Dielectric barrier discharge CO_2 TEA laser operated at frequencies up to 400 Hz

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Abstract. A dielectric barrier discharge CO_2 TEA laser excited by a thyratron driven power supply has been developed and characterized. Laser output was observed at frequencies up to 25 Hz for an electrode separation of 10 mm with 1.8 mm suprasil glass covering the electrodes. At this gap separation, pulsed power output of about 9 W was detected for gas pressures between 100 and 400 mbar. Changing the electrode separation to 5 mm and using 1.4 mm suprasil glass dielectric increased the output power to 23 W and enabled laser output to be observed at gas pressures upto 700 mbar and maximum pulse excitation frequencies of up to 400 Hz. The developed laser does not require water cooling since the system operates in burst pulse mode.

1. Introduction

Despite current advances in high power fibre laser development, the CO_2 laser remains the preferred laser when high beam quality and focusability are required. CO_2 lasers are excited by d.c. [1, 2], high frequency (10 kHz–3 MHz) [3-6], radio frequency (13–1500 MHz) [7] and microwave (2.45 GHz) [8, 9] power supplies. Dielectric barrier discharges (DBDs) have also been used in the excitation of CO_2 lasers but to date, only high frequency excitation and radio frequency excitation has resulted in cw lasing [6, 10-12] in these systems. Such lasers make use of special gas mixtures which usually has 30 % helium and more than 50 % nitrogen content. In most instances, DBD excited lasers use a trigger unit [11, 13] as a form of preionization to enable the generation of a uniform discharge and in other cases, a damped oscillation discharge is used to excited the DBD excited system [14].

DBD excitation of the TEA CO_2 laser has the following advantages. Critical alignment is avoided. Compact laser structures that do not require preionization can be employed and the metal electrode is not inside the laser discharge cavity. This can increase the lifetime of sealed-off CO_2 lasers by reducing oxide formation [15]. The self ballasting effect of the dielectric makes this possible.

We have developed a small CO_2 TEA laser excited by a DBD which can operate at frequencies up to 400 Hz without the use of preionization. This laser uses either the 1:1:3 or 1:1:8 CO_2:N_2:He gas mixtures. We believe this is the first time that such a laser is being demonstrated at these frequencies. This work aims at prolonging the electrode life of mini CO_2 TEA lasers which have arcing and pitting problems from continuous use as well as demonstrate that DBD excited lasers do not require pre-ionization when operated at atmospheric pressures (≤500 mbar).

2. Description of a dielectric barrier discharge excited CO_2 TEA laser

Self adhesive aluminium foil electrodes, 40 cm long and 18 mm wide, used with this laser are covered with suprasil glass and are neither in contact with the plasma nor the vacuum as shown in Figure 1. Suprasil glasses 1.8 mm and 1.4 mm in thickness have been used with either a gap separation of 5 mm or 10 mm measured between the dielectrics. At the center of the discharge cavity, the discharge is estimated to have a width of 3 mm, resulting in estimated mode volumes of 6 cm^3 and 12 cm^3 respectively. The developed low cost DBD excited CO_2 TEA laser has ZnSe windows fitted at both ends of the discharge cavity. A 99.8 % half inch ZnSe output coupler and a copper full back reflector of 1.99 m radius of curvature demarcates the 71 cm resonant cavity. A PEM detector (Vigo System, PEMI) has been employed for measurement of the optical output of the DBD excited TEA CO_2 laser.

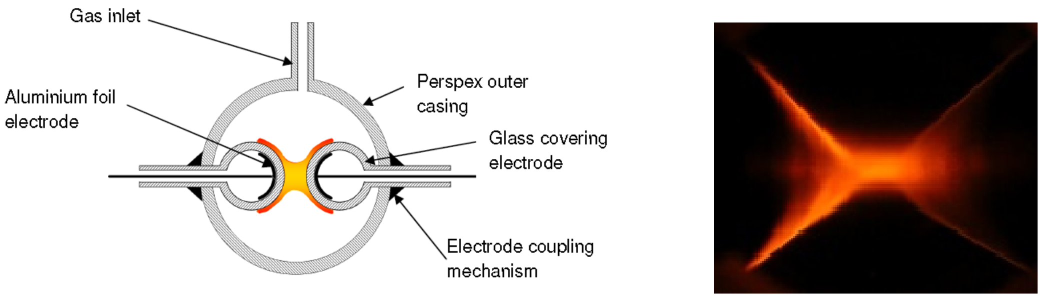
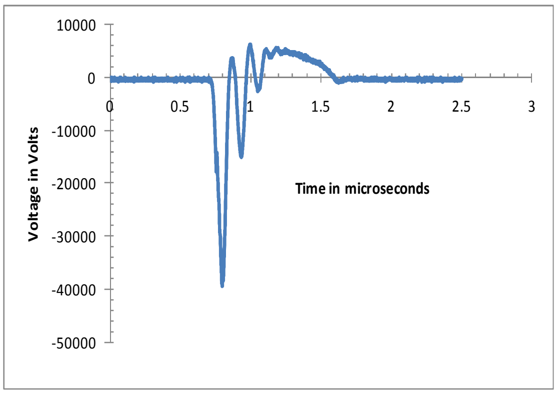


Figure 1: Sketch showing discharge cavity with electrodes inside the glass cylindrical dielectrics. The picture shows the end view of the discharge observed through a ZnSe window.

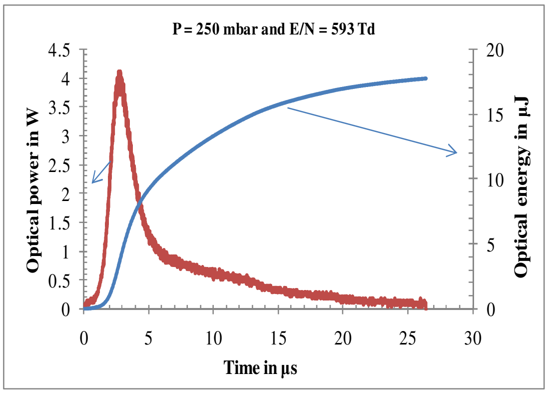
A thyratron (Triton electron technology, model F-189) driven high voltage power supply (Lambda EMI, Model 402L) with variable output voltage and repetition frequency was used to provide the excitation pulses. A capacitor bank comprising of 5 capacitors of 0.92 nF capacitance each connected in parallel was selected resulting in a energy storage of the capacitor bank of 2 J at a charging voltage of 30 kV. The 5 mm electrode gap in our DBD system gives a gas load capacitance of 12.74 pF.

3. Results, analysis and discussion

Figure 2(a) show the voltage pulse used during excitation and Figure 2(b) show the measured optical power and the integrated energy obtained with this laser. Two different CO_2 laser gas mixtures, the 1:1:3 and 1:1:8 CO_2:N_2:He were used during the characterization of the developed laser system.



(a)



b)

Figure 2: a) Voltage signal used in the excitation of the laser b) optical power and energy of the DBD excited laser. The 1:1:3 laser gas mixture at 500 mbar constituted the laser active medium.

Breakdown occurred at about 18 kV and the pulse duration was about 0.3 µs with a risetime of ~100 ns. In Figure 2(b) peak optical power of 9 W and pulse energy of 8 µJ was detected of the laser when the electrode gap was 10 mm.

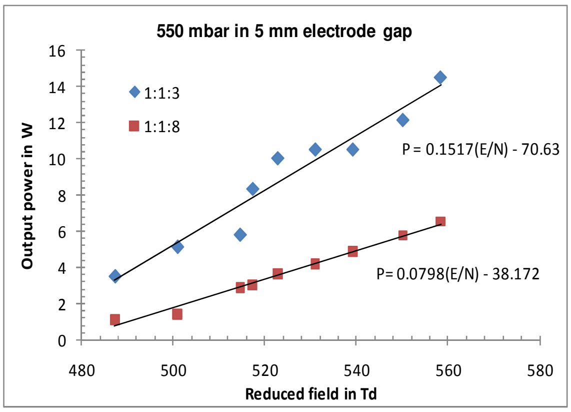
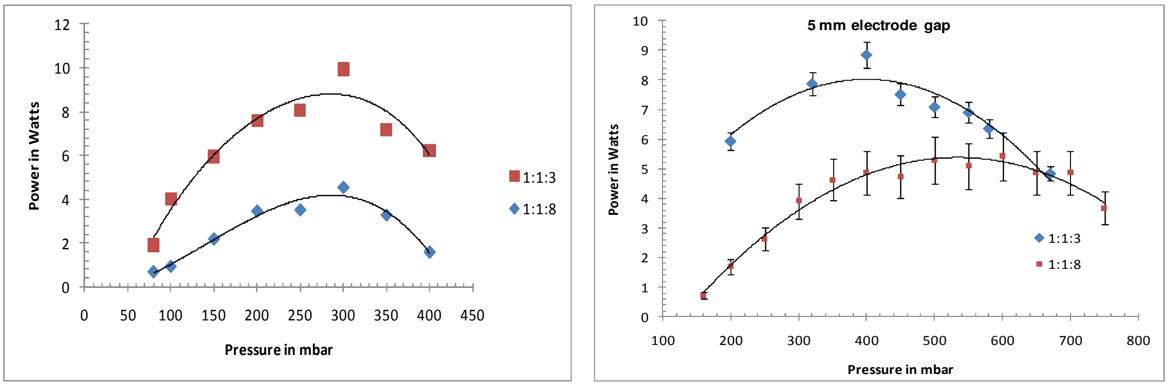


Figure 3: Variation of output power with reduced field for gas pressure of 550 mbar and electrode gap of 5 mm using the 1:1:3 and 1:1:8 CO_2:N_2:He gas mixtures.

A threshold reduced field (*E/N*) exists for this laser as reflected from Figure 3. The graph was obtained with a 1.4 mm dielectrics and a gap separation of 5 mm. Power output values plotted against *E/N* in Figure 3 show a linear relationship between the two quantities. Optical power is a function of the reduced field. The threshold reduced field required before any optical output could be detected for the two gas mixtures used is 470 ± 8 Td (1 Td = 10^{-17} Vcm^2). High values of optical pulse power e.g. 50 W would require a reduced field of 800 Td.

The constant of proportionality for the pressure and *E/N* relationship is 2 times smaller at 300 mbar as compared to 500 mbar. This means by raising the pressure by 200 mbar from 300 mbar, the population of the upper laser level is almost doubled.

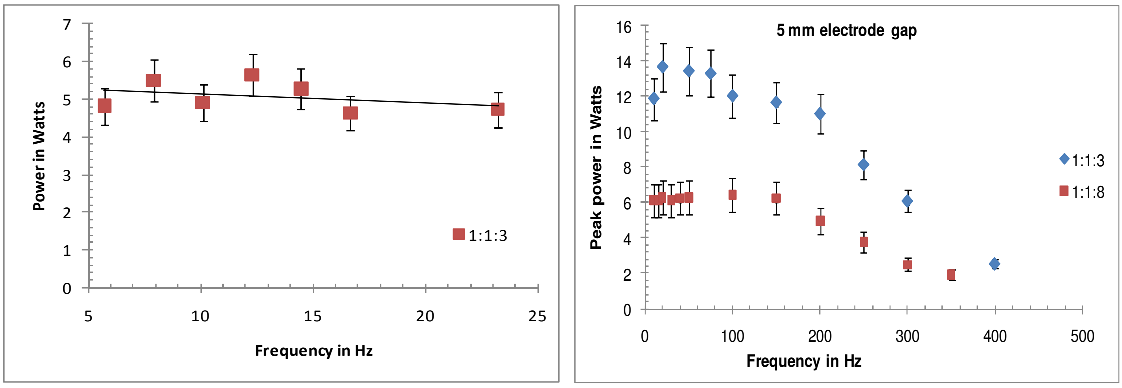


(a) (b)

Figure 4: Variation of power output with pressure a) with a 10 mm electrode gap and dielectric thickness of 1.8 mm and b) 5 mm electrode gap with a dielectric thickness of 1.4 mm.

The optimum pressure observed for maximum optical output energy in Figure 4(b) was 300 mbar for a gap separation of 10 mm and 400 mbar for a 5 mm electrode gap with a 1:1:3 gas mixture. Maximum pulse power of 14.0 ±1.0 W was obtained with the 1:1:3 CO_2 laser gas at a pressure of 300 mbar. Optimum pressure for the 10 mm electrode gap with a 1.8 mm thick glass dielectric is 300 mbar for the two gas mixtures used in this research as shown in Figure 4(a). As pressure was increased, optical output power increased up to a maximum value before decreasing again. In Figure 4(b) the variation of power output with pressure for an electrode gap of 5 mm and with 1.4 mm glass dielectrics shows that higher optical output could be obtained at higher pressures. The optimum operating pressure was 550 mbar and at this pressure 7 μJ of optical pulse energy with a gas mixture of 1:1:8 was measured. It is evident that, after the modifications, the laser could give an optical output at pressures above 500 mbar and an optimum pressure of 400 mbar for the 1:1:3 gas mixture. The maximum optical power did not vary significantly in magnitude as compared with prior to the modifications. Pressure above the optimum values resulted in lower population levels of the upper laser levels and therefore in gain reduction. The steep decrease of the output at pressures above 300 mbar for the 10 mm gap and above 500 mbar for the 5 mm gap is attributed to the fact that the voltage across the discharge was not high enough resulting in a highly filamentary discharge.

The developed laser gives high values of output optical power for frequencies up to 100 Hz for the 5 mm electrode separation as shown in Figure 5. Results in Figure 5(a) show that laser output is obtained at frequencies less than 25 Hz. With half the initial electrode separation and double the intial pressure the optical output was increased two fold as observed in Figure 5(b). Exciting the laser using higher frequencies resulted in reduced optical power output which could be a result of electron trapping in the discharge gap preventing the bulk of the electrons from crossing the gap. Gas heating resulting in increased CO_2 dissociation is also one of the reasons for the decrease in output.



(a) (b)

Figure 5: Variation of optical power with excitation frequency for a) a 1 cm electrode gap and 1.8 mm thickness glass dielectric and gas pressure of 250 mbar and b) 0.5 cm electrode gap and 1.4 mm thickness glass dielectric and gas pressure of 500 mbar.

When the frequency was varied, the output power changed as reflected in Figure 5. Exciting the DBD CO_2 TEA laser with an electrode gap of 5 mm increased the frequency window for which the laser can be used as exposed by Figure 5(b). High optical powers where obtained at low frequencies of up to 150 Hz. The power output decreased as excitation frequency was further increased and no output was observed at frequencies above 400 Hz. By increasing the pulse repetition rate, we increased the energy deposition into the gas. Without water cooling, the gas temperature increased for pulse repetition rates greater than 150 Hz. Once dielectric electrodes charge up, the discharge current terminates and the large part of the stored energy remains in the charging capacitor and the dielectric electrodes without being transferred to the laser medium. The optical output is also sensitive to gas mixture. Using the 1:1:3 CO_2:N_2:He gas mixture, the optical power increased two fold when compared with results obtained using 1:1:8 CO_2:N_2:He gas mixture.

4. Conclusion

A DBD excited CO_2 TEA laser operating at frequencies normally associated with DBD excited excimer lamps has been demonstrated. Laser output was observed in pulsed mode with maximum energy per pulse being 10.0 ± 1.0 μJ and a maximum of 400 Hz pulse frequency for a 5 mm electrode gap separation. The laser optical pulse was observed about 5 μs after the excitation pulse and its duration was 3 to 5 μs. Our results show that it is possible to prolong electrode life of mini CO_2 TEA lasers by covering the metal electrodes with a dielectric and continue operating such lasers in a real pulsed mode. To improve the optical power output, besides increasing the excitation voltage, the electrode gap could be further reduced, a barium titanate ($BaTiO_3$), a ceramic with high dielectric constant of more than 3000 could be used instead of glass or a thinner dielectric would be a viable option. These modifications increase the dielectric capacitance and should result in increased pulse energy. Also different gas mixtures with varying proportions of CO_2 and N_2 could be investigated in an attempt to increase the optical output.

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