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Enhanced performance of a wide-aperture copper vapour laser with hydrogen additive in neon buffer gas

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Abstract. A wide-aperture copper vapour laser was demonstrated at ∼10 kHz rep-rate with hydrogen additive in its buffer gas. Maximum power in excess of ∼50 W (at 10 kHz) was achieved by adding 1.96% hydrogen to the neon buffer gas at 20 mbar total gas pressure. This increase in output power was about 70% as compared to ∼30 W achieved with pure neon at 5.5 kHz rep-rate. The 70% enhancement achieved was significantly higher than the maximum reported value of 50% so far in the literature. The enhancement was much higher (about 150%) as compared to its 20 W power at 10 kHz rep-rate using pure neon as the standard CVL operation.

Keywords. Copper vapour laser; additives; buffer gas; enhancement.

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1. Introduction

Copper vapour lasers (CVL) operating in the visible region ($\lambda_1 \sim 510.6$ nm and $\lambda_2 \sim 578.2$ nm) have important applications in research and industry [1]. The CVL technology has undergone rapid and significant changes since its first demonstration by Walter *et al* in 1966 [1]. Since then, major technological advancements such as large-bore CVLs and power-enhanced CVLs with additives have been reported from various laboratories and also by us [1–11]. Standard CVLs using C–C transfer circuits and pure neon as buffer gas, though simple in design and construction, offer low output power and efficiency which limits their various applications. Also, due to load mismatch conditions between the modulator and the laser head, the laser system often encounters frequent latch-on conditions in the high voltage switch thyratron resulting in frequent interruptions. The additives such as hydrogen in optimized proportion to the buffer gas neon, kinetically provide better interpulse plasma relaxation, reduction in pre-pulse electron density and also minimizes the phantom current, which are pre-requisite for establishing high discharge voltage, high gain at the centre of the tube due to discharge penetration and hence higher output power and efficiency. Removal of excess electrons by additives from the discharge reduces skin effects and hence increased radial field penetration in the discharge column. To the best of our knowledge, the maximum enhancement in output power of a CVL by hydrogen additive have been reported to be about 50% in a small-size ∼20 mm bore CVL and about 25–30% in large-bore devices [4,5]. But, the enhancement factor will depend on the fine optimization of the mixture, size of the discharge tube and various other operating parameters of the laser also. Here in this paper, we for the first time report power enhancement of ∼70% in a wide-aperture (50 mm bore) CVL system operating at ∼10 kHz rep-rate with an overall wall plug efficiency of ∼1%, using hydrogen as an additive in pure neon buffer gas.

2. The laser system and experimental set-up

The laser set-up is shown in figure 1, which consisted of a new thermal assembly based on longitudinal step profiling of the thermal insulation density around the CVL discharge tube. Such design changes have been discussed elsewhere in detail [11]. The main objective of using the step profiling was to reduce end thermal losses particularly in wide-aperture discharge tube with a high aspect ratio (D/L) and to increase tube operating temperature to ∼1600°C which otherwise is limited to ∼1500°C with un-profiled normal assembly. The discharge tube used in the CVL was of about 50 mm bore, 1500 mm length and with a discharge volume of about ∼2.8 l. The discharge tube and the profiled thermal insulation were concentrically placed in quartz pipe section of 150 mm inner diameter and 1500 mm length. The density of alumina fibre was varied (step-profiled) as shown in figure 2 with the highest density of ∼400 kg/m^3 at the extreme ends of the discharge tube, zone (C). The second zone (B) comprised of tightly filled alumina fibre

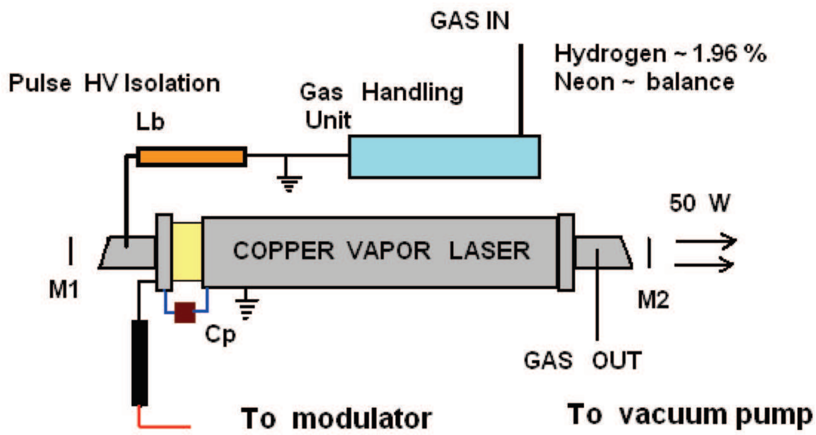

Figure 1. Laser system lay-out.

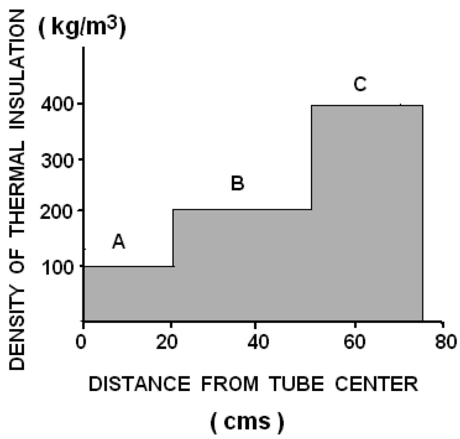

Figure 2. Thermal density variation (step-profiling) along the discharge tube.

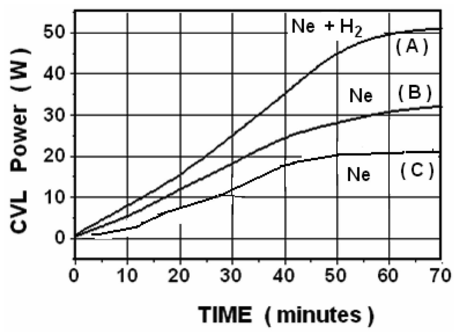

Figure 3. CVL power build-up with time from threshold lasing with the same input power ∼5 kW in (A) neon + hydrogen buffer gas at 10 kHz, (B) pure neon buffer gas mixture at 6 kHz, (C) pure neon buffer gas mixture at ∼10 kHz.

at ∼180 kg/m^3. The central zone (A) consisted of lightly filled alumina fibre at ∼100 kg/m^3. The step profile was chosen based on the nearest available material with us to meet such objectives. Other design considerations were as per standard CVL requirements with vacuum and gas handling arrangement of high integrity. Precision needle valves were used to control the gas flow and pressure in the laser head. The discharge circuit was the simple C–C transfer type with CX 1535 thyratron as high voltage switch. The HV modulator was capable of switching about 5.5 kW of electrical power under various combinations of storage capacitor, charging voltage and operating frequency (repetition-rate).

3. Results and discussion

After assembly and proper conditioning of the laser head to the extent that it was suitable for experiments with additives, the CVL was operated with pure neon and

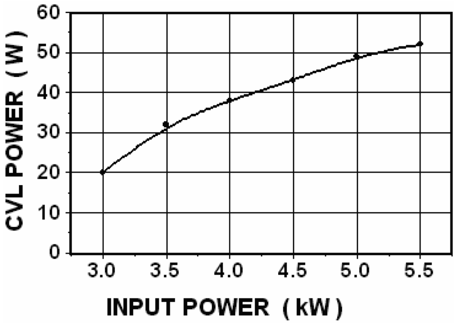

Figure 4. CVL output power at various input power levels using the admixture of neon + hydrogen as buffer gas.

thereafter using a buffer gas consisting of hydrogen (∼1.96%) + neon as balance. The CVL operation with hydrogen additive was monitored with a storage capacitor value set to ∼3 nF and peaking capacitor as ∼2 nF. At ∼10 kHz rep-rate and ∼13.5 kV charging voltage, the laser build-up with time is shown in figure 3 (curve A). The maximum power achieved from the laser was in excess of 50 W with a green-to-yellow ratio of about 1.3 : 1. The laser power build-up curves in pure neon at 6 kHz and 10 kHz are also given in figure 3 monitored with the same input power of ∼5 kW. The enhancement in laser output power capability was thus about 70% when compared with ∼30 W maximum power normally obtained with pure neon at ∼6 kHz, which to our knowledge is the highest in this type of wide-aperture CVL systems. The main reason for better enhancement is the high operating temperature of ∼1600°C established using this special thermal design with step profiling. It should also be noted that at 10 kHz, the CVL power in standard mode of operation using pure neon was ∼20 W. Therefore, the enhancement factor is ∼150% at the same rep-rate of 10 kHz using hydrogen as additive. Figure 4 shows laser power at various input power levels. It is observed that the laser efficiency is close to 1% considering 10% power losses in the modulator.

4. Conclusion

Following are the main conclusions of the paper:

(1) For the first time we have demonstrated a wide-aperture copper vapour laser with 70% enhancement in the output power capability using an admixture of neon and hydrogen as the buffer gas. The role of hydrogen additive in pure neon buffer gas for achieving high enhancement (>50%) in wide-aperture CVL devices is thus established for the first time.

(2) The enhancement, we believe, is mainly because of better optimization of the mixture, high discharge tube temperature of ∼1600°C due to effective thermal insulation profiling and better power coupling to the laser head [5].

(3) The increased trend in enhancement with hydrogen additive in CVLs as established here is promising and may reduce the gap in performances (efficiency and power) of CVLs and KE-CVLs which are based on HCl + H_2 additives in buffer gas [8–10].

Further investigations are in progress and will be reported elsewhere.

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