Switching of a TEA CO_2 laser with its own UV emitting parallel spark channels

J. Padma Nilaya, Pallavi Raote, Gautam Patil, Dhruba J. Biswas

Infrared Laser Section
Laser and Plasma Technology Division
Bhabha Atomic Research Centre
Mumbai - 400 085, India
lpt@.barc.gov.in

Abstract: The efficient operation of a TEA CO_2 laser wherein the parallel spark channel preioniser of the laser itself functioned as a switch is reported. Simultaneous closure of the parallel gaps without an external switch has been achieved by ballasting them with mutually coupled inductances. The repetitive operation capability of such a laser is also discussed.

OCIS codes: (140.3470) lasers, carbon dioxide: (140.3570) Lasers, single-mode: (999.9999) Laser pulser

---

References and links:

1. D. J. Biswas and J. P. Nilaya, "Repetitive transversely excited gas laser pulsers," Prog. Quantum Electron. **26**, 1-63 (2002).
2. S. Friedman and R. F. Caristi, "Users guide to thyratrons for laser applications," Laser Focus p-70 (July 1987).
3. H. Tanaka, H. Hatanaka, and M. Obara, "High-efficiency, all-solid-state exciters for high-repetition-rated, high-power TEA CO_2 lasers," Rev. Sci. Instrum. **61**, 2092-2096 (1990).
4. A. Sylvan, P. K. Bhadani, and R. G. Harrison, "A photo switched small TEA CO_2 laser," Meas. Sci. Technol. **3**, 200-203 (1992).
5. 3. K. Jayaram and A. J. Alcock, "X-ray initiated high pressure glow discharges," Appl. Phys. Lett. **46**, 636-638 (1985).
6. V. P. Singal, R. Vijayan, B. S. Narayan, D. J. Biswas, U. Nundy, "A highly efficient electron beam controlled switchless multi-joule TEA CO_2 laser," Inf. Phys. Technol. **44**, 69-73 (2003).
7. D. J. Biswas, J. P. Nilaya, M. B. Sai Prasad, P. Raote, "Switch-less operation of a TEA CO_2 laser," Opt. Express **13**, 9636 (2005).
8. M. Kumar, P. Choudhary, S. Tiwari, and A. K. Nath, in:O. P. Nijhawan, A.K. Gupta, AK.Murla, K. Singh (Eds), Optics and Optoelectronics – Theory, Devices, and Applications, Vol 2, Narosa Pub., New Delhi, pp1017-1020 (1999).
9. A. Kumar, R. B. Bhatt, D. J. Biswas, N. S. Benerjee, A. Mokhriwale, U. Nundy, "A novel method of measuring delay between the pre and the main discharges in TE gas lasers," Meas. Sci. Technol. 12, 1739 (2001).
10. C. Yamabe, T. Matsushita, S. Sato, K. Horii, "Characteristics of a TEA CO_2 laser preionised by UV light," J. Appl. Phys. **51**, 1345 (1980).
11. S. Howells and J. V. Cridland, "Performance of a TEA CO_2 laser with high levels of O_2 contamination,",J. Appl. Phys. **53**, 5323 (1982).
12. D. J. Biswas, J. P. Nilaya, and A. Kumar, "Operation of Helium free TEA CO_2 lasers," Opt. Commun. 248, 521 (2005).
13. N. Menyuk and P. F. Moulton, "Development of a high repetition rate mini-TEA CO_2 laser," Rev. Sci. Instrum. **51**, 216 (1980).

---

1. Introduction

In the operation of a TEA CO_2 laser, the energy initially stored in a condenser is discharged into the laser load with the help of a fast, high current, high voltage switch, conventionally a spark gap or a thyratron. Spark gaps, which operate in the arc mode, are unsuitable for repetitive applications as they suffer from recovery problem with increasing charging current [1]. Thyratrons, on the other hand, withstand much higher hold over current by virtue of their operation in the glow mode and are, therefore, preferred as switches in the repetitive operation of the laser [2]. Thyratrons are expensive and have limited life and therefore there is a growing interest in replacing them by all-solid-state-exciters (ASSE) in conjunction with magnetic pulse compression (MPC) [3]. Although such systems have long life and high degree of reliability, they are bulky and also suffer from low wall plug efficiency [3]. Efforts have, therefore, been expended in the past to eliminate the main discharge switch altogether in the operation of TEA CO_2 lasers [4-6]. In these methods the main discharge condenser, which is charged to a voltage lower than the d-c breakdown voltage of the inter-electrode gap, is directly connected across the laser electrodes. The condenser automatically switches its stored energy into the laser load when preconditioning of the inter-electrode gap with uv photons [4], X-rays [5], or electrons from an external source [6] brings down the impedance of the gap. In all these methods, although no switch has been employed for the functioning of the main discharge, a switch is needed to initiate the preconditioning of the inter-electrode volume. The operation of the laser based on these schemes cannot therefore be regarded as switch-less in a true sense as the operational life of the laser in the repetitive mode will once again be limited by the life of the switch required for the generation of the preionising pulse. We have, of late, succeeded in achieving operation of a uv preionised TEA CO_2 laser by dispensing with the service of any such extraneous switch [7]. In this method, the preionising spark array, an integral part of the laser head, was made to serve the dual role- that of a switch, as well as, of a source of UV photons essential for the pre-conditioning of the inter-electrode volume. The sequential pre-ionising spark array used in this experiment was constructed by segmenting the main spark gap into smaller adjustable gaps and then placing them in series along the length and to one side of the discharge. One obvious disadvantage here is that the entire discharge current flows through each of the spark channels. This not only limits the life of the array but also hinders the recovery of the gaps in the repetitive operation.

In this communication, we report the switch-less operation of a TEA CO_2 laser that is free from this drawback. This was made possible by devising a novel method that allowed switching of the laser by its own parallel spark array preioniser. In contrast to the case of switching the laser with a sequential preioniser, the discharge current in the switch is now shared among number of parallel spark channels easing their process of recovery and enhancing, at the same time, the operational life of the preioniser.

2. Laser head and the excitation circuit:

As depicted in Fig. 1, conventional operation of a parallel spark array preioniser has hitherto been achieved with the help of an external switch to over-volt all the parallel gaps ensuring their simultaneous closure. This is made possible by adjusting the breakdown voltage of the switch to be significantly higher than that of the individual gaps. The maximum current that can flow through any spark channel is limited by connecting a ballast element (Z) in series with it. In the absence of any external switch, the slightest mismatch in the breakdown voltages of the gaps, which is inevitable, results in the closure of the gap with the least breakdown voltage. The entire preionisation energy is then drained through this single spark channel leading to a highly localized preconditioning of the inter-electrode volume. The individual ballasting of the gaps does not help the situation in any way as the ballast element can limit the flow of current only through the gap in series with it and has no influence on the flow of current through any of the remaining gaps. If coupling of all the spark channels were possible so as to equalize the current flowing through them, simultaneous closure of all the

#75907 - $15.00 USD Received 9 October 2006; revised 15 December 2006; accepted 19 December 2006

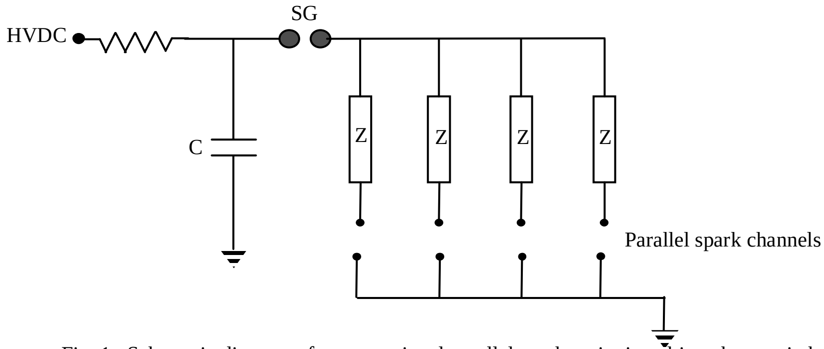

Fig. 1. Schematic diagram of a conventional parallel spark preioniser driven by a switch. 'Z' represents the ballast element.

parallel gaps without a switch could be a reality. We have achieved this by exploiting the property of mutual inductance. The principle of simultaneous closure of a number of parallel gaps without an external switch can be understood by referring to the circuit diagram shown in Fig. 2. The parallel gaps 'B' are individually ballasted by inductances that are mutually coupled to one another through ferrite cores. The mutual inductive coupling ensures the flow

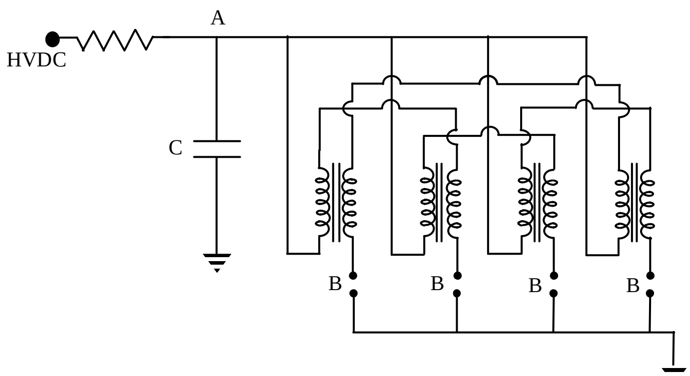

Fig. 2. Schematic diagram of the switch-less parallel spark preioniser. The spark channels are ballasted by mutually coupled inductances.

of equal current through all the spark channels. Change of current through any one of the spark channels induces an emf through the mutual coupling in the remaining ballast elements in such a way that the current through them too changes in a similar fashion. A condenser 'C' resistively charged to a suitable voltage is made to discharge directly into the parallel spark channels through the mutually coupled inductances. The breakdown voltage of all the parallel gaps cannot be made identical. However, the equalization of current through them by mutually coupling the ballast inductances enables the simultaneous closure of the channels without the need of an external switch. We note here that Kumar et al [8] have used the mutual inductance coupling to develop an elegant method of equalizing the preionisation currents through all the parallel spark channels. In their work, however, a switch was used to over-volt the parallel gaps while mutually coupling them by inductances rendered equalization of current through all the gaps. In order to ascertain the suitability of the parallel spark array as a switch of a TEA CO_2 laser, the simultaneity of their closure was measured by the technique described in reference 9. The closure of the gaps was found to be well synchronized with a maximum jitter of ~ 7 ns. The jitter increased beyond 50 ns when the spark channels were isolated from each other with opaque partitions revealing clearly that the uv photons emanating from the spark channel that closed first also aided the rapid closure of the rest. This observation gives rise to the prospect of triggering and synchronising such a parallel spark array switch with an external spark source by deriving light of appropriate intensity from it.

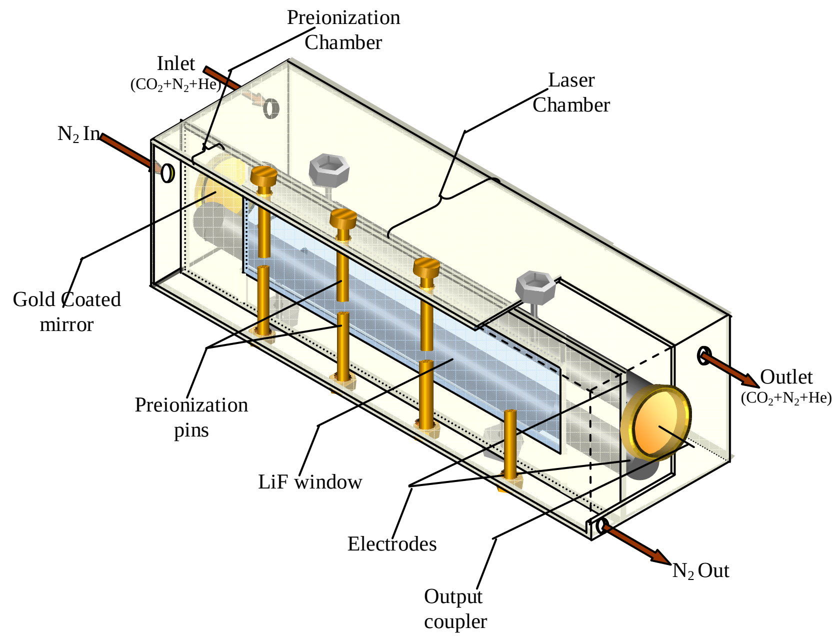

Fig. 3. A 3-D view of the laser head and the preionization chamber.

A three dimensional view of the laser head along with the preionisation chamber is shown in fig 3. The discharge chamber comprised of cylindrical electrodes defining a discharge of cross-section 2mm × 6.5mm and length 70 mm enclosed in a Perspex chamber the ends of which were 'O' ring sealed with a ~ 100% reflective 1m concave gold coated mirror and a 95% reflective ZnSe output coupler that formed an optical cavity of length 20 cm. The preioniser comprised of four pairs of brass pins interspaced at 2 cm and placed along the length of the electrodes at a distance of ~ 3 cm from the discharge center. The gap between the pins of each pair, which were arranged face to face, could be adjusted from ~2mm to ~5mm leading to a corresponding change in their breakdown voltage. This essentially controls the voltage appearing across the laser electrodes. Besides the gap length, the breakdown voltage of the pre-ionising gaps is also a function of the gas pressure and its composition. To have an independent control on the gas composition and pressure in the preionisation chamber, it was physically isolated from the laser chamber by means of a LiF window which offered appreciable transmission to the UV photons in the range of 117-124 nm that cause effective photo-ionisation [10] of the laser gas mixture. The side Perspex wall of the preionisation chamber has been removed in the figure so as to provide a clearer view of the inside elements including the LiF window. To be noted that in the absence of any isolation between the preionisation and the main discharge chambers, the maximum breakdown voltage that could be achieved in presence of the laser gas mixture that includes helium, was not enough to provide an arc-free discharge. The isolation of the two chambers allowed the usage of any desired gas above atmospheric pressure in the preionisation chamber thus providing a scope for enhancing the operating voltage of the laser. In this experiment the preionisation chamber was filled with N_2 gas up to 2 atmospheric pressure.

#75907 - $15.00 USD Received 9 October 2006; revised 15 December 2006; accepted 19 December 2006

A schematic diagram of the excitation circuit based on the principle of L-C inversion [11] for which the mutually coupled preioniser described above also functioned as a switch is depicted in fig 4. A high voltage DC supply charges the condensers C_1 andC_2 (C_1=C_2 = C) to an appropriate voltage V when the preioniser gaps close resulting in the voltage at A to swing from +V to –V. As a result of the dissipation in the preioniser loop, the voltage that appears across the laser electrodes is somewhat less than twice this voltage, which results in a constricted discharge that eventually degenerates into an arc. The usage of a capacitor (C_p) of a value much smaller than that of C_1 and C_2 in series results in a reliable arc free operation of the laser presumably due to the high value of di/dt associated with the discharge of C_p into the laser load. C_1 and C_2 too discharge into the lasing medium albeit at slower rate resulting in the sustenance of the discharge. It was observed that the presence of a lumped inductance

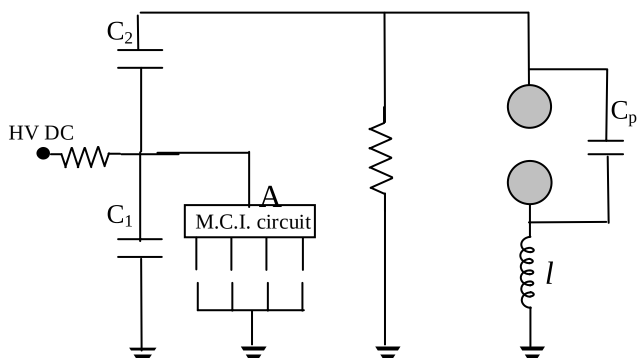

Fig. 4. Schematic diagram of the excitation circuit used for energizing the laser. C_1=C_2=2 nF, C_{sp}=100 pF, L=~8μH. MCI represents the mutually coupled inductance circuit shown in fig 2.

(l) in the discharge path of C_1 and C_2 not only improved the electro-optic efficiency of the laser to some extent but also provided a control on the peak power and the duration of the emission of the laser pulse. To be noted here that the energy stored in C_1 alone flows through the preioniser pins before a significant part of it appears in the load while C_2 directly discharges into the load. Thus employing an L-C inversion circuit not only enhances the voltage across the load, but also reduces the current loading of the spark channels. This increases the electro-optic efficiency, hastens the recovery of the spark channels that, in turn, enhances the repetition rate capability of the laser.

3. Results and discussion

Reliable arc free operation of the TEA CO_2 laser when switched by its own preioniser was achieved for a wide range of operating gas mixtures and input energy loadings. In the first set of experiments, the electro-optic efficiency of the laser was studied as a function of the charging voltage V for different gas mixtures. The most optimized performance in terms of efficiency was found to shift towards gas mixture with lesser helium concentration for increasing operating voltage. This can be qualitatively understood in the following manner. With reduced helium, rate of loss of electrons through attachment processes in a discharge increases. Higher field now enables electrons to cause more ionization before they are lost and thereby help sustain the discharge. This observation corroborates with the findings of the works pertaining to obtaining glow discharges in both helium free [12] and helium lean [13] operation of TEA CO_2 lasers. For V=10.8 kV, a gas mixture of CO_2:N_2: He:: 1:1:1 yielded the maximum efficiency ~8.8%. The overall efficiency, however, is ~7%, when the energy expended in the preionisation is also included in the input energy. The dependence of

#75907 - $15.00 USD Received 9 October 2006; revised 15 December 2006; accepted 19 December 2006

efficiency with the input voltage for this gas composition is depicted in fig 5. The efficiency obtained from this laser compares

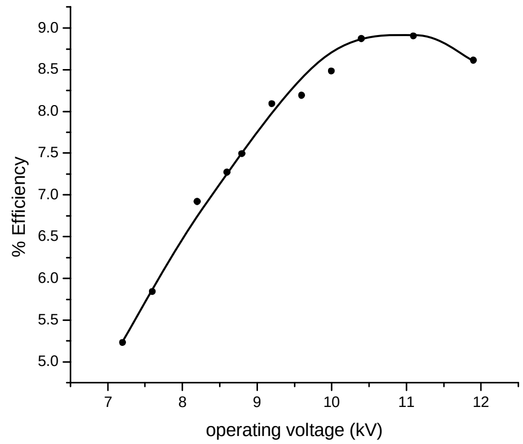

Fig. 5. The electro-optic efficiency of the laser as a function of the charging voltage of the capacitors for a gas mixture CO_2:N_2:He::1:1:1

well with that obtained from conventional self-sustained TEA CO_2 laser systems that are operated with an external switch. However, the energy that could be extracted from this system for this gas mixture, although at the expense of the efficiency, increased with increasing input

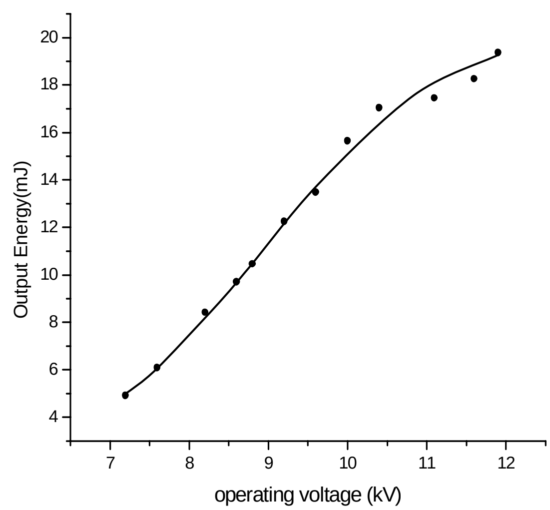

Fig. 6. The output energy as a function of the charging voltage of the capacitors for a gas mixture CO_2:N_2:He::1:1:1

voltage up to V= 11.9 kV (see fig 6) beyond which the quality of the glow discharge deteriorated resulting in arcing. To be noted here that a maximum extractable energy of ~19.5 mJ/pulse was possible for an input energy loading of ~ 225J/lit-atm. Such energy loading is achieved despite only 40-50% coupling of the UV preionising photons of appropriate frequency (117nm to130nm) through the LiF window into the inter-electrode

#75907 - $15.00 USD Received 9 October 2006; revised 15 December 2006; accepted 19 December 2006

volume. This points to the effectiveness of the excitation circuit employed for energizing the laser. The remaining experiments were performed with this gas mixture maintaining 10.8 kV as the charging voltage.

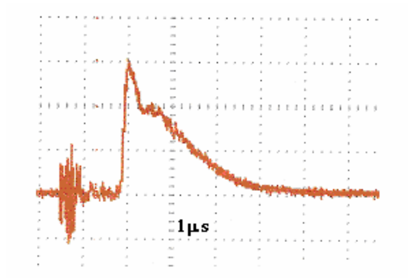

Fig. 7. The temporal profile of the laser emission as recorded by a fast detector.

In the next set of experiments we monitored both the temporal and the spatial profiles of the laser emission. The temporal record of the laser pulse obtained by a room temperature fast MCT detector is shown in fig 7. The pulse is of ~3 μsec duration with a FWHM of ~1.2 μsec and devoid of any mode beating, a signature of emission in the single longitudinal and transverse mode. The duration and the peak power of the emission compared well with that obtained when the laser was operated in the conventional mode. This is due to the fact that the mutual coupling of the inductances results in virtually ballast free operation of the gaps in series with it [8]. The rise time of the current pulse is, therefore, not limited by the large inductance in series with the spark channel. The large free spectral range of the cavity and the cylindrical electrodes utilized here are responsible for such spectral purity of the emission. The spatial profile of the emission was also reconfirmed by translating the combination of a narrow slit and an energy meter across the laser beam. The profile thus obtained indicated the oscillation to be on a TEM_{00} mode with a width of ~1.9 mm measured at half intensity points. As noted before, the variation of *l* from 0 to 12μH resulted in the reduction of the peak power by ~25% while the duration of the emission stretched by ~50%. The delay between the onset of laser oscillation from the point of closing of the preionisation gaps can be seen to be ~1.4 μsec. By varying the operating voltage and the gas composition, this delay could be varied. Such variation in the delay is a result of the change in the laser gain with the above parameters.

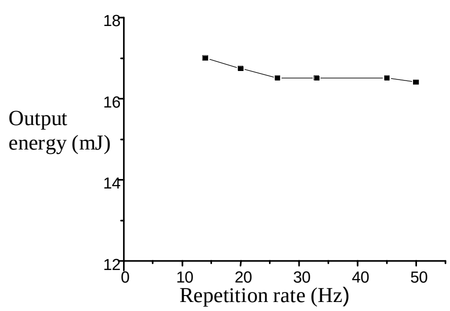

Fig. 8. Dependence of the output energy on the repetition rate.

Finally we monitored the laser output as a function of its repetition rate and the behaviour is shown in fig 8. For this experiment, the gaps of the spark channels and the pressure in the preionisation chamber were adjusted to give the most optimized operating voltage. The repetition rate of the laser was then varied by varying the supply voltage. It was seen that

#75907 - $15.00 USD Received 9 October 2006; revised 15 December 2006; accepted 19 December 2006

good quality glow discharge could be obtained upto a repetition rate of ~50 Hz, also corroborated by the output energy of the laser. For further increase in the repetition rate, the output energy deteriorated rapidly as the build-up of oxygen concentration in the gas mixture resulted in the filamentation and eventual arcing of the discharge. This is owing to the inadequate replenishment of the contaminated gas in the inter-electrode volume between two successive discharges. We note here that the gas flow loop of the laser was not designed for high repetition rate operation.

4. Conclusion

Reliable arc-free operation of a mini-TEA CO_2 laser has been obtained wherein the parallel spark channels of the preioniser, an integral part of the laser, functioned as a switch as well as a source of UV photons. Usage of an L-C inversion circuit in conjunction with a peaking capacitor helped achieve the appropriate conditions prerequisite for an arc-free efficient operation of the laser. The short cavity length of the laser and usage of cylindrical electrodes allowed emission on a single longitudinal and transverse mode. The sharing of the discharge current by the parallel spark channels gives this switch-less laser an advantage with regard to its repetitive operation.

Acknowledgments

The authors thank M. B. Sai Prasad for useful discussions and R. A. Nakhwa for his excellent technical help during the course of this work. They also thank L. M. Gantayet and A. K. Ray for their continued support and encouragement.