rise as a function of the total circuit inductance.

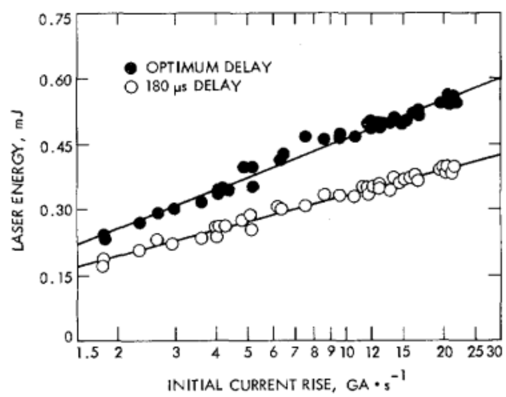

Fig. 3. Laser energy at optimum delay and at 180 μs as a function of the logarithm of the initial current rise.

creasing added inductance. For the range of inductance considered in this study, the relationship was found to be logarithmic. Since the initial current rise is inversely proportional to the total circuit inductance, the optimum laser energy is logarithmically dependent upon the initial current rise. A plot of optimum laser energy as a function of the logarithm of the initial current rise, given as Fig. 3, displays the correlation

$$E = a + b \ln \dot{I}. \tag{3}$$

A logarithmic fit [15] of the data to (3) yields $a = 0.171$ mJ, $b = 0.126$ mJ, and a regression coefficient of 0.98, with $\dot{I}$ in GA/s.

Since the optimum delay changes with added inductance, the laser energy curves for optimum delay represent the combined effects of pumping efficiency and the chemistry which occurs in the laser tube. In order to separate the effect of inductance and initial current rise on the pumping of the laser, the laser energy is considered at a particular delay time. The chemistry of the laser remains constant for a fixed time delay because the dissociation pulse was not changed. A delay time of 180 μs was selected for illustration because the meta-

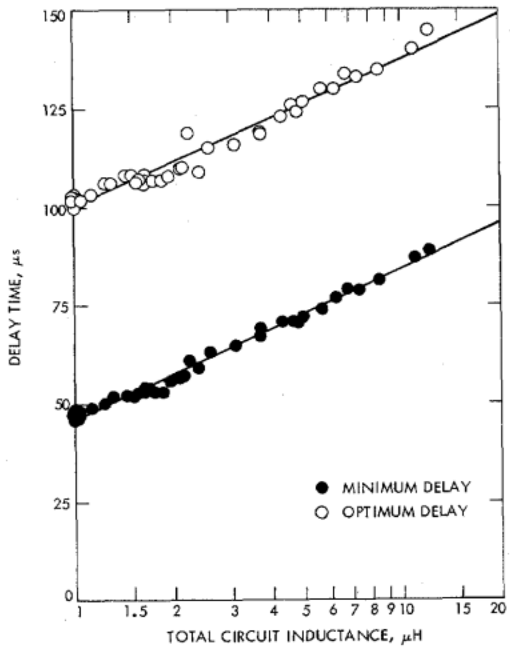

Fig. 4. Optimum and minimum delays as functions of the total circuit inductance.

stable level populations (the lower laser levels) have substantially decayed by this time so that the effect of pumping the ground state is further isolated. The laser energy is used as an indicator of the relative pumping efficiency; a larger output is indicative of a greater number of copper atoms having been pumped to the upper laser levels.

The laser output at 180-μs delay time is plotted as a function of initial current rise in Fig. 3. A fit of the data to (3) yields $a = 0.137$ mJ, $b = 0.0852$ mJ, and a regression coefficient of 0.979. Since the initial current rise was measured at the optimum delay time, it was necessary to assume for this particular correlation that the initial current rise is independent of the time delay from optimum to 180 μs; this assumption is consistent with the simplified circuit analysis of (1).

Time Delay

The minimum and optimum time delays increase with increasing added inductance; Fig. 4 displays a logarithmic dependence upon the total circuit inductance. The minimum and optimum delays are functions of the populations of copper atoms in the ground state and metastable levels (lower laser levels) in the laser tube after the dissociation pulse [16]. For the conditions of this study both the metastable level and ground state populations will be decaying for the times for which lasing was observed [16]; the metastable populations decay at a higher rate than the ground state. Since the dissociation pulse remains constant in this study, the history of the populations of these levels was the same for each added inductance. The decrease in minimum delay with initial current rise implies that faster rising current pulses are more efficient at pumping copper atoms from the ground state to the upper laser level because lasing threshold occurs with a higher population in the lower laser level. The decrease in optimum delay with increasing initial current rise similarly implies more efficient pumping.

Conclusions

The laser energy of a double-pulsed CuCl laser has been experimentally determined to be a logarithmic function of the initial current rise of the pumping pulse. The faster rising current pulses pump the copper atoms from the ground state to the upper laser levels more efficiently.

The simplified circuit analysis represented by (1) is applicable to double-pulsed CuCl lasers whose discharge circuit inductance is greater than 1 μH. The lower limit of inductance for application of this analysis was not determined by this study.

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References

[1] W. T. Walter, N. Solimene, M. Piltch, and G. Gould, "6C3–Efficient pulsed gas discharge lasers," *IEEE J. Quantum Electron.*, vol. QE-2, pp. 474–479, Sept. 1966.
[2] G. G. Petrash, "Pulsed gas–discharge lasers," *Sov. Phys.–Usp.*, vol. 14, pp. 747–765, 1972.
[3] P. A. Bokhan and V. I. Solomonov, "Mechanism of laser action in copper vapor," *Sov. J. Quantum Electron.*, vol. 3, pp. 481–483, 1974.
[4] P. A. Bokhan, V. N. Nikolaev, and V. I. Solomonov, "Sealed copper vapor laser," *Sov. J. Quantum Electron.*, vol. 5, pp. 96–98, 1975.
[5] I. Smilanski, L. A. Levin, and G. Erez, "A copper laser using CuI vapor," *IEEE J. Quantum Electron.* (corresp.), vol. QE-11, pp. 919–920, Nov. 1975.
[6] C. J. Chen, N. M. Nerheim, and G. R. Russell, "Double-discharge copper vapor laser with copper chloride as lasant," *Appl. Phys. Lett.*, vol. 23, pp. 514–515, 1973.
[7] J. A. Piper, "A copper iodide laser excited by transverse discharge," *Opt. Commun.*, vol. 14, pp. 296–300, 1975.
[8] N. M. Nerheim, "A parametric study of the copper chloride laser," *J. Appl. Phys.*, vol. 48, pp. 1186–1190, 1977.
[9] C. S. Liu, E. W. Sucov, and L. A. Weaver, "Copper superradiant emission from pulsed discharge in copper iodide vapor," vol. 23, pp. 92–93, 1973.
[10] A. M. Shukhtin, V. G. Mishakov, G. A. Fedotov, and A. A. Ganeev, "Interference method for observing the dissociation of copper halide molecules in a pulsed discharge," *Opt. Spectrosc.* (USSR), vol. 39, p. 444, 1975.
[11] N. V. Subotinov, S. D. Kalchev, and P. K. Telbizov, "Copper vapor laser operating at a high pulse repetition frequency," *Sov. J. Quantum Electron.*, vol. 5, pp. 1003–1004, 1976.
[12] O. S. Akirtava, V. L. Dzhikiya, and Y. M. Oleinik, "Laser utilizing CuI transitions in copper halide vapors," *Sov. J. Quantum Electron.*, vol. 5, pp. 1001–1002, 1976.
[13] R. S. Anderson, B. G. Bricks, and T. W. Karras, "Copper oxide as the metal source in a discharge-heated copper vapor laser," *Appl. Phys. Lett.*, vol. 29, pp. 187–188, 1976.
[14] Anonymous, Hewlett-Packard Company, Rep. HP-65 E.E. Pac. I, 1974.
[15] ——, Hewlett-Packard Company, Rep. HP-65 Stat Pac. I, 1974.
[16] N. M. Nerheim, "Measurements of copper ground state and metastable state population densities in a copper-chloride laser," *J. Appl. Phys.*, to be published.