

DEVELOPMENT OF A HELIUM-FREE ATMOSPHERIC PRESSURE PULSED CO, LASER

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Introduction

The major role of helium in the pulsed atmospheric pressure operation of a transversely excited CO_2 laser, commonly termed as TEA CO_2 laser, is to stabilise the discharge. Helium, with its very low electron affinity, facilitates the occurence of an arc-free discharge at higher operating pressures and hence has been indispensable in the conventional operation of TEA CO_2 lasers. Helium, which constitutes majority of a CO_2 laser gas mixture, is expensive and scarce. A number of special techniques have, therefore, been employed in the past, to obtain helium-free operation of CO_2 lasers. These methods and their limitations are briefly described below:

1. Low pressure $\mathrm{CO_2}$ laser: Helium-free operation has been successfully achieved in TE $\mathrm{CO_2}$ lasers [1, 2] at sub-atmospheric pressures or low pressure synchronous longitudinal discharges [3] or cw operation of low pressure $\mathrm{CO_2}$ lasers [4]. While the variations in the excitation circuits allowed helium-free operation in TE systems, albeit below atmospheric pressure, the low operating pressure in CW systems intrinsically ensures, glow mode operation of the discharge in the absence of helium.

Due to the sub-atmospheric pressure operation of these systems, the maximum coherent power that can be obtained from them, is always lower than TEA systems with similar active volume.

2. Rapid discharge technique: This approach [5-7] takes advantage of a very rapid discharge (few tens of nsec as against hundreds of nsec in a conventional operation) to realise helium-free operation, as the glow-to-arc transition in the absence of helium is very fast. Thus the discharge extinguishes before arcing can set in.

Helium-free operation by rapid discharge technique, can be effected only in specially designed mini laser systems, that inherently offer low discharge loop inductance. Such operation, therefore, restricts the active volume and hence also reduces the maximum obtainable energy output from the system. Rapid excitation invariably results in the emission of optical pulses of short duration. Conventional long pulse operation is therefore not possible by this method.

3. Seeding the laser gas mixture with Low Ionisation Potential (LIP) additives: In the absence of helium, the electrons in the discharge are lost largely by negative ion attachment processes, giving rise to the formation of an arc discharge. The addition of LIP



hydrocarbons increases the primary photoelectron density thereby compensating the loss of electrons in the absence of helium, leading to arc-free operation [8].

The LIP additives seeded in the laser gas mixture undergo dissociation in an electric discharge and tend to settle on the optics, electrode and the internal surface of the laser head, rapidly degrading the performance of the laser.

4. Preconditioning the inter-electrode volume, by electrons from an external source: Loss of electrons in the absence of helium can be overcome by deluging the active volume, with electrons produced externally, as in the case of an electron beam controlled CO₂ laser, resulting in arc-free operation [9]. In this system, helium-free operation of TEA CO₂ lasers, calls for an external source of electrons, thereby making the system more complicated, expensive and bulky. Moreover, this is achieved at the expense of the wall plug efficiency.

We describe here helium-free operation of a conventional TEA CO, laser, which has been achieved in systems where the active volume ranged from \sim 1cc to ~200 cc and was irrespective of i) the geometry of electrodes, viz., profiled, un-profiled or cylindrical, ii) the type of ballasting used for preionisation viz., resistive, inductive or capacitive and iii) the location of the preioniser, viz., beneath the semi-transparent electrode or along the side/sides of the electrodes [10]. This was rendered possible by integrating the spiker and sustainer-like actions, into a single pulser network, by making use of a coupling inductance. Another important advantage of this excitation circuit is its simplicity. A single source powers and a single switch controls the preionisation, the spiker and the sustainer discharges.

Experimental System

As stated before, helium-free operation has been achieved in a wide variety of systems, but we describe here in detail, the operation of a medium sized TEA CO, laser, with contoured electrodes. A 3-dimensional view of the laser head is shown in Fig. 1. It consists of two Ernst profiled [11] electrodes, which define a discharge cross section of 1.5×1.5 cm² and a length of 30 cm. Preconditioning of the laser gas mixture is accomplished, by creating auxiliary spark discharges between brass preionising pins (14 pairs on either side) placed at regular intervals, along the length of the discharge and at a distance of 5 cm from its centre. The entire assembly is housed in a leak tight Perspex chamber (36 cm X 12 cm \times 15 cm) the ends of which are 'O'ring sealed with a concave 4 m ROC gold coated mirror and a ZnSe Brewster window. A 70% reflective ZnSe plane output mirror, together with the gold-coated mirror defines the 65 cm long optical cavity. The flow of current through each of the auxiliary sparks is limited by connecting a small capacitance in series with it.

The schematic of the excitation technique, employed to operate the TEA CO, laser, wherein the spiker and sustainer like actions have been integrated into a single pulser network with the help of a coupling inductance (/), is shown in Fig. 2. Such an integration has made possible a single source to power and a single switch driven pulser to control all the three discharges, viz., the pre, the spiker and the sustainer discharges as against the conventional spiker sustainer excitation scheme, that requires two sources and two switches to achieve the same [10]. The usage of a two-stage Marx generator allows the condenser C₁, on closure of the switch SG₁, to power the pre-discharge. Alongside the preionisation, on closure of SG, the main condensers C, and C, come in series and charge transfer through the inductance, causes the voltage across the spiker condenser C_{sp}, to build up rapidly as shown in Fig. 3 (a). Fig. 3 (b) represents the current flowing from the main condensers following the closure of the spark gap SG₃. The first forward cycle



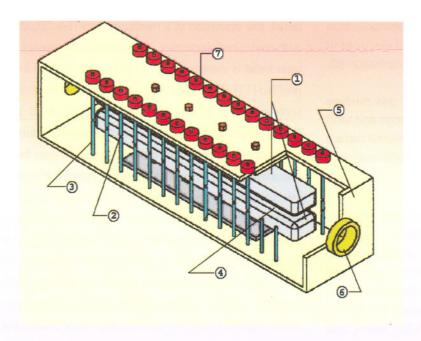


Fig. 1: Three-dimensional view of the laser head.

1. Uniform field electrodes 2. Preionisation gap 3. Preionisation pins
4. Inter-electrode gap 5. Perspex housing 6. Cavity mirror
7. Preionisation capacitors.

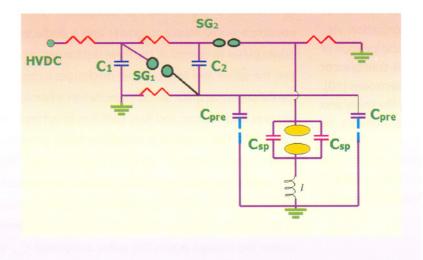


Fig. 2: Schematic of the excitation circuit for helium-free operation of a TEA CO, laser.

of the current pulse, charges up the spiker condenser C_{so} to its peak voltage. As this high voltage impulse is impressed across the inter electrode gap, it closes, leading to the flow of the spiker current. The presence of inductance in the spiker charge-up loop, automatically delays the main discharge, with respect to the pre discharge. This small delay can be readily measured from the temporal wave-forms of Fig. 3 and has also been corroborated by adopting the delay measuring method [12] based on the collection of light originating from the preioniser main discharges separately. The initial voltage to which the main condensers are charged and the values of C_1 , C_2 , C_{pre} and C_{sp} are so chosen, that after the switching of the Marx Bank, the voltage across the preionised inter-electrode gap results in an E/N, appropriate for the initiation of the discharge. The reduced voltage across the main condenser, by virtue of its powering the preioniser discharge and spiker discharges, in conjunction with the inductance (I) maintains an E/N condition, suitable for the sustenance of the discharge. Decoupling of the two discharges viz., the spiker and the sustainer and the tailoring of the sustainer pulse by making use of the inductance, resulted in a condition where glow discharge



could be reliably obtained even in the absence of helium under a wide range of operating conditions. The inductance plays a very crucial role as it controls the delay between both pre and spiker as well as spiker and sustainer discharges, in addition to deciding the rate of rise in voltage across the electrodes.

Performance of the Laser

We monitored the energy, peak power and the FWHM value of the emitted laser pulse, as a function of the partial pressure of $\rm CO_2$ gas, for a particular value of inductance. The results of these studies are summarized in Fig. 4 and Fig. 5. As can be seen, the most optimised performance of the laser in terms of its output energy, occurs for equal concentrations of $\rm CO_2$ and $\rm N_2$ (Fig. 4). The electro-optic efficiency is estimated to be $\sim 7\%$

after accounting for the residual energy in the condenser at the end of the discharge (Fig. 3 (a)).

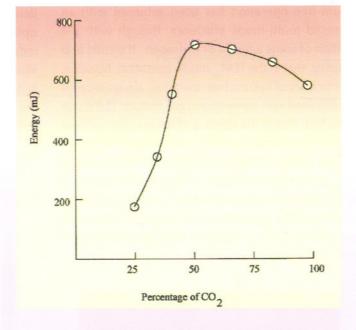
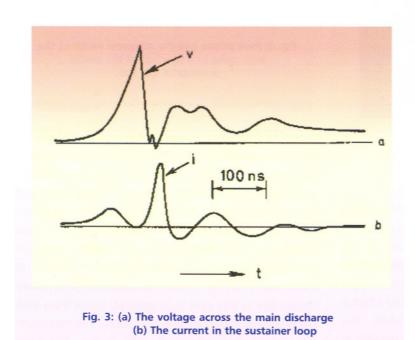


Fig. 4: Output energy of the laser as a function of the partial pressure of CO₂ gas.

The electro-optic efficiency is measured to be 7.8% for multi mode operation, when the same laser operates

with conventional gas mixture (N₂:CO₂:He::1:1:5). It may be noted here, that the efficiency would be higher in both the cases, if the fraction of the stored energy expended in the preconditioning is also taken into account. Besides contributing to the stabilisation of the discharge, helium also helps in depopulating the lower laser level, thereby allowing the participation of the same CO, molecule in the lasing process more than once. Although this process, is slowed down in the absence of helium. owing to the large concentration of CO, molecules (50%) in the gas mixture, the electro-optic efficiency reduces only marginally. With only addition of small amount of hydrogen to the gas mixture (N₂:CO₂:H₂::1:1.2:0.1), the multimode efficiency increases to ~8.8%. Thus





helium-free operation has been achieved with an increased multi-mode efficiency, though with the addition of some amount of hydrogen. It should also be noted, that in the TEM $_{\infty}$ mode operation, however, the efficiency of helium-free operation, always exceeds that obtained with conventional gas mixture. This is due to the fact, that in the absence of helium, the width of the glow discharge is less [13] and hence TEM $_{\infty}$ mode filling is better. A logical conclusion of this finding is that, the emission from helium-free TEA CO $_{2}$ laser will be less divergent as compared to the emission from a conventionally operated laser. A typical multimode laser beam profile as captured on a graphite block is shown in Fig. 5.

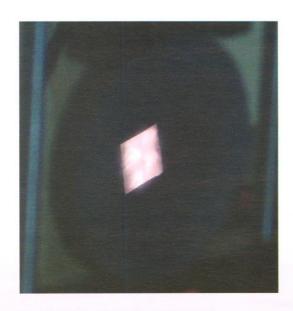


Fig. 5: The laser beam as seen on a graphite block.

The peak power, duration and energy of the laser pulse can be varied by varying the partial pressures of $\rm N_2$ and $\rm CO_2$ as shown in Fig. 6. As the concentration of $\rm CO_2$ reduces from 92 % to 27 %, the FWHM value of the laser pulse increases (from 80 nsec to 590 nsec) by a factor of \sim 7.5, while the peak power drops by a factor of almost 5.25 (from \sim 2.84 MW to 0.54 MW). The peak power increases monotonically with increase in $\rm CO_2$ concentration, revealing higher gain at higher

density of active molecules. The FWHM value of the optical pulse, on the other hand, increases with reduction in the concentration of CO_2 . N_2 can hold vibrational energy for longer duration and any increase in its concentration, therefore, leads to the flattening of the pulse. Such large variation of the peak power and pulse width, is a direct consequence of utilising only

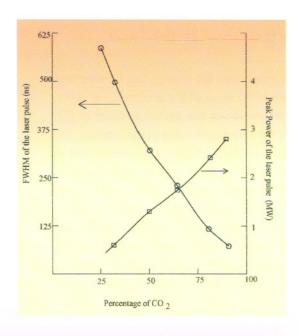


Fig. 6: Peak power and the temporal width of the laser pulse as a function of the partial pressure of CO₂ gas.

molecular gases for the operation of this laser. The same laser when operated with the conventional gas mixture, (consisting of helium), exhibits much smaller variation in the pulse duration with changing partial pressures of the molecular gases. As can be seen from Fig. 6, the FWHM value of the laser pulse when the present system is operated with conventional gas mixture, changes atmost by a factor of ~ 1.6 (from 800 ns to 1350 ns). It is also seen from Fig. 7, that the maximum peak power obtainable in this case is in general, lower than that obtainable with helium-free operation. The maximum value of small signal gain for this system, has been measured to be ~ 2.7 %/cm. The optimum value of the



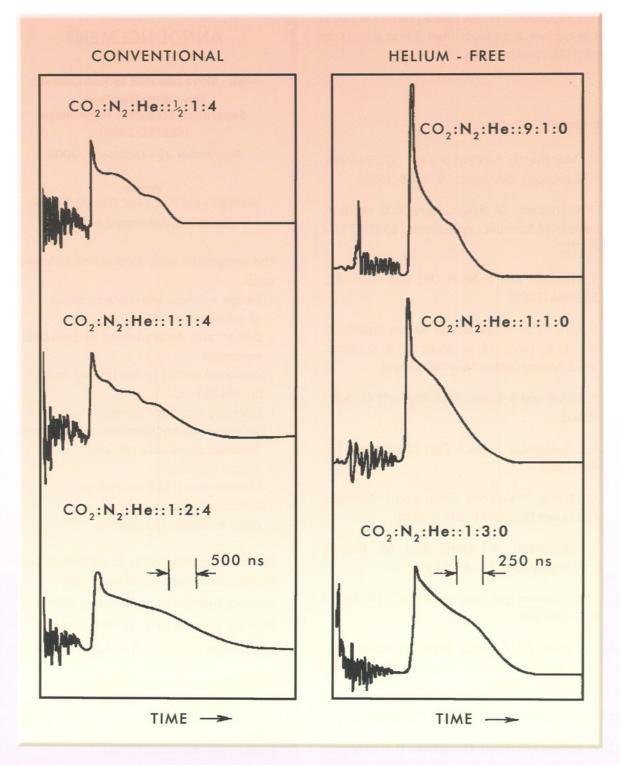


Fig. 7: Temporal shape of the laser pulse for conventional and helium-free operations, as a function of the gas composition.



inductance, depends on the partial pressure of CO_2 in the gas mixture and ranges from 0.5 to 6.5 μH for different CO_2 concentrations.

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