Simple and compact neutral metal vapor laser assembly operating in a low-temperature region

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A compact and inexpensive technique is reported for a discharge-excited pulsed metal vapor laser (MVL) at a low operating temperature utilizing an air-blown-type spark-gap switch. A laser is excited in an aperiodic pulse train by successive pulsed discharges of a storage capacitor through a spark-gap switch. A variety of neutral metal vapor laser (MVL) using metal compound as a lasant is briefly reported with the compact device.

INTRODUCTION

An elemental metal vapor laser (MVL) possesses some excellent features[1] such as high output, high efficiency, high gain, large cross section of the output beam, and high pulse repetition frequency; although a major disadvantage is its high operating temperature. Substitution of a metal halide,[2–5] volatile metal compound, and/or organometallic compound[6–9] as the lasant permits operation in a low temperature and allows considerable simplification of the design of the laser tube. MVL will be used extensively because of the great variety and if it is simple and easy to handle. This paper describes a compact and inexpensive technique for the pulsed MVL system at a low operating temperature.

I. APPARATUS

A. General description of the MVL system

An electrical circuit used to excite the MVL is shown in Fig. 1, where a handmade air-blown-type spark-gap switch (GS) is used as a substitute for the usual thyratron. By using this GS, a compact and inexpensive MVL system can be realized.

A laser is driven by successive pulsed discharges of an energy storage capacitor ($C = 4\times 1$ nF; ceramic capacitor of doorknob type) through the free-running GS. This is done in an aperiodic pulse train as a boosted-ac (50 Hz) high voltage of about 5.4 kV rms, during each half-cycle of the 50-Hz ac.

Flowing He gas is used as a buffer gas in order to purge the discharge products from the tube by a vacuum pump together with the gas flow. He gas flow rate and internal pressure (p) of the tube are kept throughout experiments. Their values are in the region of 15–30 cc/min and 2–20 Torr.

The optical resonator of ~55-cm spacing is formed by a flat dielectric-coated mirror with high reflectivity and an output coupler of a flat dielectric-coated mirror with an adequate transmittance at a desirable wavelength.

B. GS construction

Figure 2 shows a schematic construction of the GS. The electrodes of the GS are made of brass. An ~2-mm hole is drilled in the center of the one-sided electrode and compressed air (1.5–2.0 kg cm^{-2} gauge) is blown to the opposite electrode through the hole. The spacing between the electrodes is adjusted by screwing one of the rods in and out, thus the discharge voltage and the pulse repetition rate are controlled. Typical spacing of the GS electrodes (d) in the present system is about 1 mm for applied voltage (V_a) and about 5.4 kV rms and about 10-kHz repetition rate of pulsed discharges.

C. Laser tube (LT) construction

Figure 3 shows a construction of the laser tube (LT). A LT is made of a 1.2–1.3-cm-i.d. T-shaped Pyrex or quartz

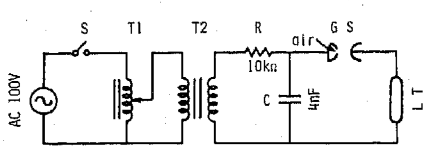

FIG. 1. An electrical circuit used to excite the metal vapor laser. S: knife switch, T1: 0–130 V, 2-kV A autotransformer, T2: 1:60, 3-kV A single-phase transformer, GS: air-blown-type spark-gap switch, LT: laser tube, C: energy storage capacitor.

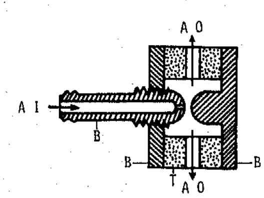

FIG. 2. A schematic construction of the air-blown-type spark-gap switch. AI: compressed air in, AO: air out, B: brass, T: Teflon.

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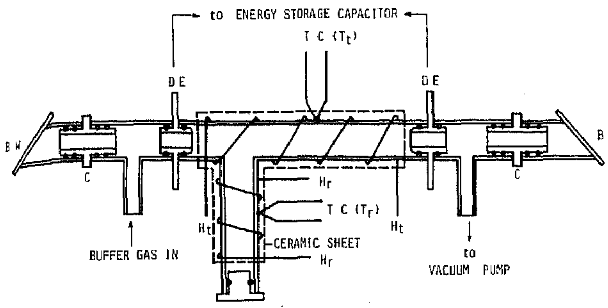

FIG. 3. Axial cross-sectional view of the metal vapor laser tube. BW: Brewster window, C: connector, DE: discharge electrode, H_t and H_r: heater for tube and reservoir heating, respectively, TC(T_t) and TC(T_r): thermocouple for tube temperature (T_t) and reservoir temperature (T_r), respectively.

tube with Brewster windows made of photographic glass plate at both ends. The annular discharge electrodes made of brass are separated by 17–20 cm and the total length of the laser tube is about 40 cm. The i.d. of the discharge electrodes is about 0.5–0.6 cm. The portion of the branch in the T-shaped tube is employed as a reservoir for the lasant. The metal vapor is introduced from the reservoir into the discharge region.

Outside the portions of the reservoir and the discharge tube, nichrome wire heaters are separately wound and wrapped in ceramic sheets for thermal shielding. As self-heating by repetitive pulsed discharges gradually raises the tube temperature, independent winding (of reservoir/tube winding) of the heaters is reasonable in order to obtain an adequate vapor pressure of volatile compounds and to control the vapor pressure for a practical use. The reservoir temperature (T_r) and the discharge tube temperature (T_t) in the center of each portion are measured independently by Chromel–Alumel thermocouples (TC). Rubber "O" rings are used for gas sealing of the connections in the LT because of the low operating temperature. Thus quick assembly and disassembly of the LT become possible.

TABLE I. Metal compounds obtained from laser oscillation.

Lasant[a]	p (Torr)	Oscillation T_r	Temperature (°C) T_t
CuCl	(5)	300–600 ,	$\simeq T_r$
$Cu(AA)_2$	(2)	140–160 ,	$\simeq T_r$
$Cu(TAA)_2$	(3–7)	94–120 ,	$\simeq T_r$
$Cu(HFA)_2$	(3)	37– 80 ,	$\simeq T_r$
$MnCl_2$	(5–20)	600–750 ,	$\simeq T_r$
$Mn(AA)_2$	(4)	165–180 ,	$\simeq T_r$
$Mn(AA)_3$	(4)	120–130 165–200 '	$\simeq T_r$
$HAuCl_4 \cdot 4H_2O$[b]	(4)	— ,	70–150[c]

[a]Detailed explanation was presented in Ref. 9.
[b]Unpublished.
[c]With straight discharge tube, He flow rate was 110 cc/min.

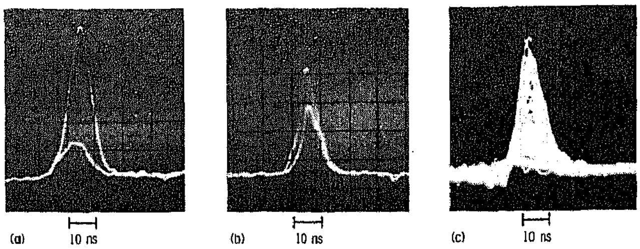

FIG. 4. Typical multiexposed oscilloscope traces of laser-output pulses. (a) $Cu(AA)_2$, $T_r = 50$ °C, $T_t = 60$ °C, (b) $Mn(AA)_3$, $T_r = 180$ °C, $T_t = 185$ °C, (c) CuCl: $T_r = 540$ °C, $T_t = 330$ °C.

II. EXPERIMENTAL RESULTS

A. GS operation and discharge characteristics

A switching rate of the GS reached about 600 Hz and 10 kHz, without and with blowing the compressed air, respectively. It was under the conditions of optimum operation in the former, and of $d = 1$ mm, $V_a = 5.4$ kV rms in the latter. The higher pulse repetition rate was achieved by removing the free ions between the GS electrodes with the compressed-air flow. Although an excitation pulse was aperiodic due to driving with an ac source, the time interval of each pulse in an aperiodic excitation pulse train was located in the range between the minimum and the maximum delay time[3] when a metal compound as a lasant was well dissociated and excited.

B. Laser operation

Laser operation was obtained using the metal halide of CuCl, $MnCl_2$, the metal β-diketone chelate of $Cu(AA)_2$ (copper acetylacetonate), $Cu(TAA)_2$ (copper trifluoroacetylacetonate), $Cu(HFA)_2$ (copper hexafluoroacetylacetonate), $Mn(AA)_2$, $Mn(AA)_3$ (manganese acetylacetonate), and the volatile metal compound of $HAuCl_4$, $4H_2O$ (chloroauric acid) as a lasant.

The laser-oscillation wavelength was 510.6 (and 578.2 nm at the higher temperature), 534.1, and 627.8 nm for the copper, the manganese, and the gold compound, respectively. The metal compounds obtained from laser oscillation are listed in Table I. The lowest operating temperature of 37 °C could be obtained using the $Cu(HFA)_2$ chelate, which was prepared in our laboratory. Typical multiexposed oscilloscope traces of the laser output pulses are shown in Fig. 4. These figures indicate how the number of the oscillation pulses in the metal β-diketone chelate laser are few compared with that in the CuCl laser.

III. DISCUSSION

In summary, we were able to realize laser operation in a low-temperature region using a compact and inexpensive MVL system. Construction technique of the system was reported.

The present system is not constructed to optimize the laser operation. The MVL operates only near the peak voltage of each half-cycle of the 50-Hz ac because the driving voltage is low and the active length of the laser is relatively short compared with that of the usual device. Modification of the high-voltage power supply and the laser tube may lead to even more improved laser performance.

Further, this approach will enable us to use the MVL system using the other metal compounds.

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