20-W sealed-off CuBr vapour laser excited with modified Blumlein circuit

Bangning Mao (毛邦宁), Bailiang Pan (潘佰良), Yubo Wang (王煜博),
Li Chen (陈 立), and Limin Wang (王丽敏)

Department of Physics, Zhejiang University, Hangzhou 310027

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A sealed-off CuBr vapour laser with the maximal average output laser power of 20 W was fabricated and investigated. The corresponding efficiency is 1.2% and the specific average output laser power is 123 mW/cm^3 in an active volume of 163 cm^3. The lifetime of the laser is more than 300 hours operating at $12-15$ W.

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The CuBr laser with high average output power and high efficiency exceeding 1% at 510.6/578.2 nm laser lines has many applications in laser entertainment, industry machining, material processing, medical treatment, and so on[1−5]. The CuBr laser with the output power of about one hundred watts and high beam quality is very suitable for high precise machine processing[1]. By doubling frequency, writing the fiber Bragg gratings (FBGs) is also available with the ultraviolet laser line of 255 nm[2]. Its high repetition frequency ($5-50$ kHz) and short laser pulse ($15-50$ ns) are excellent for particle image velocimetry (PIV) and particle tracking anemometry (PTA)[3]. This laser can be used in medical cosmetics and treatment, optical display as well[4,5]. Compared with the copper vapour laser, the CuBr laser operates at much lower tube wall temperature (about 750 K), which simplifies the laser tube construction and the operation procedure. To develop practical devices, researchers have investigated the characteristics and the kinetics of the CuBr vapour laser[6−8]. There are commercial sealed-off CuBr vapour lasers with $5-10$ W output power and over 500-h lifetime in Bulgaria and Russia now.

On the basis of our previous works on the excitation circuit, the thermal distribution, and the kinetics process of the CuBr vapour laser[9−12], we fabricated a sealed-off CuBr laser excited by the modified Blumlein circuit. The average output laser power was optimized on buffer gas pressure, hydrogen additive pressure, input voltage, and discharge repetition frequency. The optimal buffer gas pressure is about 4000 Pa, which is consistent with the results in Refs. [6] and [7]. The frequency characteristic is the same as that of Ref. [7] but different from that of Ref. [8]. It may be attributed to the scale of the tube radius. The maximal average output laser power of 20 W was obtained at the efficiency of 1.2%. At the average output laser power of about $12-15$ W, the laser accumulatively operated for 300 hours and there seemed no symptom of deterioration.

The laser tube structure and the excitation circuit are shown in Fig. 1. To reduce the impurity released by the quartz, the base tube is made of fused silica. The inner diameter of the base tube is 4 cm and four discharge confining diaphragms with the inner diameter of 2 cm are equally distributed in the base tube. The electrodes, spacing 62 cm apart, were specially designed, and the impurity diffused to the electrodes could be condensed to an outer impurity capture. High purity neon (99.999%) and distilling purified CuBr crystal were employed. The CuBr vapour density required was provided by discharge heating and the axial temperature controller.

In our previous experiments, the interacting circuit (IC) worked well in the CuBr laser with flowing buffer gas system[12]. But in a sealed-off laser tube, the discharge current and voltage waveform were bad under some discharge condition of the IC circuit, while the ordinary circuit had low efficiency. The modified Blumlein circuit quadruples the input voltage and has lower requirement of the plasma purity. It makes a rapid rising edge of the current pulse which is suitable for the self-terminating laser. And the grounded electrode is good for application safety. It maintained long time stable discharge and exhibited high efficiency in the experiments. The combination of the capacity was determined as $C_1 = 500$ pF and $C_2 = 300$ pF after trying on some combinations. The waveforms of the discharge current and voltage were detected with a Rogowski-coil probe and a Textronix P6015A HV probe, respectively, both of which were monitored on a Textronix TDS 754C oscillograph. The average output laser power was detected with a Thorlabs power meter.

Figure 2 shows the average output laser power at different neon buffer gas pressures without hydrogen additive. At each buffer gas pressure, other discharge

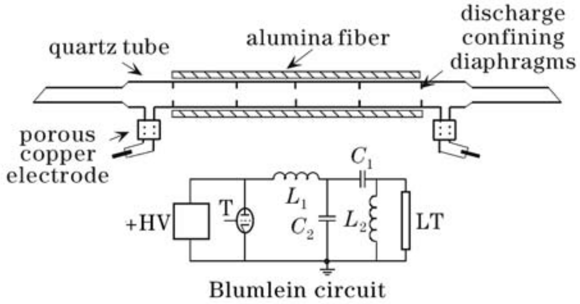

Fig. 1. Laser tube and modified Blumlein circuit.

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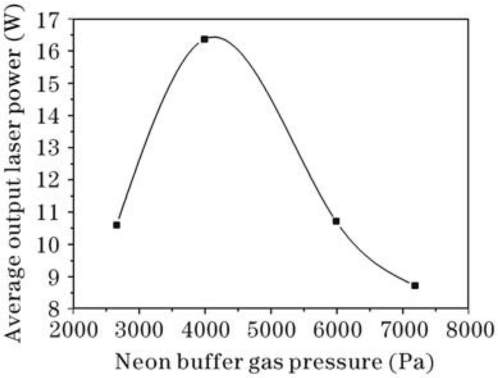

Fig. 2. Dependence of the average output laser power on the buffer gas pressure.

parameters were optimized. The optimal neon pressure was found to be around 4000 Pa, the maximum average output laser power of 16 W with the efficiency of 1.26% was obtained. And it exhibits similar tendency of the results reported in Ref. [6], it seems that the optimal buffer gas pressure is little dependent on the tube radius. The hydrogen additive experiments later were done at this optimal buffer gas pressure.

At the buffer gas pressure of 4000 Pa, the dependence of the average output laser power on the discharge frequency is shown in Fig. 3. At the frequency of 16 kHz, the laser exhibited higher efficiency and stabler operation. When the repetition frequency was about 21 kHz, the average power and efficiency were even higher but not so stable than that at 16 kHz. While around the frequency of 19 kHz, the discharge became unstable and the laser exhibited low efficiency, and dense CuBr vapour was ejected to the direction of the laser tube windows at relatively low operating temperature. The result in Fig. 3 is quite close to that of Ref. [7], but different from that of Ref. [6] in which the optimal discharge repetition frequency is around 24 kHz. Maybe it is because that the inner diameter in Ref. [7] is also 4 cm, but in Ref. [6] it is 1.3 cm. It is assumed that the discharge stability is related to the inner diameter of the discharge tube, which influences the formation of the standing acoustic waves in the active zone to some extent.

The dependence of the average output laser power on the input voltage was obtained at stable operation as shown in Fig. 4. The average output laser power can be determined by the input power and the corresponding efficiency at different input voltages. Apparently the average output laser power does not increase monotonously with the input voltage and the input power. At the buffer gas pressure of 7200 Pa, the optimal input voltages are 4.2 and 4.9 kV at the discharge repetition frequencies of 20.7 and 16.1 kHz, respectively. It seems that the optimal input voltage increases with the decrease of the discharge repetition frequency. The optimal input voltage of 4.3 kV at the buffer gas pressure of 4000 Pa is slightly higher than that of 4.2 kV at 7200 Pa, which is caused by the difference of the discharge repetition frequency. Generally, the ratio of electric field to gas pressure, E/P, is thought to greatly influence the laser power and the discharge character, and the input voltage is thought to be associated with E/P. However, monotone adjustment of the input voltage does not definitely lead to monotone change of E/P, for what directly related to the electric field E is not the input voltage but the real discharge voltage on the laser tube which is decided by the compositive discharge parameters. Because of the complexity of E/P, the optimization of the laser characteristics needs further investigation in experiment and theory.

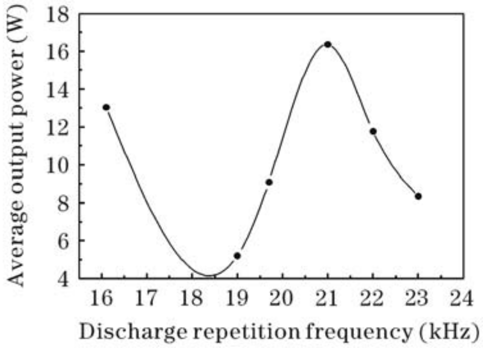

Fig. 3. Dependence of the average output laser power on the discharge repetition frequency.

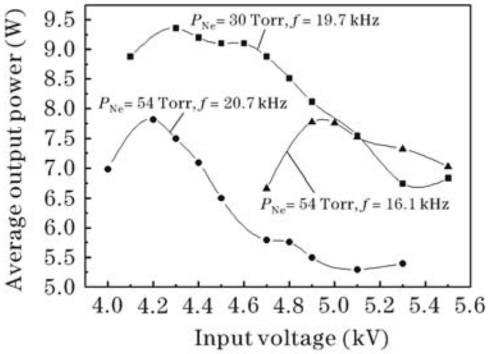

Fig. 4. Dependence of the average output laser power on the input voltage.

The hydrogen additive experiments were carried out at the optimal buffer gas pressure of 4000 Pa. Figure 5 shows the dependence of the laser output power on the external heater temperature with and without hydrogen additive. The hydrogen additive made the laser power rise more rapidly and steadily with the heater temperature, and with hydrogen additive the laser emerged at higher temperature. The possible reason for the hydrogen enhancement effect on the laser behavior is due to the electron attachment and detachment of the

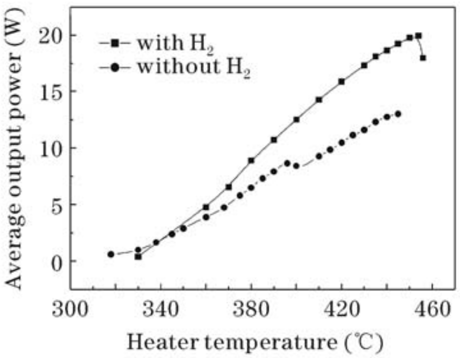

Fig. 5. Influence of the heater temperature on the output laser power with and without hydrogen additive.

hydrogen species during the discharge-afterglow period. The experimental result shows that the hydrogen additive is effective just in a narrow region from 13 to 80 Pa, beyond this region it is inefficient or even negative.

The maximal average output laser power of 20 W was obtained with the hydrogen additive of about 40 Pa at the discharge frequency of 21 kHz and the input voltage of 4.75 kV. For the distance between the diaphragms nearest to the electrodes is 52 cm, the specific average power is 123 mW/cm^3. The accumulative operation time of the laser exceeded 300 hours, and the longest consecutive operation time was 8 hours. Such a sealed-off CuBr laser is of practical value and can be used in PIV, PTA, strong background photography, medical cosmetics and treatment, and so on.

The instability of CuBr vapour pressure was occasionally observed in the experiments, which induced unstable discharge and affected the laser output power. This problem may be solved by introducing the side armed laser tube structure, with which the CuBr vapour pressure is independently controlled by the oven temperature.

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