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A compact spark pre-ionized pulser sustainer TE–CO_2 laser

N S BENERJI, NEERAJ VARSHNAY, LALA ABHINANDAN and U NUNDY

Chemical and Excimer Laser Section, Centre for Advanced Techonology, Indore 452 013
e-mail: nsb@cat.ernet.in

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Abstract. A compact spark pre-ionized pulser sustainer TE–CO_2 laser that can produce an output energy of one joule with an overall efficiency of 12·4% is presented. Optical pulses have durations of 7·15 μs FWHM. Here, the laser uses all solid-state excitation (ASSE) circuit and the discharge formed between two uniform field electrodes placed 1·5 cm apart ultimately leads to a discharge volume of 50 cm $\times$ 1·5 cm $\times$ 1·5 cm.

Keywords. All solid-state exciter; pulser sustainer; TE–CO_2 laser; saturable inductor; resonant overshoot mode.

1. Introduction

Compact transversely excited atmospheric (TEA) CO_2 lasers (Marchetti *et al* 1983) find numerous scientific and technical applications. These include pulsed laser deposition (PLD) (Sankur *et al* 1988), photo-chemistry (Baranov 1983), lidar (Killinger & Menyuk 1981), optical pumping of molecular lasers (Midorikawa *et al* 1985) etc. These lasers can produce high energy and high average output power with high efficiency. Furthermore, these can be operated at high repetition rates.

A fast high voltage and high current switch is required to initiate a volumetric discharge for pumping TEA gas lasers. Conventional exciters employ thyratrons or sparkgaps as discharge switches. However, the aforesaid thyratrons which are expensive have lifetime problems. At the same time, the sparkgaps that often require maintenance have limitations at high repetition rates. The use of all solid-state exciter (ASSE) (Tanaka 1990) offers several advantages over conventional excitation circuits. ASSE employs solid-state switches which are combinations of high power semiconductor switches and magnetic switches. These are less expensive and more reliable, and are able to operate at high repetition rates. These do not have lifetime limitations also. Moreover, there is no warming-up time as in the case of thyratron.

The availability of lasers with long pulse duration and relatively high energy capability enhances the development of new applications. Long pulse allows large number of laser cavity round trips for the oscillating modes. This results in better control of linewidth, divergence and polarization of the laser. A long pulse also means lower laser peak powers and hence longer lifetime for the intra cavity and extra cavity optical components. These long pulse laser systems are required for Doppler radars in atmospheric wind field measurements, laser-assisted CVD, and pulsed laser deposition applications. In conventional schemes, glow discharge is obtained by applying a pulsed voltage much higher than breakdown voltage of the gas medium between the electrodes. The efficiency in this case is low as the field is not optimum for medium excitation. The most effective way is employing double pulse-pulser sustainer concept which was first introduced by Reilly (1972) for producing efficient CO2 laser operation at low pressure. In this approach, the laser excitation is provided from two separate but related circuits. If the applied voltage is below the gas breakdown voltage, obviously no discharge is possible. Nevertheless, it is possible to initiate the discharge with a high voltage low energy pulse by pulser. This rising high voltage pulse is imperative since it increases the electron density from its pre-ionization value to its quasi-steady state value. Once the discharge is excited, the sustainer circuit deposits the stored energy efficiently in to the discharge at an optimum field for best excitation of the laser medium for a longer period. The spiker cannot be connected directly to the sustainer during its active phase since it can quickly dissipate its energy into the large capacitance of the sustainer. This apparent problem is solved by using a saturable magnetic inductor (Fisher *et al* 1986) for isolating the sustainer initially. The absence of any switch in the main discharge loop is an added advantage in this scheme of excitation, since the laser gas mixture holds the sustainer voltage. Here, the laser is operated by switch in the primary part of the pulser which handles much lower voltages, longer pulses and smaller energies. The successful operation of pulser sustainer TEA–CO_2 laser (Taylor & Lepold 1985, 1994; Sylvan *et al* 1991) and excimer laser (Timmeraans *et al* 1993) using ASSE has been reported.

In this paper we report on the generation of long optical pulses (7·15 μs) from a compact and reliable TE–CO_2 laser using pulser sustainer technique. The single shot operation of the laser produces multimode output pulses of one joule energy with overall efficiency of 12·4% at a total pressure of 88 kPa. The sustainer capacitor is charged by pulse-charging power supply. Here, the laser uses Ernst profiled electrodes of dimension $18 \times 32 \times 532$ mm which forms a discharge volume of $15 \times 15 \times 500\,\text{mm}^3$.

2. Construction

The TE–CO_2 laser is depicted schematically in figure 1. It mainly consists of laser head, pulser and pulse charging power supply.

2.1 *Laser head*

The laser head consists of two Ernst-profiled (Ernst 1983) solid brass electrodes of 50 cm effective length. The use of these uniform field electrodes based on the Ernst profile permits

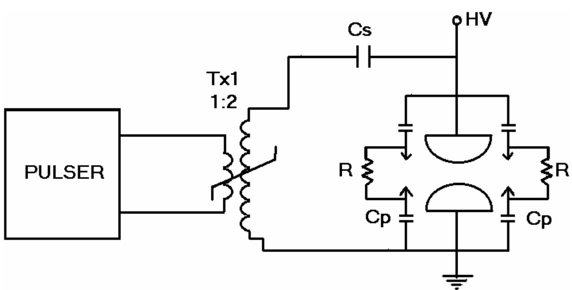

Figure 1. Schematic of pulser sustainer TE–CO_2. In this figure, C_S is sustainer capacitor, C_P represents pre-ionizer capacitor, T is 1:2 pulse transformer, R is charging resistor for PI capacitors.

placement of the pre-ionizer close to the discharge region. The electrodes, separated by 1·5 cm, constitute a discharge volume of 112·5 cm^3. This discharge volume is pre-ionized by sparks produced by capacitively ballasted pin pairs. The use of the spark UV pre-ionization technique has the advantage that it can be automatically integrated as a part of spiker circuit. Each pin is ballasted by a 100 pF capacitor and there are 30 such pin pairs placed on either side of the electrodes along its length. This results in a total peaking capacitance of 1·5 nF across the discharge electrodes. These pins have a gap of 6 mm between their tips and each pin pair has a 50 kΩ resistance across the gap. These resistances allow the pre-ionizer capacitors to charge up when the voltage is applied. In the absence of these resistances, the charging of the capacitors tries to take place by breaking the gap.

The laser head is housed in a vacuum-tight metal chamber. The electrode assembly together with pre-ionizer occupies a space of size 80 × 100 × 550 mm. The resonator for the laser is a 100% reflecting gold mirror of 5 m ROC, while a plane ZnSe output coupler of 80% reflectivity forms a cavity of 100 cm length. The optics are placed directly on the chamber with the help of teflon bellows.

2.2 *Pulser*

The spark gap-driven pulser would be the simplest when the laser is operated in single shot mode. Nevertheless, ASSE followed by 4 stages of MPC has been used in this system, as the aim here is to develop long optical pulsed CO_2 laser at 100 Hz for PLD applications. A schematic of the pulser is shown in figure 2. The pulser circuit used in this system basically consists of a 4-stage magnetic pulse compression (MPC) circuit switched by SCR. A capacitor charging power supply charges the primary capacitance C_0 to a maximum voltage of 1 kV. Upon switching of the SCR (S_1), the capacitor C_1 is charged to 22 kV in 9 μs. by discharging the C_0 through a step-up transformer (1:22 ratio). This pulse is further compressed to 100 ns. by four successive stages of the MPC circuit. The metglas core can be effectively used for microsecond time scale, while ferrite works better on a sub-microsecond time scale. The first two stages of the MPC use metglas 2605 SC and last two stages use Ni–Zn toroids as cores for saturable inductor. The pulse is coupled to the laser head using a 1:2 step-up transformer having six Ni–Zn toroidal ferrites cores. This transformer also serves as saturable inductor and isolates the sustainer capacitor initially from discharging. The efficiency of the MPC stages is 85% and the MPC circuit used as pulser has been described earlier by Nundy *et al* (1994).

2.3 *Pulse charging power supply*

Continuous DC across the electrodes can cause occasional misfiring and arcing in the discharge. In order to obviate this, the pulse-charging mode of sustainer capacitor has been chosen. Certain formative time period is required for breakdown of laser gas medium between the

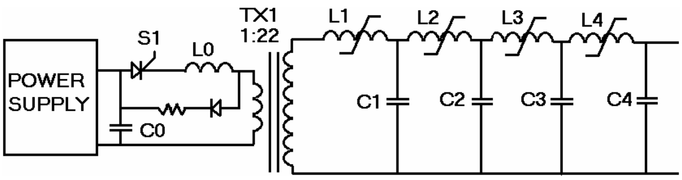

Figure 2. Electrical circuit for pulser, a four-stage magnetic pulse compressor. L_1, L_2, L_3, L_4 are saturable inductors. S_1 is SCR. C1, C2, C3, C4 are capacitors of value 4nF each. $T \times 1$ is a 1:22 step-up transformer.

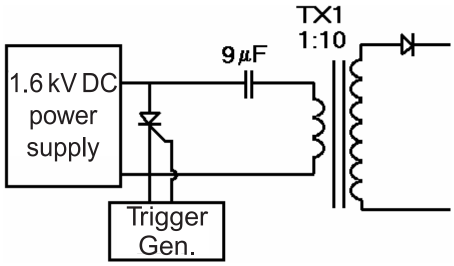

Figure 3. Pulse-charging power supply circuit.

electrodes. Rapid charging permits over voltage on the laser electrodes. This in turn allows greater input energy loading. The pulse-charging power supply circuit is shown in the figure 3. A 9 μF capacitor is charged to 1·6 kV with the help of pulse-charging power supply. Switching the SCR leads to the charging of 80 nF storage capacitor to 16 kV through a step-up ferrite core transformer (1:10 ratio). Sectionalized windings have been used in this transformer for minimizing the leakage inductance. In this, the primary winding has been divided into two equal parts and these have been sandwiched between three equal parts of the secondary winding. This type of winding has been carried out on both limbs separately. Then parts of the primary winding are connected in parallel and those of the secondary are connected in series. This pulse-charging power supply also charges the peaking capacitors C_p. In order to assure the complete charging of these capacitors, the SCR in the pulse-charging power supply is triggered first and after a delay of 13 micro seconds, the SCR in the pulser is triggered.

3. Working and performance of the laser

The principal excitation of the laser is provided by the discharge of the sustainer capacitor through the laser medium. The sustainer capacitor is charged by pulse-charging power supply. The sustainer and peaking capacitors are charged to $+14{\cdot}5$ kV in 13 μs. This voltage is slightly less than the breakdown voltage of the gas between the electrodes. The laser is operated in magnetic overshoot mode in which the pulser voltage is such that the medium does not break down. The spiker polarity is opposite to the polarity of the sustainer voltage. In this configuration, the spiker produces pre-ionization and a voltage pulse to initiate the discharge. Besides, it creates a large voltage across the magnetic switch to drive the magnetic material into the saturation quickly thereby lowering the value of the inductance. The pulser voltage across the secondary of the transformer with no voltage across the sustainer capacitor is shown in figure 4. This voltage is sufficient to cause sparks between the capacitor pins but does not produce any discharge between the electrodes. As soon as the pins are fired, the pre-ionization current flows and charges the peaking capacitors to a high negative voltage. When this voltage reaches a peak, the secondary of the transformer saturates in the other direction. This causes resonant overshooting of the peaking capacitors to a large positive voltage, much higher than the sustainer voltage. Then, these peaking capacitors discharge into a medium, thereby leading to uniform discharge. Once this gas breakdown occurs, the energy stored in the sustainer capacitor also gets dumped into the medium. The discharge voltage is shown in figures 5a and b. Initially, the laser was operated at 1 atmospheric pressure and the pulse-to-pulse output stability was found to be quite considerable. Later on, in order to optimise the laser system, we have carried out the experiments at different pressures and gas mixtures. Here, it was found that an operating pressure of 88 kPa and a gas mixture of 7 kPa CO_2, 11 kPa

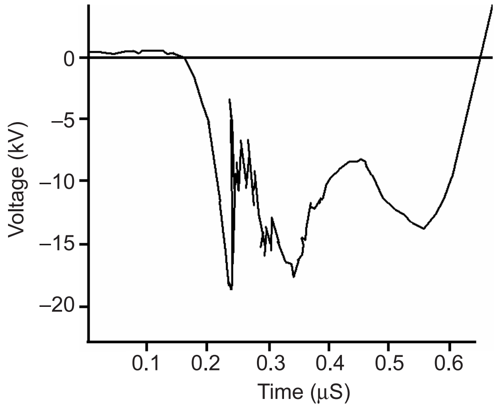

Figure 4. Pulser voltage waveform.

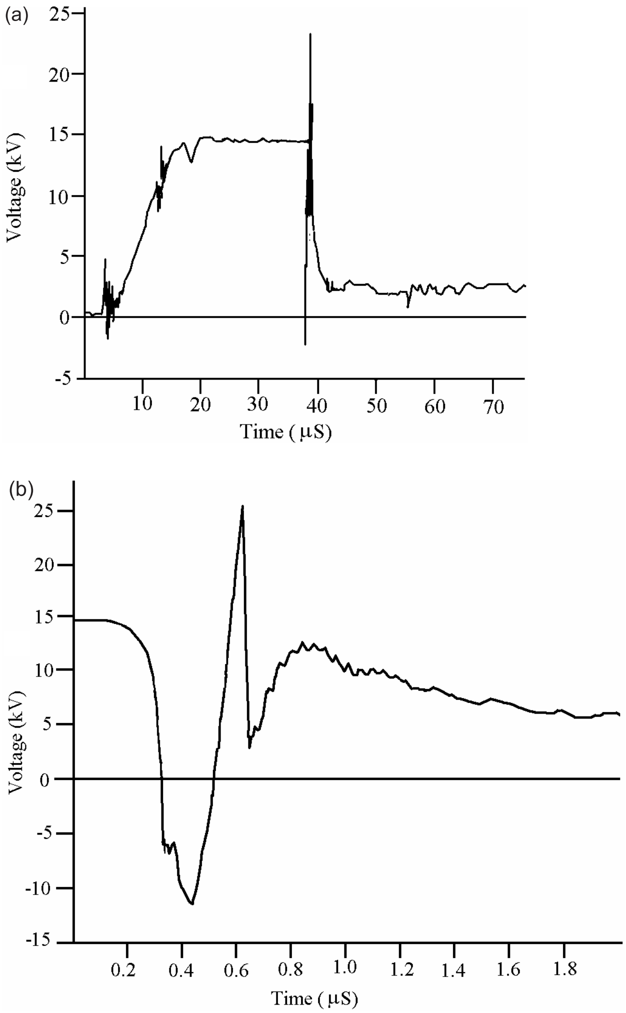

Figure 5. Voltage waveform of the discharge with charging voltage of the sustainer was 14·5 kV. The laser gas constituted a mixture of 70 mbar CO_2, 110 N_2 and the rest is helium at an operating pressure of 880 mbar. Time scale **(a)** 10 μs/division, **(b)** 0·2 μs/division.

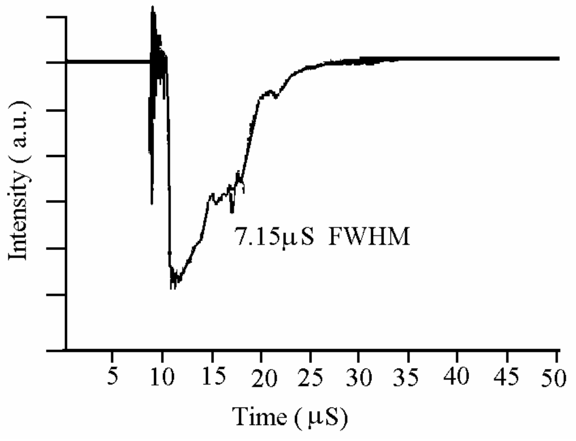

Figure 6. The temporal distribution of laser pulse energy. The FWHM was 7·15 μs.

N_2 and 60 kPa helium lead to the energy of one joule multi mode optical output pulses and pulse-to-pulse output stability better than 5%. This improvement in output energy stability made us operate the laser at this pressure. Under these conditions, single pulse operation of the laser was able to produce 7·15 μs. (FWHM) optical pulses. This typical laser pulse is shown in figure 6. In order to obtain long optical pulses, it is necessary to produce stable glow discharges. For these discharges, uniform electric field and effective pre-ionization are imperative. In this system, fast voltage-rise time leads to effective pre-ionization whereas uniform electric field has been achieved by using Ernst-profiled electrodes. Here controlled power deposition by sustainer circuit results in longer output pulses. The optical pulses are detected by pyro electric detector and temporal profile of the laser is monitored by LN_2 cooled germanium detector. The discharge voltage curve depicted in figure 5a evinces that the sustainer capacitor does not get totally discharged and a residual voltage remains. The input energy pertinent to efficiency calculations includes pre-ionization energy and sustainer energy. Here, the energy left on the sustainer capacitor is subtracted from its initial stored energy. We have tried this procedure with 70% and 80% R output couplers that are available with us and the results with the 80% output coupler are better.

4. Conclusion

In conclusion, a compact spark pre-ionized pulser sustainer TE–CO_2 laser has been developed and long optical pulses of 7·15 μs duration with one joule energy have been obtained. The laser is energized by all solid-state excitation (ASSE). The sustainer capacitor is charged by pulse-charging power supply. The overall efficiency of the laser obtained in this mode of operation is 12·4%. The work pertinent to the development of a 100 Hz long pulse pulser sustainer TE–CO_2 laser is in progress. This laser will be used for pulsed-laser deposition applications.

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