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Development of copper bromide laser master oscillator power amplifier system

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Abstract. Development of master oscillator power amplifier (MOPA) system of copper bromide laser (CBL) operating at 110 W average power is reported. The spectral distribution of power at green (510.6 nm) and yellow (578.2 nm) components in the output of a copper bromide laser is studied as a function of operating parameters. The electrical input power was varied from 2.6 to 4.3 kW, the pulse repetition frequency (PRF) was changed from 16 to 19 kHz, and the pressure of the buffer gas (neon) was kept fixed at 20 mbar. When the electrical input power was increased to 4.3 kW from 2.6 kW, the tube-wall temperature also increased to 488°C from 426°C but the ratio of the green to yellow power decreased to 1.53 from 3.73. The ratio of green to yellow power decreased to 1.53 from 1.63 when the PRF of the laser was increased to 19 kHz from 16 kHz. These observations are explained in terms of electron temperature, energy levels of transitions, and voltage and current waveforms across the laser head.

Keywords. Copper bromide laser; laser amplifiers; high repetition rate laser.

PACS Nos 42.55.Lt; 42.55.−f; 40.20.Da; 42.60.Jf

1. Introduction

The copper bromide laser (CBL) is a prominent laser belonging to the class of copper halide lasers [1,2], which are developed to overcome the problems of pure metal copper vapour laser (CVL). In conventional pure-metal CVL, high temperature (∼1500°C) is required to obtain the required atomic copper density in the laser active region. In a CBL, copper bromide (CuBr) is used in the discharge zone and its molecular dissociation in the discharge by the collisions of energetic electrons provides free copper atoms, which are excited in the same manner as in the CVL [3]. In the CBL, due to the volatile nature of the CuBr molecules, around 500°C temperature is sufficient to generate sufficient copper vapour in the discharge tube compared to about 1500°C in the elemental CVL. The low temperature of the active medium of the CBL gives it several advantages over the elemental CVL, like use of materials within their limits of operation, simpler construction of tube, reduction of start-up time for laser oscillation from cold start, air-cooled operation etc. Low operating temperature allows the use of fused silica tube and lower out-gassing rates at this temperature support the sealed-off operation. The other advantages of the CBL are: higher pulse repetition frequency (PRF), higher wall-plug efficiency, and a pseudo-Gaussian beam intensity profile that is better suited for many applications than the top-hat profile of elemental CVL [4]. The output power from a single laser can be increased either by increasing the active length or by increasing the cross-section of the active medium. Increasing the length increases the cavity round-trip time and therefore it reduces the yield of good beam quality output [5]. Increasing the cross-section requires an increase in resonator magnification and therefore power extraction from gain medium is reduced because of reduced feedback. The problems, which make a single laser with large Fresnel number not suitable for providing high power with good beam quality, are reported [6]. However, there are many applications of copper lasers which require large power with minimum divergence angle [5]. The best alternative to obtain high power with good beam quality from copper lasers is the use of the master oscillator power amplifier (MOPA) configuration. Only a few reports are available in literature on the CBL MOPA system. A CBL MOPA system of 10 W average power for high-speed micromachining applications is reported, however, details of the MOPA are not given [7]. A low-power CBL MOPA with generalized diffraction filtered resonator (GDFR) is compared with stable and unstable resonators in [8]. In this paper, development of CBL MOPA system, which produced 110 W of average laser power, is reported.

2. Experimental details

The indigenously developed CBL MOPA system consisted of three identical laser units, one configured as master oscillator and the other two as power amplifiers. The CBL discharge tubes were made of fused silica tubes of 50 mm internal diameter with an inter-electrode distance of 1500 mm. Total length of the laser tube including the extended

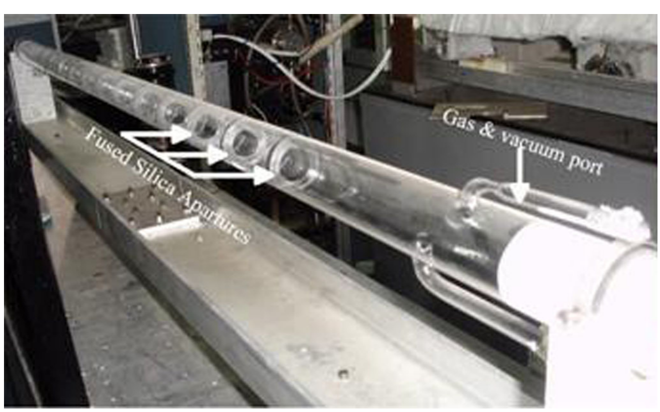

Figure 1. The CBL tube.

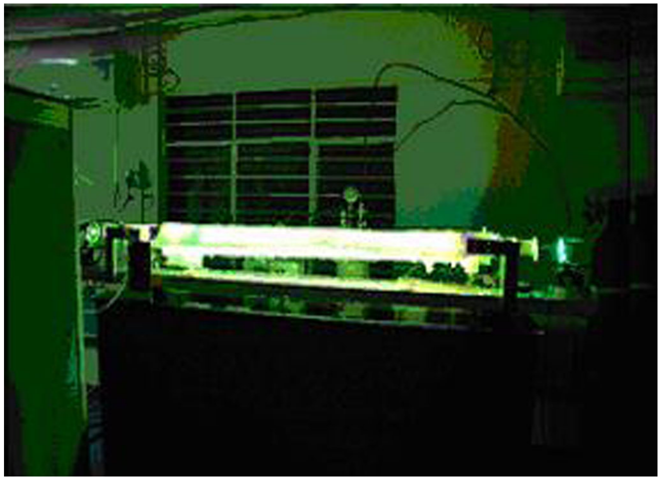

Figure 2. The CBL oscillator.

window region was 2000 mm. Twelve fused silica discs of 30 mm internal diameter and 3 mm thickness, equally spaced all along the length of the tube were used to stabilize the discharge. The photograph of bare copper bromide laser tube is shown in figure 1. A photograph of the CBL oscillator is shown in figure 2.

Operation of the tube was in the sealed-off mode. A thyratron-based pulsed power supply working on LC inversion mode was used as the pump source for the laser. The tube was self-discharge heated and its temperature was allowed to increase with input electrical power. The laser power is very sensitive to the density of CuBr molecules and so control of tube temperature is required. The tube wall temperature was monitored using thermocouple during laser operation and proper operating point for the laser system was maintained. The laser power was measured by Gentec TPM-300 power meter. The voltage and current waveforms were recorded with Agilent oscilloscope (Model No. DSO 6104A with 1 GHz bandwidth) using Tektronix high voltage probe and Pearson CT probe respectively. The laser pulse was recorded with a Hamamatsu biplanar phototube (Model No. R1193U-52) of rise time less than 1 ns. The laser tube wall temperature was monitored using K-type thermocouple. The input electrical power was calculated from the average power switched from the storage capacitor, which was given by $(1/2)C_sV^2f$ where C_s is the value of storage capacitor, V is the charging voltage of the storage capacitor, and f is the repetition rate of the CBL pulses. All the three CBL lasers were operated under the sealed-off mode and typical warm-up time was about 15 min only.

3. Results and discussion

3.1 *Spectral distribution of power in CBL*

Like a CVL, the output of a CBL is also composed of two wavelengths: 510.6 nm (green) and 578.2 nm (yellow) corresponding to transitions $(^2P_{3/2} \rightarrow {}^2D_{5/2})$ and $(^2P_{1/2} \rightarrow {}^2D_{3/2})$ respectively. The spectral distribution of power at 510.6 nm and 578.2 nm is

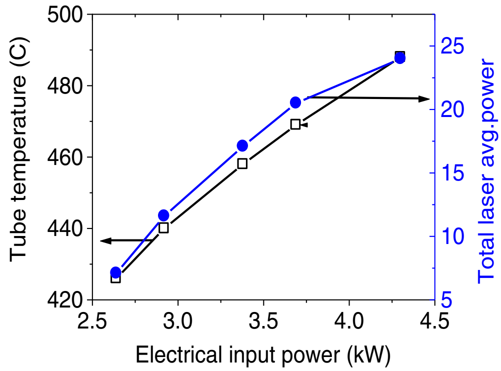

Figure 3. Variation of tube wall temperature and total laser average power with electrical input power at 20 mbar neon pressure and 19 kHz PRF.

important in many areas like pumping of tunable dye lasers and medical applications. The spectral distribution of power at 510.6 nm and 578.2 nm in terms of operating parameters is studied in the case of CVL [9]. However, the green-yellow characteristics of CBL differ from that of the CVL. Therefore, the spectral distribution of power at 510.6 nm and 578.2 nm in the CBL oscillator is studied. In the case of elemental CVL, the flowing buffer gas is neon and therefore to compare the performance of CBL with elemental CVL, the CBL oscillator was first operated with neon as the buffer gas. Neon gas of 99.995% purity was used as the buffer gas and the operating buffer gas pressure was 20 mbar. A plane–plane resonator, consisting of a flat dielectric-coated high-reflectivity ($R > 99.5\%$) mirror and an uncoated quartz flat acting as an output coupler, was applied to the CBL oscillator. The electrical input power was varied from 2.6 kW to 4.3 kW at 19 kHz pulse repetition frequency (PRF). Figure 3 shows the total laser power which includes both spectral components and tube wall temperature as a function of electrical input power. At 2.6 kW, total laser power was 7.1 W which was increased to 24 W at 4.3 kW input electrical power. As the input electrical power increases, more heat is generated in the tube and more copper atoms are available for excitation to upper laser labels ($^2P_{3/2\,1/2}$).

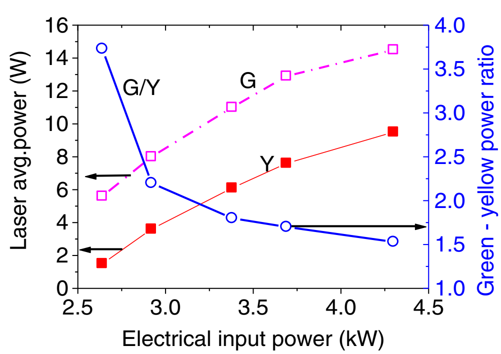

Figure 4. Variation of green (G) and yellow (Y) average power and G/Y power ratio with electrical input power at 20 mbar neon pressure and 19 kHz PRF.

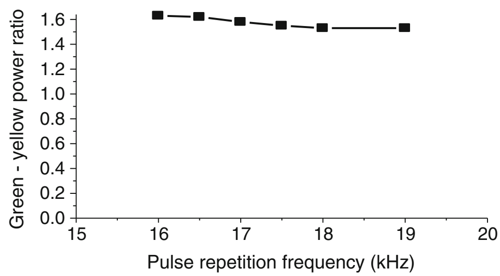

Figure 5. Variation of the ratio of green (G) to yellow (Y) powers with PRF at 20 mbar neon pressure and fixed electrical input power of 4.3 kW.

Consequently, when there was an increase in electrical input power from 2.6 kW to 4.3 kW, the total laser average power increased.

A dichroic mirror separating green and yellow wavelengths was used for separating the wavelengths for measuring individual powers of the two wavelengths. Figure 4 shows variation of green and yellow power with input electrical power. The ratio of green to yellow power at 2.6 kW electrical input power was 3.73, which was decreased to 1.53 at 4.3 kW electrical input power. The ratio of green to yellow power in CBL is very sensitive to peak electron temperature [6]. The increase in electrical input power increases the density of CuBr molecules, which causes a fall in the peak electron temperature due to increased electron energy losses in collisions. Furthermore, the lower level of the 510.6 nm transition ($^2D_{5/2}$ at 1.39 eV) is lower than that of the 578.2 nm transition ($^2D_{3/2}$ at 1.64 eV). Thus, the decrease in the ratio of green to yellow power at higher electrical input powers is due to decrease in the peak electron temperature and enhancement of lower level pump rates over upper level pump rates.

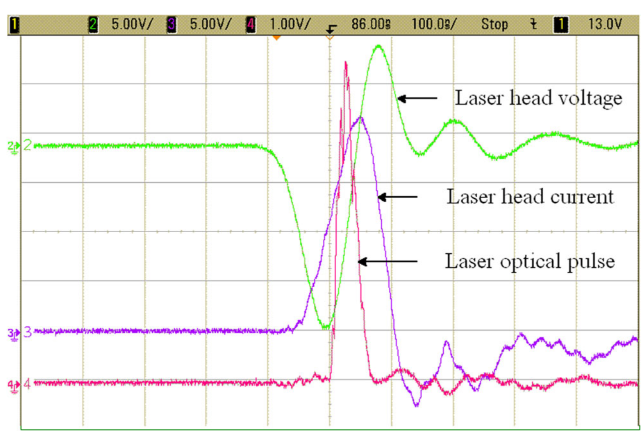

Figure 6. Oscillograms of voltage and current pulses across the laser head and laser optical pulse containing both the spectral components (510.6 and 578.2 nm) for 20 mbar neon buffer gas pressure and 4.3 kW electrical input power at 16 kHz PRF.

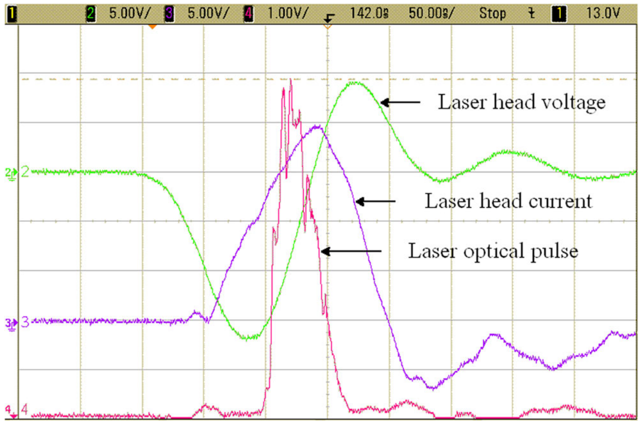

Figure 7. Oscillograms of voltage and current pulses across the laser head and laser optical pulse containing both the spectral components (510.6 and 578.2 nm) for 20 mbar neon buffer gas pressure and 4.3 kW electrical input power at 19 kHz PRF.

The variation of the ratio of green to yellow power was also observed with increase in PRF. It was observed that the ratio of green to yellow power, which was 1.63 at a PRF of 16 kHz was reduced to 1.53 as PRF was increased to 19 kHz (figure 5).

The voltage and current waveforms across the laser head and the laser pulse containing both spectral components at PRF of 16 kHz and 19 kHz are shown in figures 6 and 7 respectively. It is evident from the voltage waveforms that the breakdown voltage drops at higher PRF. A reduction of voltage across the laser head at higher PRF reduces the peak electron temperature, which results in decreasing the ratio of green to yellow power.

3.2 *Power scaling of CBL by the addition of hydrogen in neon buffer gas*

Hydrogen gas was added to the neon gas in different proportions to observe its effect on the output power of the CBL oscillator. Different proportions of molecular hydrogen gas were mixed with neon ranging from 1% to 2.5% of neon and the output power was optimized. The maximum output power of 40 W was obtained with (neon + 2.5% hydrogen) at a buffer gas pressure of 20 mbar and a PRF of 19 kHz. The green output was 25 W with green to yellow power ratio of 1.7. This is due to the better power coupling and higher breakdown voltages across the laser head when hydrogen is added.

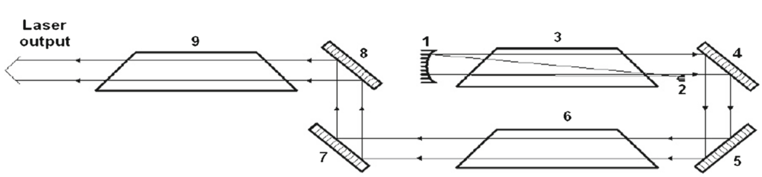

Figure 8. Experimental set-up of the CBL MOPA system.

Table 1. Results of CBL MOPA system.

Laser system	Laser power (W)	Energy per pulse @ 19 kHz (mJ)
Oscillator ($M = 50$)	34	1.79
Oscillator + one amplifier	75	3.95
Oscillator + two amplifiers	110	5.79

3.3 *CBL MOPA system*

Figure 8 shows the experimental set-up of the CBL MOPA system. The MOPA system consisted of three identical laser units, one configured as master–oscillator and two as power amplifiers.

Each CBL was optimized for maximum stable output power with plane–plane resonator. With plane–plane resonator, the laser average power obtained was 40 W with buffer gas (neon+2.5% hydrogen) pressure of 20 mbar, PRF of 19 kHz and laser tube temperature of 500°C. Average electrical input power in each laser tube was about 2.72 kW. A positive branch unstable resonator (PBUR) of magnification (M) 50 was applied to the CBL oscillator for maximum utilization of the active medium in the oscillator as well as in the amplifiers. A combination of concave mirror of focal length (f_1) of 2500 mm and a convex button mirror of focal length (f_2) of 50 mm was used to obtain the magnification of 50 in the PBUR. The cavity length of the CBL oscillator was adjusted for collimated output beam past the convex button mirror and it was found that cavity length was slightly less than ($f_1 - f_2$).

Compared to the CBL oscillator with plane–plane resonator, the CBL oscillator with PBUR of $M = 50$ produced 34 W of laser average power under identical operating parameters. Optical alignment of the lasers was carried out to minimize the optical loss. The temporal delays between the oscillator and the two amplifiers were optimized to extract

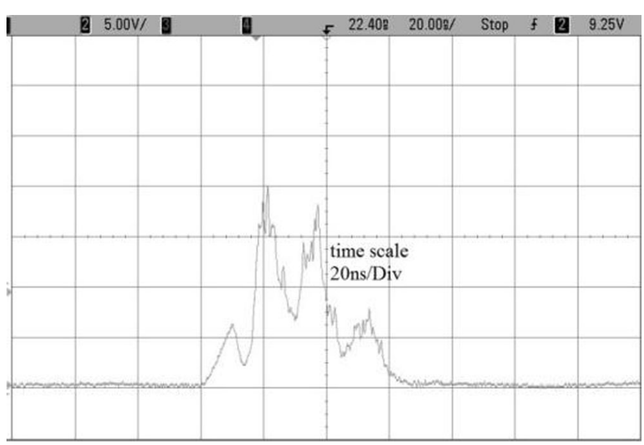

Figure 9. Laser pulse of MOPA oscillator.

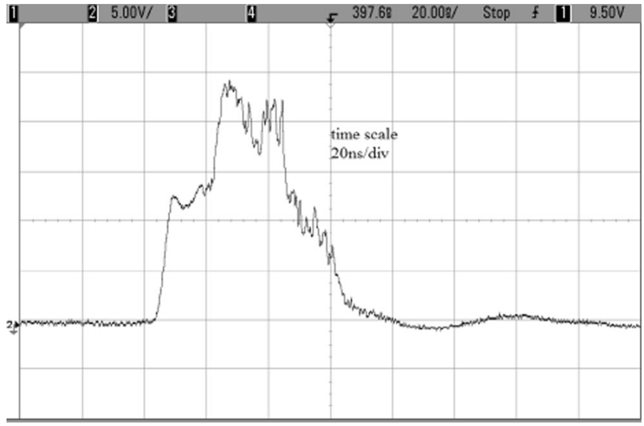

Figure 10. Laser pulse of MOPA system with one amplifier.

maximum gain of the active medium for maximizing the total power of the MOPA system. The combination of the oscillator and one amplifier produced 75 W of laser average power while the combination of the oscillator and two amplifiers produced 110 W of laser average power. Table 1 summarizes the results of copper bromide laser MOPA system.

Figure 9 shows the pulse shape of the laser output of MOPA oscillator, operating at 34 W. Figure 10 shows the pulse shape of the laser output of MOPA system, consisting of the oscillator and one amplifier, operating at 75 W.

4. Conclusions

Development of master oscillator power amplifier (MOPA) system of copper bromide laser operating at 110 W average laser power is reported. The MOPA system consisted of three identical laser units, each giving 40 W with plane–plane resonator. In MOPA configuration, the oscillator produced 34 W in confocal positive branch unstable resonator configuration of magnification 50 and operating at a pulse repetition frequency of 19 kHz. The laser output power was increased to 75 W after the first amplifier and after the second amplifier, the laser power was increased to 110 W. The CBL output consisted of two wavelengths, 510.6 nm (green) and 578.2 nm (yellow). In the CBL oscillator, with pure neon as the buffer gas, when the electrical input power was varied from 2.6 kW to 4.3 kW, the laser average power varied from 7.1 W to 24 W, while the green power varied from 5.6 W to 14.5 W and the ratio of green to yellow power varied from 3.73 to 1.53. The ratio of green to yellow power decreased from 1.63 to 1.53 when PRF was increased from 16 to 19 kHz. The total power of the CBL oscillator, which was operated at a PRF of 19 kHz and with a buffer gas pressure of 20 mbar, was increased to 40 W when 2.5% hydrogen was added to the neon buffer gas. In this case, the green component in the total power was 25 W while the ratio of green to yellow was 1.7. The CBL MOPA system delivered laser power of 110 W in a warm-up time of only 15 min and the system could be switched off without any post-switch-off cooling requirement. In addition to this, the MOPA system was operated in the sealed-off mode.

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