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# Towards a triggerable switchless TEA $CO_2$ laser

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ABSTRACT

The possibility of triggering a switch-less TE gas laser has been experimentally explored. To this end, the parallel spark preioniser array that functions as a switch of the switch-less laser has been optically triggered by transporting UV photons from the triggering discharge by means of an optical fiber. The maximum triggerable range was studied as a function of the number of spark channels in the triggering discharge and the gas composition in the triggered parallel spark preioniser.

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The operational life of a TE gas laser in the repetitive mode is often limited by the switch, generally a thyratron or a spark gap, used in the pulser employed to energise the laser. Several attempts have been made in the past to dispense with the switch, albeit with limited success, in the operation of such lasers [1–3]. We have been successful in achieving efficient operation of a switch-less TEA $CO_2$ laser wherein the preioniser spark array, an integral part of the laser, functioned as a switch as well [4–6]. The operation with parallel spark array type preioniser [5] is of particular interest as here the current is shared among the parallel channels enhancing, thereby, their life in the repetitive mode. Synchronization of the operation of a laser with an event may assume significance under certain conditions, e.g., operation of an oscillator and an amplifier. In the absence of a conventional switch, e.g., a spark gap or a thyratron, the triggering of a switch-less laser is not straight-forward. In this paper we address the issue of triggering a switch-less TE gas laser and provide experimental results revealing the possibility of synchronized operation of such lasers.

As noted in Ref. [5] the possibility of optical triggering of the parallel preioniser switch became evident when the reason for the excellent synchronization between the closure of the parallel spark channels was traced to their being optically coupled in addition to the mutual inductive coupling. We describe here the experiment that established the simultaneity of the closure of the mutually coupled parallel sparks (MCPS). The schematic diagram of the experimental setup is as shown in Fig. 1. Once the condenser C is charged to the appropriate voltage, the mutual coupling ensures the closure of all the parallel spark channels. In order to measure the extent of their simultaneity, any two spark channels were randomly chosen and the light emitted following their closure was collected with the help of optical fibers placed in their vicinity. The light reaching the other ends of the fibers was made to trigger two opto-electronic circuits. The delay between their triggering is a direct measure of the simultaneity of the closure of the parallel spark channels from where the light was collected.

The delay thus measured was found to vary between 0 and 7 ns for any two randomly selected parallel gaps. We next operated the same preioniser in the conventional mode, i.e., by over-volting the parallel gaps with an external switch. The results of this experiment are summarized in Table 1. As would be seen, the performance of the mutually coupled preioniser switch can be matched by the conventional method only when the gaps are overvolted by a factor of 2 or more. In the next set of experiments, we operated the MCPS by isolating the parallel spark channels by means of opaque partitions (Fig. 1) and measured the synchronization between their closures as before. The simultaneity now was found to deteriorate and the delay

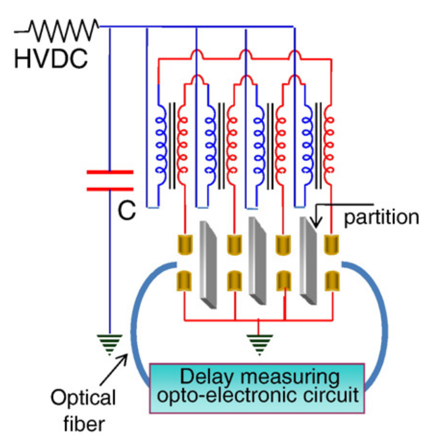


**Fig. 1.** Schematic diagram of the experimental set-up for the study of extent of synchronization between the closure of the parallel spark channels of the preioniser switch.

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**Table 1**
Comparison of the simultaneity of the closure of the parallel spark channels of the preioniser switch with and without an external switch. DC breakdown voltage of the all the parallel gaps was maintained at ~9 kV.

| Voltage (KV) | Delay (ns) | |
|---|---|---|
| | With switch | Without switch |
| 9 (self breakdown voltage of the gaps) | - | 0-7 |
| 12 | 0-50 | - |
| 15 | 0-30 | - |
| 18 | 0-5 | - |
| 22 | 0-5 | - |

increased to ~70 ns. This clearly indicated that the photons emanating from the gap that closed first initiated the closure of the remaining gaps. This gave rise to the prospect of triggering a switch-less laser optically as has been demonstrated in this paper.

The schematic diagram to effect the optical triggering of a preioniser switch is shown in Fig. 2. Capacitor $C_1$ ($=2$ nF) was charged to a voltage $V_1$ ($=15$ kV) that allowed the operation of Spark Gap $SG_1$ in the self-breakdown mode while the voltage $V_2$ ($=20$ kV) to which $C_2$ ($=2$ nF) was charged was less than the breakdown voltage of any of the mutually coupled parallel spark channels (4 in the present case) of the preioniser. The spark gap and the preioniser switch were separated by a distance of ~1 m. It was observed that the closure of $SG_1$ never triggered the closure of the preioniser switch even when $V_2$ was only marginally smaller than the self breakdown voltage of the parallel gaps. We next made use of a UV optical fiber (~1100 micron core diameter) of suitable length to couple the light emitted following the closure of $SG_1$ into the vicinity of one of the parallel spark channels of the preioniser switch. This, to the best of our knowledge, is the first report that makes use of fibre-based optical triggering. The coupling of light in this manner resulted in the simultaneous closure of all the parallel spark channels of the preioniser switch in synchronism with that of $SG_1$. We next monitored the triggerability of the preioniser switch as a function of $V_2$ to obtain the maximum triggerable range ($\Delta V$), which basically is the difference between the maximum and the minimum values of $V_2$ over which triggering is possible; the maximum value being just below the self-breakdown voltage of the preioniser switch. Simultaneous closure was observed up to a minimum value of $V_2$ that was ~7% less than the self breakdown voltage of this switch.

The UV light generated due the closure of a spark gap is much more intense than that due to the closure of any of the parallel gaps of the MCPS. Therefore, the same experiment was repeated by replacing $SG_1$ by an $MCPS_1$ that triggered a $MCPS_2$ which, in turn, self-switched a TEA $CO_2$ laser discharge of length 55 mm and cross section 9 mm × 8 mm (Fig.3). To be noted here that this method of triggering assumes importance when two switch-less lasers are to be operated in the oscillator-amplifier configuration. $V_1$ was maintained at 15 KV throughout the experiment while $V_2$ was varied as before for different self breakdown voltages. As the current is shared among the number of parallel spark channels in the triggering switch $MCPS_1$, in order to compensate for the reduced optical flux, four fibers each of 25 cm length (fused silica high OH, 1100 micron core dia.) stacked together were utilized to transport the light for triggering in this case.

Maximum triggerable range (ΔV) was studied as a function of the number of spark channels in $MCPS_1$ and the gas composition in the triggered preioniser spark chamber ($MCPS_2$). As is seen from Graph 1, ΔV increased with reducing number of spark channels in $MCPS_1$. Understandably, with reducing number of spark channels the current through them increases that, in turn, increases both the density and the frequency of UV photons emanating from these sparks [7]. This aids the process of photoionisation thereby increasing the triggerability range. As described in Ref. [6], the preionisation chamber that contained a mixture of $N_2$ and $CO_2$ gases was isolated from the discharge chamber to facilitate the efficient operation of the laser. The range of triggerability was now studied as a function of the gas

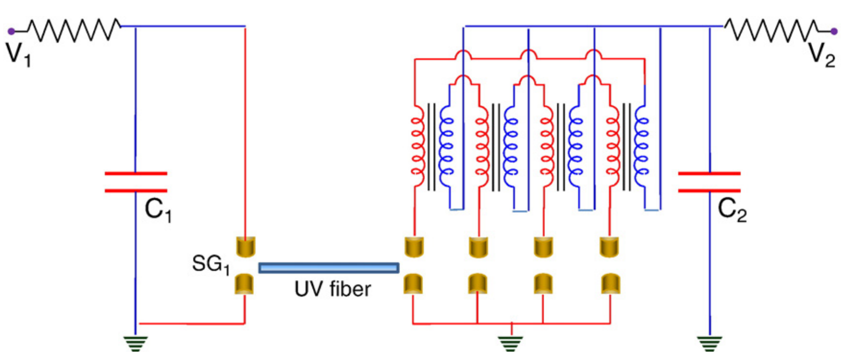



**Fig. 2.** Schematic diagram of the experimental set-up for optical triggering of the preioniser switch by the closure of a spark gap.

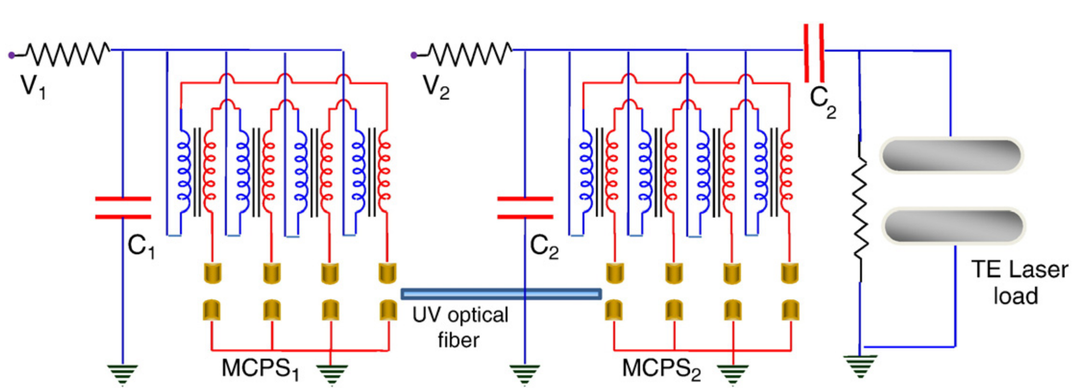
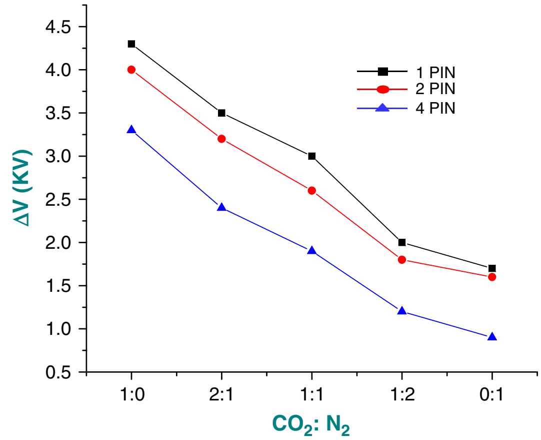
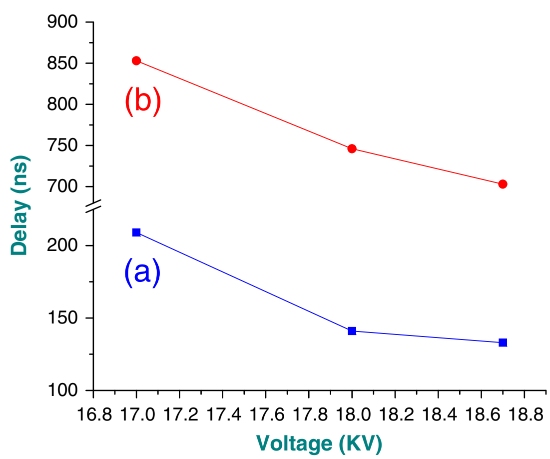



**Fig. 3.** Schematic diagram of the experimental set-up for optical triggering of the laser preioniser switch ($MCPS_2$) by $MCPS_1$ of the synchronizing discharge.




**Graph 1.** The dependence of the triggerability range ΔV with the gas composition in the preionisation chamber for varying number of parallel spark channels in $MCPS_2$.




**Graph 2.** a) Delay between the closures of $MCPS_1$ and $MCPS_2$. b) Delay between the closure of $MCPS_1$ and the onset of the optical pulse.

composition in $MCPS_2$ and the results are depicted in Graph 1. It would be seen that the range of triggerability ΔV increases with increasing partial pressure of $CO_2$.

As expected, with the reduction of $V_2$ the delay between the closure of $MCPS_1$ and $MCPS_2$ increases (Graph 2). This, in turn, results in a corresponding delay in the onset of lasing. Reduction of $V_2$, the operating voltage of the laser, also reduces the laser gain, thereby delaying the optical pulse furthermore. The operation of the laser could be delayed over 300 ns with respect to the triggering discharge.

The triggering signal derived from the preioniser switch itself allowed the operation of two switch-less lasers in synchronism and also with variable delay. While the above described method of optical triggering resulted in a maximum delay of few hundreds of nanoseconds, two other methods that provided a better control on the delay have also been tried. In the first method, the two discharges to be synchronized were coupled to each other through an LC inversion based triggering circuit. The presence of a variable inductance in the triggering circuit allowed a wide variation (200 ns to 6 μs) in the delay between the two switchless discharges. To be noted here that an inductively coupled method was employed earlier to achieve operation of two conventional high voltage discharges synchronously or with a variable delay of several tens of nanoseconds [8]. In the second case the two switchless discharges were coupled through a plasma shutter based triggering circuit that allowed a variable delay up to several microseconds. The details of these triggering mechanisms along with their application in the operation of two switchless lasers in the oscillator-amplifier configuration will be reported elsewhere.

In conclusion, synchronized operation of a switch-less TEA $CO_2$ laser with another high voltage discharge has been achieved by optical means. The UV photons from the triggering discharge when transported to the vicinity of any one of the spark channels of the triggered MCPS resulted in their simultaneous closure and, in turn, operation of the switch-less laser in the triggered mode with variable delay.

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