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R & D DEVELOPMENTS

Design and Fabrication of Externally-heated Copper Bromide Laser

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ABSTRACT

An externally-heated, longitudinally-discharged, low-repetition-rate copper bromide laser, was designed and fabricated. The green-coloured wavelength at 5106 Å from this laser can be used for underwater ranging and detection of submerged objects. Several new changes in the design of discharge tube, heating technique, buffer-gas-flow sub-system and electrical circuit have been conceived and incorporated advantageously in our system. Various parameters, for example, the type of buffer gas and its flow rate, mixture of gases, temperature of the discharge tube, delay between dissociation and excitation pulses, dissocitation and excitation energies, and various resonator configurations are being optimised to get the maximum output power/energy from the laser system.

INTRODUCTION

A copper bromide laser is a cyclic laser emitting at two wavelengths : 5106 Å (green) and 5782 Å (yellow)[1]. Out of these, the green-coloured beam, has the higher gain[2], and very low attenuation in sea water[3]. Therefore, this laser has potential applications in the underwater ranging, detection and imaging of the submerged objects like the submarines. Other areas where this laser finds application include cancer treatment[4], forensic use including detection of fingerprints[5], traces of bloodstrains, and examination of the documents to check for forgeries[6], large screen displays[7], plused holography[2], nonlinear optics[8], high-speed photography[9], photoionisation spectroscopy[10], pumping dye lasers[11], and laser isotope separation[12].

A pure copper-vapour laser also emits at the above mentioned wavelengths but to get a sufficient vapour pressure of copper for lasing action, the discharge tube containing the elemental copper has to be heated to temperatures[13] of about 1500-1600 °C. Earlier workers used externally-heated ovens, built of alumina tubes but later a novel approach was demonstrated[14] in which the excess discharge energy was used to heat the copper to the required temperature. On the other hand, to get the same amount of vapour pressure for lasing action at the same wavelengths, the discharge tubes containing copper halides need to be heated to much lower temperatures in the range of 300-600 °C (depending on the copper halide)[15-17]. So, one can use glass or quartz material (instead of high-purity, zero-porosity alumina tube) for the discharge tube which is less expensive, technologically simpler and easily available. High repetition rate copper halide lasers are generally electric-discharge-heated like the copper vapour lasers but the efficiency of the former has been found to be higher than that of the latter due to the lower-temperature requirements[18]. The primary application of this laser intended is the detection and ranging of submerged objects, for which a repetition rate of 1-10 Hz is adequate and hence a low repetition rate laser was designed and fabricated by using spark gaps in place of highly expensive thyratrons. In this way, it was possible to get higher peak power in each pulse than in high repetition rate lasers. However, in a low repetation rate laser, the excess electric discharge will not be able to heat the copper halide material and hence external heating had to be employed in this system. Moreover, two electrical pulses are required in copper halide lasers (instead of just one electrical pulse

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in copper vapour laser) to get one laser pulse[15]. The first pulse known as the dissociation pulse dissociates copper halide and privides copper atoms. After a delay (of the order of a couple of hundred microseconds), when sufficient number of copper atoms are available in the ground state, a highly sharp second pulse known as the excitation pulse pumps the copper atoms to the upper laser levels by electron collisions. Out of the three commonly used copper halide lasers (*CuCl*, *CuBr* and *CuI*), copper bromide laser gives the highest output power under the same input conditions[19], and hence this laser has been taken for the operation[20]. The design, fabrication and performance evaluation of this laser system will now be described in the following sections.

2. DESIGN OF OPTICAL CAVITY

The design aspects of the optical cavity are shown in Fig. 1. The plasma tube consists of a quartz tube Q_1 of inner diameter 25 mm and length 400 mm. Eight quartz bowls B_1 to B_8 are fused to this tube, four each on the lower and the upper sides. The lower bowls are used as the reservoirs of high purity (99.99 percent) *CuBr* powder. This tube was heated to temperatures in the range of 375-500 °C by heating nichrome wires wound at four separate sections along the length of a coaxial quartz tube Q_2 of inner diameter 75 mm and length 360 mm. Similar windings of nichrome wire were also provided at four different sections of another coaxial quartz tube Q_3 of inner diameter 85 mm and length 400 mm such that the windings on Q_2 were in the sense opposite to those on Q_3. Such a winding has specific purpose: the inductance of windings an tube Q_2 alone would have produced a magnetic field along the axis of discharge tube Q_1 and contributed (though mildly) to the pinching of discharge. The inductance of windings on Q_3 nullifies this effect in the discharge tube Q_1. It may be clarified that the inductance of discharge tube Q_1 has no correlation with that of the winding system. The former depends on several parameters including the characteristics of the medium inside Q_1 and on the ratio of diameters of coaxial return path to that of the tube Q_1. It is to be emphasized here that the inductance of the winding system itself does not contribute to the pinching of discharge in tube Q_1. Further, the purpose of heating the tube independently at four different sections of the tube is to get a uniform temperature zone of about 40 cm length along the tube by adjusting the heating voltage of each section independently. These temperatures are measured at three separate points by introducing chromel-alumel thermocouples through L_1, L_2, L_3 (shown in Fig 1). All these quartz tubes were enclosed in a co-axial aluminium box (200 mm dia and 450 mm length) containing alumina bulk fibre for the purpose of heat-insulation. The vapours of copper bromide on subsequent cooling (after the heating system is switched off after operating the laser) get condensed on the bowls B_1-B_8 and the side tubes QC_1, QC_2 (each of 37 mm inner dia and 75 mm length); thus this bromide dust deposition on the inner walls does not obstruct the optical path of the laser beam. Three quartz rings (R_1, R_2, R_3), each of 3 mm thickness were also provided in the tube Q_1 for the

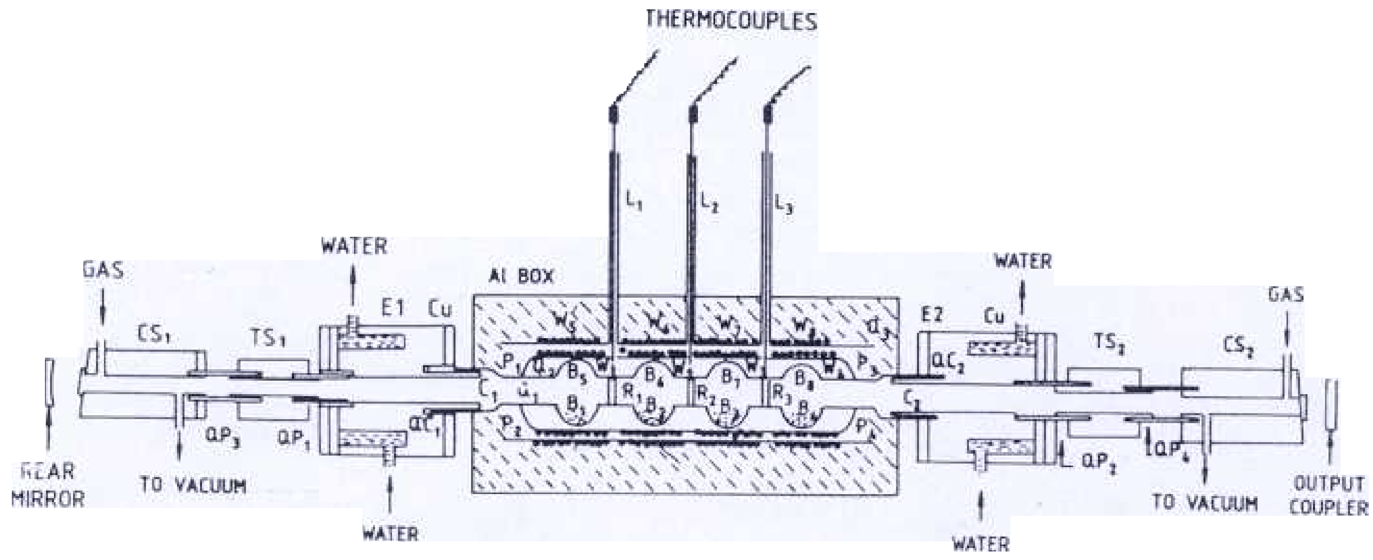

Figure 1. Optical cavity

generation of an unpinched and stable discharge in the plasma tube[21].

Hollow tubular electrodes E_1 and E_2, made of electrolytic- grade pure copper were used in this system. These electrodes extend well into the hot zone of the plasma tube to ensure the uniformity of electric discharge[22]. The electrodes were cooled by a closed-loop water-cooling system. TS_1 and TS_2 are the teflon supports which along with perspex screens (not shown in the Fig. 1) isolate electrically the electrodes from copper studs CS_1 and CS_2 having buffer-gas inlet and outlet connections and the windows (AR-coated for 5106 Å). The gas-flow-system, employed and depicted in Fig.1 ensures that the optical windows are never contaminated by the bromide dust. Both the mirrors were MLD-coated for 5106 Å. The rear mirror used was concave with a radius of curvature of 7 m and reflectivity of 99.9 per cent while the output mirror was plane with 45 percent reflectivity. The overall length of the optical cavity is 130 cm.

3. ELECTRICAL CIRCUIT

As mentioned earlier, two electrical discharge pulses of appropriate energies are required to be impressed across the plasma tube electrodes for the generation of one laser pulse. Since most of the ground state copper atoms are created after the completion of the first electrical pulse[23] and the stimulated emission occurs on the leading edge of the second pulse, the width of the dissociation pulse is not very important wereas the rise time and the duration of the excitation pulse should be extremely short[2]. The pulse repetition rate was variable from 1 to 10 Hz and the delay between the dissociation and excitation pulses could be varied from 50 to 600 μs in the low voltage double-pulse delay generator circuit. The high voltage circuit is shown in Fig. 2.

For the purpose of low-repetition-rate laser, spark gaps were used instead of highly expensive thyratrons. Since the recovery time of a spark gap is usually several milliseconds only, two separate spark gaps, one for each pulse, were used. The use of two spark gaps dictates the use of two capacitors. As a result, the dissociation and excitation energies can be adjusted independently. For this reason, two separate high voltage dc power supplies, one each for the dissociation and the excitation circuits were used. As a result of firing of the dissociation spark gap, prefiring of the excitation spark gap was prevented by adopting the following measures. The

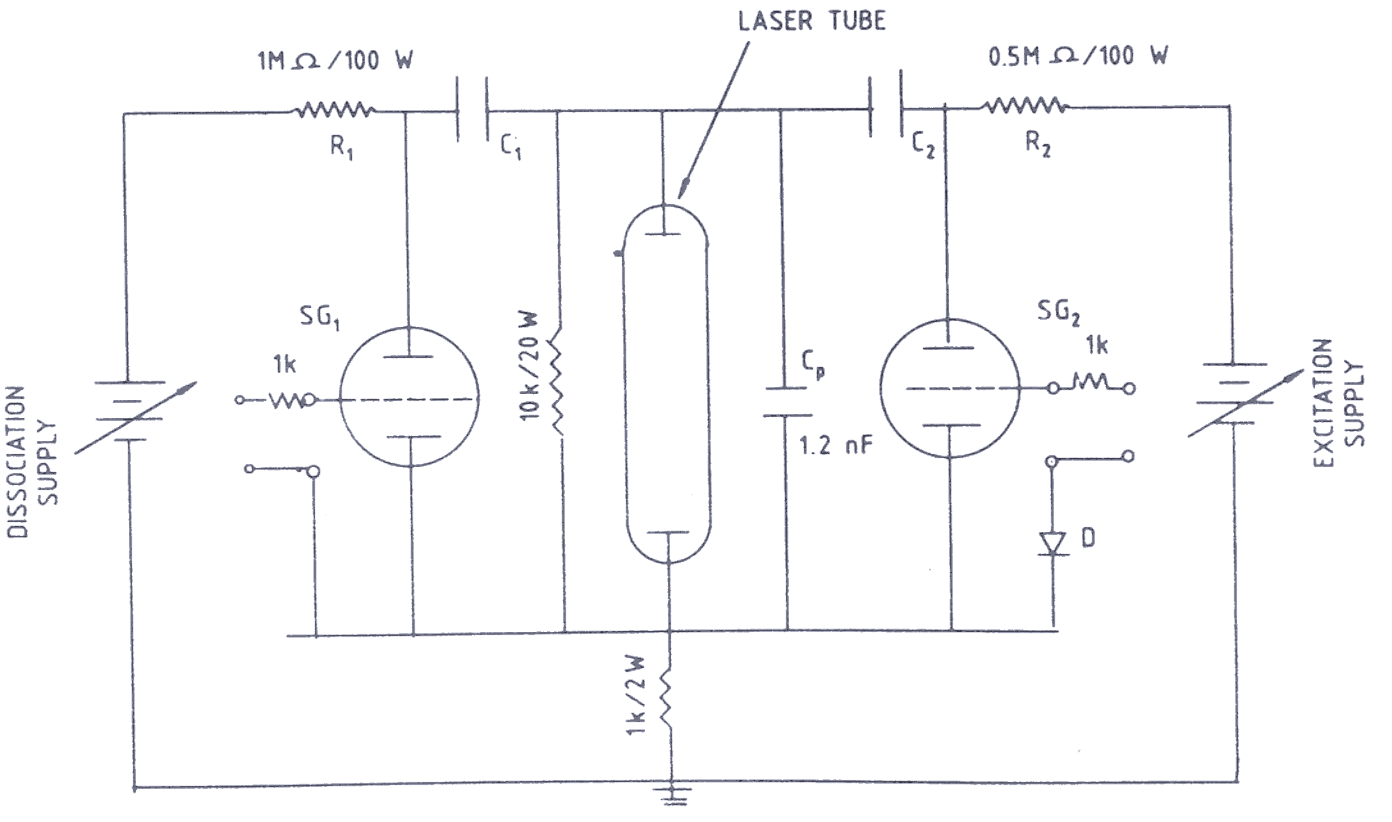

Figure 2. Electrical circuit.

dissociation and excitation circuit components (R_1, C_1 and R_2, C_2, as shown in Fig. 2) and the spark gaps (SG_1 and SG_2) were enclosed in four separate aluminium boxes and the body of each of these boxes was connected to a separate ground. The boxes containing R_1, C_1 and R_2, C_2 were filled with transformer oil. The spark gaps were placed orthogonal to each other. The diode D is a series combination of 15 diodes employed in the circuit of spark gap SG_2 for the same purpose. Further, the common voltage line was connected to the actual ground through a 1kΩ-resistance to prevent any pickup from the ground to this circuit. Since the relaxation times of the upper laser levels of copper atoms are extremely small, the risetime of the excitation pulse has to be limited by this value. To achieve a fast rise time electrical pulse, the peaking capacitor C_p ($< C_1, C_2$) is employed. Further it is kept very close to the laser tube to minimise stray inductance. The spark gaps were triggered by the two pulses from the high voltage pulse transformers (high performance ignition coils used in automobiles) through two 1kΩ-resistances employed to protect the previous stages.

4. PERFORMANCE AND EVALUATION

The energy of each output pulse of the laser was measured at various values of the parameters with the help of a photodiode (fitted with an attenuator of 10, 100 and 1000X), a storage oscilloscope (Tekhind), a callibrating equation and a curve for 5106 Å (provided for this diode from Little Mike Model 560 B of EG & G). Whereas the callibrating equation and the curve were used only once to measure the energy in millijoules, at all other times the output of the laser was optimised in terms of its relative values (arbitrary units) by observing the maximum value of the output received on the screen of storage oscilloscope each time a particular parameter was changed. The voltages from dissociation and excitation electrical pulses and the delay between these pulses were directly observed on the storage oscilloscope (with photodetector removed and a compatible high voltage attenuation probe of 1000X connected between the electrodes and the oscilloscope).

The pulse repetition frequency (PRF) could be varied between 1 and 1Q Hz and the laser system was operated at various frequencies in this interval but most of the time the PRF was kept at 5 Hz and all the following parameters were studied at this frequency. The laser action could be obtained for delays (between dissociation and excitation pulses) in the range of 150 to 350 μs but the optimum delay was found to be 175 μs. Similarly, the first laser pulse started appearing at a temperature of 375 °C of the plasma tube and the laser output continued upto a temperature of 500 °C, but the optimum temperature was found to be 430 °C for this system. Various values of dissociation, excitation and peaking capacitors were tried in our experiment but the best results were obtained for C_1 = 41 nF, C_2 = 11 nF and C_p = 1.2 nF corresponding to dissociation voltage of 6 to 9 kv (optimum 7.5 kv) and the excitation voltage of 14 to 18 kv (optimum 15.5 kv). Helium was used as a buffer gas. The laser output was obtained corresponding to any flow rate from 10 to 60 cc/min but the optimum value was found to be at a flow rate of about 20 cc/min. Similarly the range of values of pressure of helium gas, that gave laser output, was 1 to 10 torr but the optimum pressure was about 2 to 3 torr.

5. CONCLUSION

An externally-heated, longitudinally-discharged, low-repetition-rate copper bromide laser, intended to be used for detection and ranging of submerged objects, has been developed. Work is in progress to measure the output energy/power of laser by changing and optimising various parameters like different buffer gases, their mixtures in diffirent ratios, their pressures and flow rates, performance of laser beyond 500 °C, effect of addition of various chemicals along with *CuBr* powder in the plasma tube, and various configurations of optical resonators including various reflectivities of the output mirror in the stable cavity configuration and also negative- and positive- branch unstable resonator configurations. To enable this laser to be used outside the laboratory, the buffer gas flowing system will be replaced by a sealed-off system and its life test will be conducted.

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