Investigation of the effects of buffer gas pressure, electrical input power and pulse repetition rate on the output power of a metal vapor laser

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Abstract

The effects of buffer gas pressure, electrical input power and pulse repetition frequency on the output power of 510.6nm and 578.2nm transitions have been experimentally investigated in a copper vapor laser with small-bore tube (11mm of diameter and 580mm of length). It is observed that the output power characteristics are strongly influenced by these parameters. A maximum output power of laser is obtained at about 4W with 27 kHz of pulse repetition frequency, 30 torr of Ne buffer gas pressure and 1.42kW of electrical input power. The waveforms of the current, tube voltage and laser pulses have also been observed.

Keywords: Metal vapor lasers; Laser output power; Operational parameters

1. INTRODUCTION

Copper vapor lasers (CVL's) are well known as efficient high average power visible laser sources. Temporal nature of CVL's being characterized by multi-kilohertz pulse repetition frequency (PRF) and nanosecond-scale pulses. The pulsed nature of CVL's makes them ideally suited to many attractive applications in different areas of science and technology including laser isotope separation, precision metal cutting, high speed photography, underwater processing and medical applications, micro ablation, high-speed imaging, particle imaging velocimetry, holography, projection TV, photodynamic therapy, detection of forensic evidence, nonlinear frequency conversion to the ultraviolet, pumping of solid-state laser materials as Ti:Sapphire [1-5] and etc. CVL's as metal vapor laser family have an output power in the green (510.6nm) and yellow (578.2nm) regions and are inherently pulsed laser systems. In a copper vapor laser the lasing medium is copper vapor which is confined in a recrystallized alumina tube [6-8]. CVL's are discharge-heated systems which energy from the excitation pulse is used to heat the laser tube. For better performance, the laser requires fast excitation pulses of rise time typically 100ns or less, at high voltage and high PRF [9-11].

The conventional circuit for copper vapor laser excitation is a capacitor-to-capacitor charge transfer circuit in which a thyratron is used as the switch. The thyratron has proved to be a reliable switch in the circuit. Circuit schemes are reported using magnetic pulse compression and magnetic assist to reduce losses in the thyratron [12-15]. These circuits have shown better performance than the conventional thyratron-based capacitor-to-capacitor charge transfer circuit.

CVL is an excellent coherent light at the visible wavelengths region which has high output power gain and PRF. The neon buffer gas is usually used to attain highest output power. In the self-heating CVL's electron density due to ionization of copper and buffer gas atoms in the discharge reaches to about 1015 cm^{-3} and electron energy distribution lies in the range 310 eV. In elastic collisions of electrons with copper vapor atoms causes excitation of the copper atoms, so the inversion population occur and laser oscillation due to electron transition from upper level (P1/2, P3/2) to the lower meta-stable level take place (D5/2, D3/2) at the 578.2- and 510.6nm, respectively. Current peak of discharge at small bore laser reaches to hundreds amperes for 5-30 kV applied voltage dependent to values of PRF and buffer gas pressure. CVL's is a good amplifier because of high gain coefficient and low saturation intensity [16-17]. The laser used in this experiment has 11mm of diameter and 580mm of length which lies in the small bore category. The effects of operational parameters such as buffer gas pressure, electrical input power and PRF on the laser output power have been experimentally investigated. It is observed that the output power characteristics are strongly influenced by operational parameters. A maximum output power of laser is obtained at about 4W with 27 kHz of PRF, 30 torr of Ne buffer gas pressure and 1.42 kW of electrical input power.

2. EXPERIMENTAL APPARATUS

Fig.1 shows a schematic diagram of experimental arrangement. A 4W homemade self-heated longitudinal discharge CVL is employed to carry on the measurements. The tube is made up of dense alumina, 58cm long and with 11mm inner diameter, surrounded by a fibrous alumina insulation covering, with a pyrex tube and an external stainless steel tube. The windows are aligned at the Brewster angle, and the flat back and front mirrors are chosen to have 98% and 4% reflection, respectively. Hallow cylindrical electrodes are used which have been made from molybdenum. Main portion of exciting circuit consists of storage capacitor (Cs=1.62nf), peaking capacitor (Cp=1.62nf), inductance (L_c=1.62μH), 3kW power supply and thyratron switch. The gas is excited by discharging a capacitor through the thyratron.

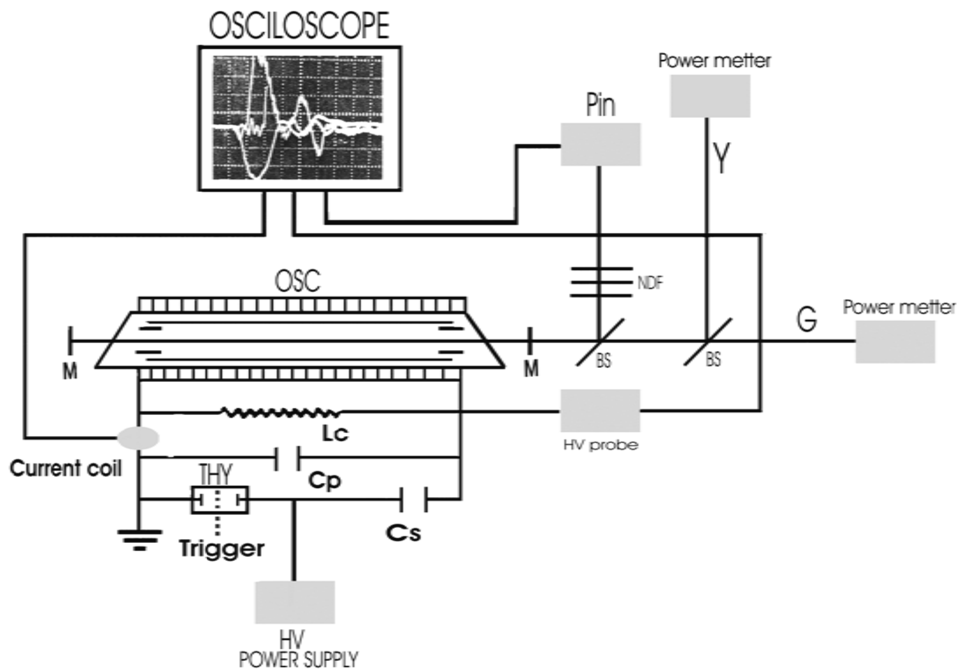

Fig.1. Schematic diagram of experimental arrangement.

The output power of about 4W can be generated by the laser at optimum condition. Tektronix four channel oscilloscope (TDS2024-200MHz, 2Gs/s), Tektronix voltage probe (P6015A), a pin semiconductor detector (FND-100, EG&G) and McPearson Rogowski coil of current (110A) are used for recording of pulse shapes. Two power meters (NTG20) are used for measuring of output power, simultaneously. The beam splitter (BS), and the neutral density filters (NDF) are used for separation of two yellow and green lines and reduction of intensity of input pulse to the detector, respectively.

3. RESULTS AND DISCUSSION

The PRF corresponding to maximum output power (PRF max), for lasers having 10 to 60mm tube bore is approximately inversely proportional to tube bore is which given by following experimental relation

$$(PRF)_{max} = 300/D \quad (1)$$

Where the $(PRF)_{max}$ is in kilohertz and the laser bore D is in millimeter (Lewis, 1991).

The maximum average output power for CVLs ranging in tube bore from 10 to 60mm, is given by

$$(P_{max})_{av} = LD/100 \quad (2)$$

With $(P_{max})_{av}$ in watts, D in millimeters and discharge length L in centimeters.

Influence of PRF on the output power is studied for fixed buffer gas pressure and electrical input power parameters. Figure 2 shows the dependence of the average laser output power of green (510.6nm) and yellow (578.2nm) transitions and total output power on the PRF when the optimal flow rate of Ne buffer gas is set to around 200ml/h, the electrical input power is 1.42kW, neon buffer gas pressure is 30 torr and C_s/C_p=2.38. It is found that at a PRF of 27 kHz, the 4W maximum total output power is obtained.

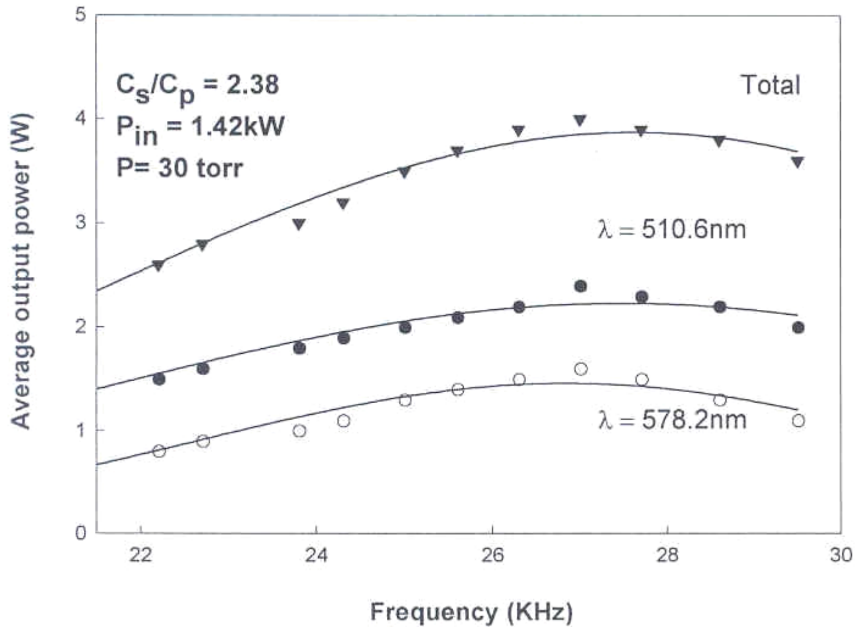

Fig. 2. Dependence of the average output power on PRF

As can be seen, the laser power had a tending to go up with an increasing in PRF at first. At higher PRFs, the output power decreases mainly due to inelastic electron-copper collisions, which subsequently causes the electron temperature to drop such that a changeover of the pumping rates occurs and the output power eventually ceases to oscillate. Figure 3 shows the dependence of the average laser output power of green and yellow transitions and total output power on the electrical input power when the PRF is fixed at optimum value of 27 kHz, neon buffer gas pressure is 30 torr and C_s/C_p=2.38. It is observed that the maximum output power of green and yellow transitions are obtained at electrical input power of 1.42 kW and 1.44 kW, respectively. The maximum total output power is obtained at about 1.42 kW of electrical input power which approximately near the green transition.

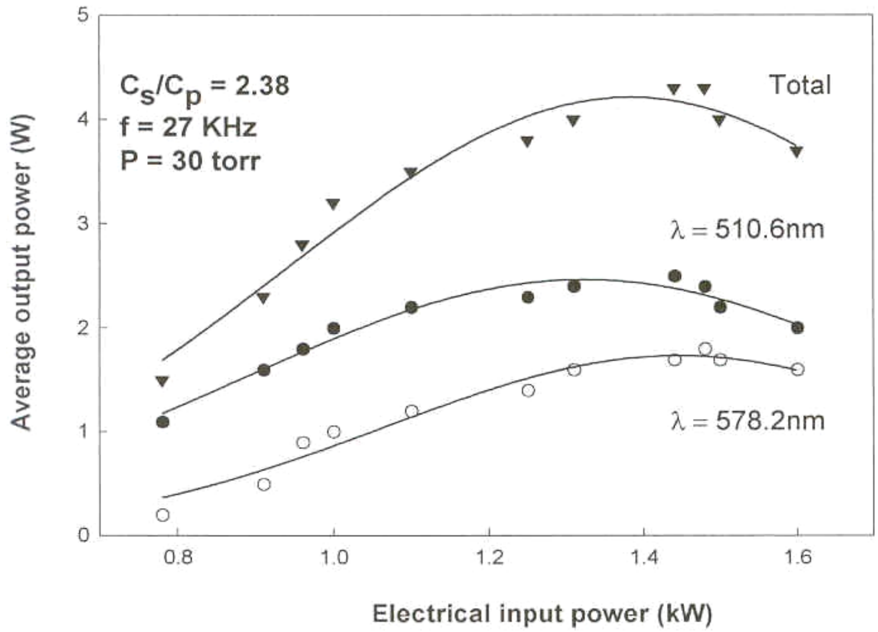

Fig. 3. Dependence of the average output power on electrical input power.

According to Fig.3, an initial increase of the output power is observed, such that a 4.2W peak occurs at an electrical input power of ~1.42 kW. The reason is that the excessive electrical input power raises the working temperature inside the laser tube; therefore, thermal populations of the lower levels of the transition increase, leading to a significant reduction of the population inversion. Referring to the CVL energy diagram, the lower level of the green line (1.39ev) is placed to be lower than that of the yellow one (1.64ev); hence, the lower level of the green transition is relatively more thermally populated than that of the other line. Therefore, the optimum electrical input power for the green transition (~1.42kW) is smaller than that of the yellow one (~1.44kW).

Figure 4 shows the dependence of average output power of green and yellow transitions and total output power on the buffer gas pressure when the PRF is 27 kHz, the electrical input power is 1.42 kW and C_s/C_p=2.38. It is observed that the maximum output powers are obtained at pressure of 30 torr.

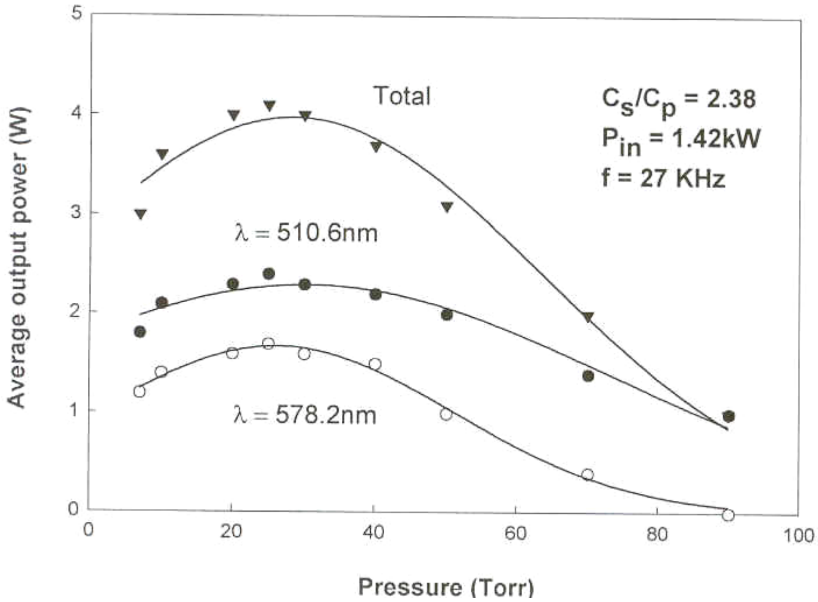

Fig.4. Laser output power as a function of buffer gas pressure at a fixed electrical input power of 1.42 kW

Typical waveforms of the discharge current, tube voltage and laser pulse (green and yellow combined) in this small bore CVL are shown in Fig.5. Ringing in the voltage and current waveforms shows that the impedance of the circuit is higher than the laser tube impedance which is usual. Oscillation occurs during the leading edge of the second half wave of the current, meanwhile in medium-bore tubes the oscillation occurs during the leading edge of the first half wave of the current.

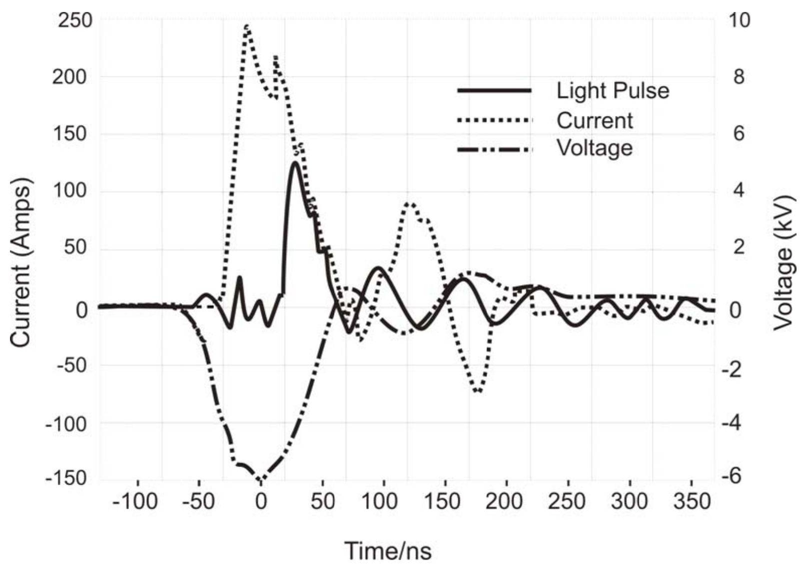

Fig.5 Typical waveforms of the discharge current (dotted line), tube voltage (dashed line) and laser pulse (bold line).

The laser tube is a non-linear load, whose impedance depends on its plasma-circuit geometry (tube capacitance and inductance) and plasma conductivity, each of which are time dependent the rise time and strength of the longitudinal electric field in the CVL and the form of the current pulse depend on the tube impedance. Matching of the external circuit is important to attain high laser efficiency. In general, the higher the rate of rise of the current di/dt, the earlier the inversion is established, and the stronger is the inversion. If di/dt is raised by increasing the applied tube voltage, with a fixed partial Cu gas pressure, p_{cu}, saturation in laser output energy will eventually occur due to excessive ionization and rapid depletion of ground state Cu atoms. The tube voltage for maximum output power is enhanced if P_{cu} is increased; however the ability of the discharge tube to hold off the voltage reduces. Therefore, for operation in the regime of high P_{cu} and high tube voltage needed for high specific output powers, the voltage must be applied in a time shorter than the characteristics breakdown time of the laser tube. This can be achieved by reducing tube inductance and using magnetic pulse compression. The current in a CVL should not be allowed to rise too quickly, however; otherwise the high rate of ionization of Cu atoms can reduce upper level excitation and shorten the gain period due to ground state depletion. Ideally, the current pulse should not last longer than the time for inversion, which is typically 30-50ns, discharge energy expended beyond this time is wasted.

Fig. 6 gives dependence of the laser efficiency on the electrical input power for the small bore CVL under investigation. It is found that the maximum efficiency take place at the about 1.6 kW of electrical input power.

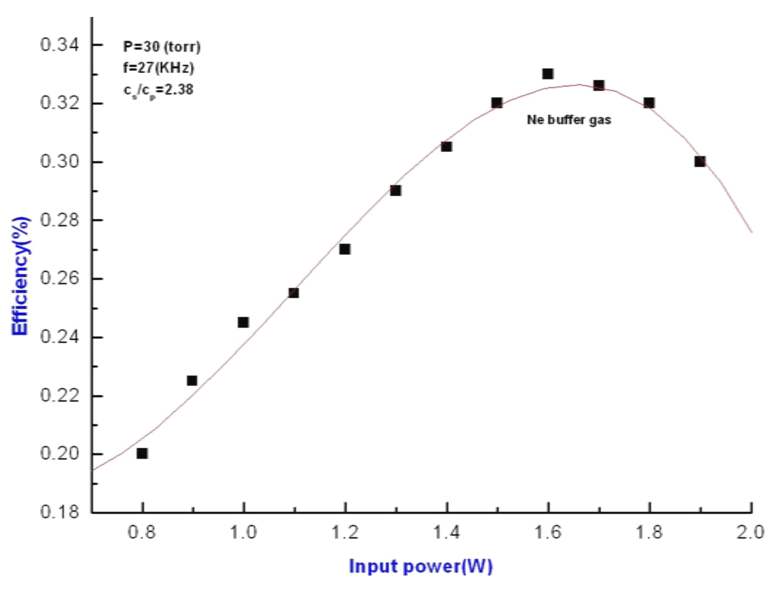

Fig.6. Dependence of the laser efficiency on the electrical input power.

The electrical input power is changed from 0.8 to 2 kW and the laser tube pressure and PRF are kept constant.

4. CONCLUSIONS

The effect of buffer gas pressure, electrical input power and PRF on output power of 510.6- and 578.2nm transitions has been experimentally investigated in a CVL with small-bore. It is shown that each parameter has an optimum value and also finds that the behaviors of green and yellow transitions are about the same with little difference value in operational parameters. The difference of operational parameters between small-bore tubes and medium ones are PRF and electrical input power, but the buffer gas pressure is the same and independent on bore-tube.

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