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On the repetitive operation of a self-switched transversely excited atmosphere CO_2 laser

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Abstract. The repetition rate capability of self-switched transversely excited atmosphere (TEA) CO_2 laser was studied for different gas flow configurations. For an optimized gas flow configuration, repetitive operation was achieved at a much smaller gas replenishment factor between two successive pulses when compared with repetitive systems energized by conventional pulsers.

Keywords. TEA CO_2 laser; repetitive; self-switched.

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1. Introduction

One of the important features of a TE gas laser source is its repetition rate capability, which is mainly governed by the performance of the excitation circuit and the gas flow system. The repetition rate compatibility of the excitation circuit is decided by the efficiency of the repetitive charging of the condenser and the capability of the switch used to discharge it into the load at that repetition rate. All conventional switches generally used in TE gas laser pulsers have their own limitations. We have successfully operated a TEA CO_2 laser by dispensing with the need of any conventional switch. Here the discharge is switched by its own UV emitting parallel spark pre-ionizer [1,2]. Absence of an external switch makes these systems inherently repetition rate compatible. In this paper, studies pertaining to the repetitive operation of self-switched TEA CO_2 lasers for various gas flow configurations are presented.

In the first set of experiments, the efficacy of the switchless operation technique in repetitive mode was studied in a mini-TEA CO_2 laser with cylindrical electrodes (active volume $\sim$1 cc) having longitudinal gas flow configuration [1]. Under optimized conditions, a good quality glow discharge could be obtained up to a repetition rate of $\sim$50 Hz (replenishment factor $\sim$4). Any further increase in the repetition rate deteriorated the discharge and hence reduced the output. This restriction on the repetition rate was, however, not imposed by the pre-ionizer switch. The inadequate replacement of the contaminated gas from the inter-electrode volume between the successive pulses hindered the performance of the laser beyond this repetition rate. It is well known that for efficient repetitive operation of a laser, the gas replenishment factor between the two successive pulses should be greater than 2. With the longitudinal flow system, at higher flow rates, the pressure gradient builds up and the removal of the contaminated gas efficiently from the discharge region becomes difficult. The laser gas residue blown upstream by the shock wave of the previous pulse further enhances the threshold flow requirement to obtain glow discharge in the repetitive operation. Making the laser head transverse flow compatible is therefore an ideal option to overcome this problem.

In conventional repetitive TE gas lasers, the pre-ionization sparks are generally placed beneath a perforated electrode. This allows unhindered flow of gas in the transverse direction. But, for switchless TEA CO_2 laser, the pre-ionization chamber is isolated from the main discharge by means of LiF windows [1,2]. The presence of LiF windows in the laser head makes the conventional transverse gas flow configuration difficult to achieve. Therefore, the gas flow system needs to be modified suitably. We have studied a variety of gas flow configurations and the maximum achievable repetition rate in each case.

2. Experimental set-up

The experiments were carried out with a switchless TEA CO_2 laser where the discharge chamber comprised of a cylindrical upper electrode (length = $\sim$30 cm) and Ernst profiled centrally perforated lower electrode ($\sim$1 mm holes) placed 1.2 cm apart from each other thus defining $\sim$15.6 cc discharge volume (12 mm $\times$ 5 mm $\times$ 260 mm). The cylindrical electrode was used in the system to avoid arcing due to the edge effects at repetitive operation. The pair of electrodes were enclosed

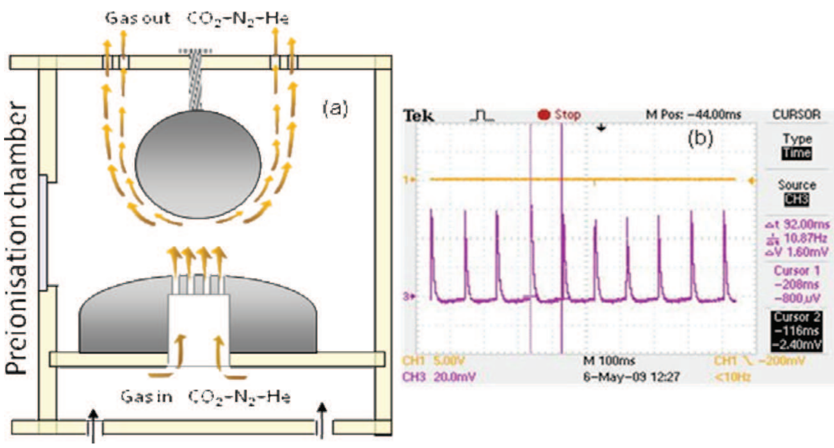

Figure 1. (**a**) Schematic of the laser assembly with perforated Ernst-profiled electrode. (**b**) Energy output of the laser at repetitive operation ($\sim$11 Hz) for gas flow though the electrode. Gas flow rate $\sim$33 l/min.

in a Perspex chamber the ends of which were 'O' ring sealed with an ~100% reflective 2 m concave gold-coated mirror and ~60% reflective ZnSe output coupler (6 m ROC) forming an optical cavity of ~42 cm length. The pre-ionization chamber consisting of 13 pairs of brass pins interspaced at ~2 cm and placed on one side along the length of the electrodes at a distance of ~4.5 cm from the discharge centre. The parallel pre-ionizer array was physically isolated from discharge chamber by means of LiF windows. At the most optimized condition the laser was capable of producing an output energy of ~147 mJ/pulse at an electro-optic efficiency of ~6.11% with input energy loading of ~150 J/l-atm. The output energy of the system could be further increased up to ~190 mJ/pulse by increasing the operating voltage to ~21 kV, however, at the expense of efficiency. For the repetition rate study, the laser was operated at its highest efficiency. The energy was measured using a pyroelectric detector after suitably attenuating the output energy of the laser.

3. Results and discussion

3.1 *Repetitive operation of a switchless TEA CO_2 laser: Transverse flow with one perforated electrode*

In this system the lower Ernst profiled electrode was perforated at the centre by ~1 mm holes interspaced at ~4 mm from each other. The gas enters the discharge zone through the perforations in the electrode and flows out though the holes drilled on the top wall along the length of the electrode as shown in figure 1a.

With this configuration, we have successfully operated the switchless laser up to a repetition rate of ~11 Hz where gas was flown at a rate of 33 l/min corresponding to a gas replenishment factor of ~3.1. The quality of the discharge, the output energy and efficiency of the laser remained unchanged at this repetition rate (figure 1b). Further increase in the repetition rate resulted in the deterioration of the discharge.

We attribute the modest repetition rate obtained here to the fact that the contaminated gas in the central zone along the length of the discharge does not get replenished at the same rate as that at the edges due to the channelling effect provided by the location of the inlets and outlets. Inadequate replenishment of the contaminated gas, therefore, puts a restriction on the maximum achievable repetition rate here.

3.2 *Repetitive operation of a switchless TEA CO_2 laser: Near transverse flow with solid electrodes*

The laser head in this configuration too is similar to the earlier two systems except that the electrodes here were not perforated. The gas entered the discharge zone through a number of holes provided along the length of the electrodes in a direction transverse to the optics axis. After travelling through the inter-electrode distance, the contaminated gas was guided by the LiF windows to flow out from the openings provided on the top and bottom plates of the discharge chamber. The schematic of this arrangement is shown in figure 2a.

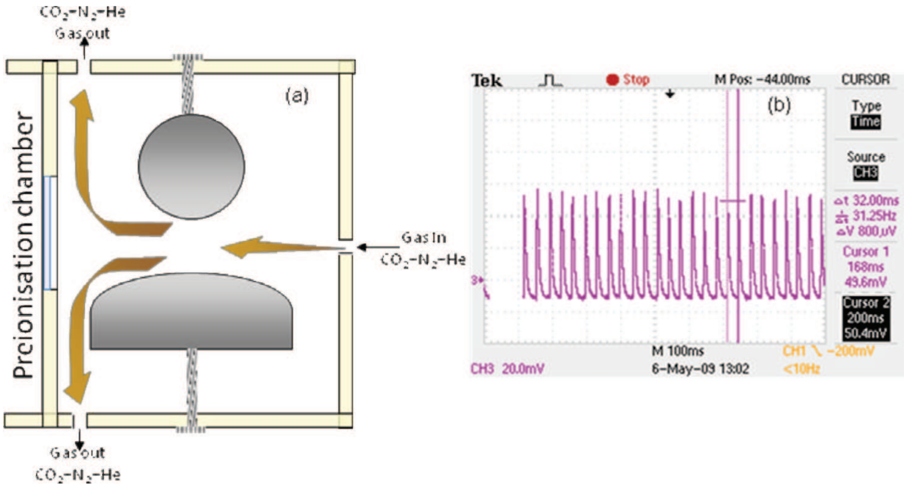

Figure 2. (**a**) Schematic of the laser assembly. (**b**) Energy output at repetitive operation (~31 Hz) for gas flow transverse to the electrodes and optics axis as well. Gas flow rate ~33 l/min.

In this configuration, for same flow rate of the gas as before (~33 l/min) we were able to achieve much higher repetition rate, viz. ~31 Hz with output energy and efficiency remaining nearly the same (figure 2b). The gas replenishment factor between two successive pulses here is about ~1.13 times only. The efficient operation of the laser in the repetitive mode with such a small replenishment is, we believe, a consequence of better replenishment of the contaminated gas. In addition the physical isolation of the pre-ionizer from the active volume reduces the contamination level in the laser gas mixture when compared with the conventional systems where the pre-ionizer sparks take place in the same enclosure that also houses the active gas mixture. But, the presence of LiF windows on the other hand, restricted the maximum gas flow rate, thereby the maximum achievable repetition rate.

3.3 *Repetitive operation of a switchless TEA CO_2 laser: Transverse flow with both the electrodes perforated*

To overcome the drawback described in the previous case, we used an identical laser head except that in this case both the electrodes were centrally perforated and the gas was flown in the transverse direction as shown in figure 3a.

By keeping the same gas flow rate, i.e., ~33 l/min, we have successfully operated this laser up to ~20 Hz with gas replenishment between two successive pulses being ~1.7 times (figure 3b). In this configuration, the top electrode had holes of diameter 1 mm drilled on two rows, separated by 4 mm. Each of these rows contained 65 such holes spaced 4 mm from one another. These holes were meant to provide an outlet path for the gas. All these holes together defined a total outlet area of 1.02 cm^2, considerably less compared to the inlet area of 6.5 cm^2. The pressure head created as a result of this inhibited proper replenishment of the gas, restricting the achievable repetition rate.

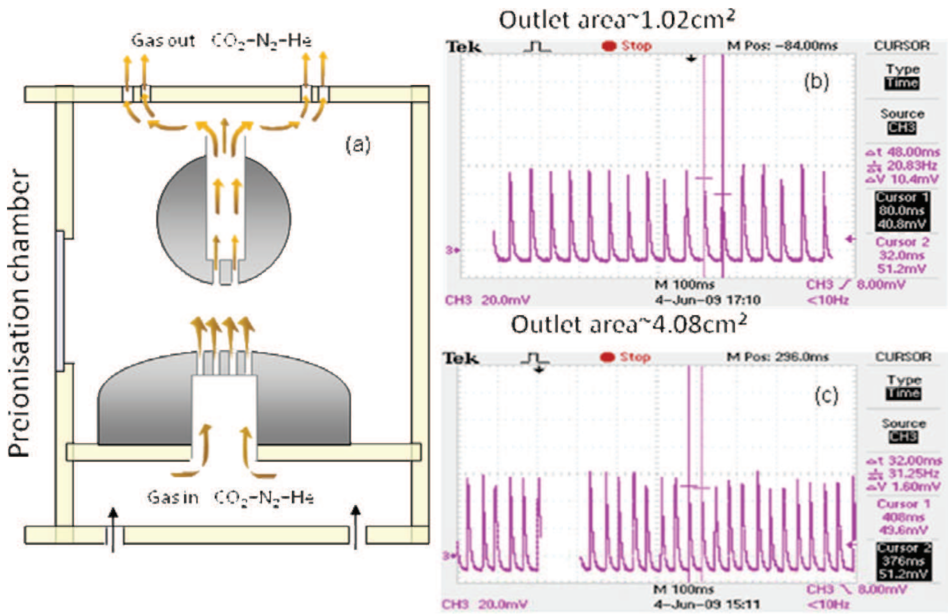

Figure 3. (**a**) Schematic diagram of the laser assembly with both perforated electrodes. Energy output of the laser at repetitive operation for gas flow though both perforated electrodes. (**b**) Outlet area 1.02 cm^2, repetition rate ∼20 Hz, (**c**) outlet area 4.08 cm^2, repetition rate ∼31 Hz (gas flow rate ∼33 l/min).

Table 1. Comparison of repetition rate capability of switchless TEA CO_2 laser for three different gas flow configurations.

Gas flow rate (l/min)	Gas flow configuration		Maximum achievable repetition rate (Hz)	Replenishment factor
∼33	Transverse flow with one perforated electrode		∼11	∼3.1
∼33	Near transverse flow with both solid electrodes		∼31	∼1.13
∼33	Transverse flow with both perforated electrode	Outlet area ∼1.02 cm^2	∼20	∼1.76
∼33		Outlet area ∼4.08 cm^2	∼31	∼1.13
∼60		Outlet area ∼4.08 cm^2	∼50	∼1.28

We next increased the diameter of each of the holes on the top electrode to 2 mm that defined now a total outlet area of 4.08 cm^2. In this configuration, by keeping the same gas flow rate of ~33 l/min, a repetition rate of ~31 Hz has been achieved at ~1.13 times gas replenishment between successive pulses (figure 3c).

By increasing the gas flow rate to ~60 l/min (transverse flow with outlet area ~4.08 cm^2) we were able to increase the repetition rate up to ~50 Hz producing an average power of ~7.3 W. The energy output of ~146 mJ/pulse and input energy density of ~150 J/l-atm remained nearly constant even at 50 Hz repetition rate. Further increase in the repetition rate should also be possible with the corresponding increase in the flow rate.

All these results are summarized in table 1.

Although we have operated the system in open loop, i.e. flowing contaminated gas out, the requirement of less replenishment shows the efficacy of the system to work in the sealed-off mode. The designing of the re-circulatory loop with catalytic converter and blower for TE CO_2 lasers is well studied, documented and implemented in conventional TEA CO_2 lasers. Such a re-circulatory loop can be easily incorporated with the switchless system developed by us that will reduce the load on the catalytic convertor and blower owing to the lower replenishment, increasing thereby, their operational life.

References

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