Appl. Phys. B 57, 441–445 (1993)

Applied Physics B Photophysics and Laser Chemistry

A New Mode to Excite a Gas-Discharge XeCl Laser

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Received 19 April 1993/Accepted 2 August 1993

Abstract. The charge mode is a new mode to excite a discharge XeCl laser based on the dynamics of a spiker-sustainer circuit with a magnetic pulse compressor. The breakdown voltage is higher than in any other mode, due to a very fast rise time. The higher breakdown voltage provides a wider discharge and we found that more energy can be deposited before discharge instabilities terminate the optical output.

PACS: 42.55.Gp

The efficiency of high-pressure, self-sustained, gas-discharge excited lasers, like excimers, can be improved by separating the electrical circuit in a high-impedance, high-voltage spiker circuit and a low impedance sustainer circuit which deposits the main part of the stored energy into the discharge [1]. The spiker circuit provides a fast rising voltage pulse to increase the electron density from its preionization value to its quasi steady state value. Once the discharge has been excited, the sustainer circuit can deposit the stored energy efficiently into the discharge because impedance matching is achieved by charging a Pulse Forming Network (PFN) to twice the dc-breakdown voltage of the gas. To separate the two circuits from each other at least one low inductance switch is needed to prevent the spiker energy from flowing into the low impedance sustainer circuit. Use can be made of a rail-gap switch [1] or an array of switches like thyratrons [2]. Very promising is the application of fast saturable inductors enabling high repetition rate operation. Several circuits have been proposed in which low-loss, high-frequency ferrites are applied to operate the spiker-sustainer circuit in a variety of modes [3–5]. Also saturable inductors made of glassy alloys have been used, however, these appear to have higher losses [3].

There is a number of reasons why the rise time of the spiker voltage should be as short as possible. Firstly, besides making an electron avalanche, the spiker circuit must also bring the saturable inductor into saturation when a magnetic switch is used. A short rise time lowers the amount of magnetic core material needed and therefore decreases the loss in the saturable inductor.

Secondly, a short rise time increases the breakdown voltage of the gas and this provides longer stability. Dyer [6] showed for a TEA CO_2 laser, that small perturbations in the electrical field during the avalanche phase cause fluctuations in the electron density which in case of an excimer laser can initiate long term instabilities like the halogen depletion instability [7].

Thirdly, a short rise time prevents preionisation electrons from drifting away from the cathode during the pre-avalanche phase, which can cause a region with insufficient overlap of the avalanche heads that leads to the onset of streamers [8].

Finally, a high breakdown voltage ignites a larger part of the preionized volume as will be shown in this paper. The width of the discharge also depends on the curvature of the electrodes and on the spatial distribution of the preionization electron density.

In this paper we describe the performance of an X-ray preionized XeCl-laser excited by a self-sustained discharge using a spiker-sustainer circuit. The circuit operates either in the resonant overshoot mode [5] or in the charge mode, a new mode based on the dynamics of the charging circuit.

1 Experimental Setup

The experimental configuration is shown in, Fig. 1. The laser chamber is made of PVDF. The anode is a uniform field electrode according to Ernst [9] facing a flat aluminium cathode at a distance of 2.5 cm. A pulsed, collimated X-ray beam enters the discharge chamber through a 2 cm × 60 cm window of 1 mm thickness in the grounded aluminium plate. The X-ray preionization pulse, with a rise time of less than 10 ns and a duration of about 50 ns (FWHM), is produced by an X-ray generator using a corona plasma cathode [10].

Figure 2 shows the electrical circuit. This circuit will be used for a high repetition rate, high power (1 kHz, 1 kW) XeCl laser, which is currently under construction in our laboratory as part of the EU213 Eureka project. A

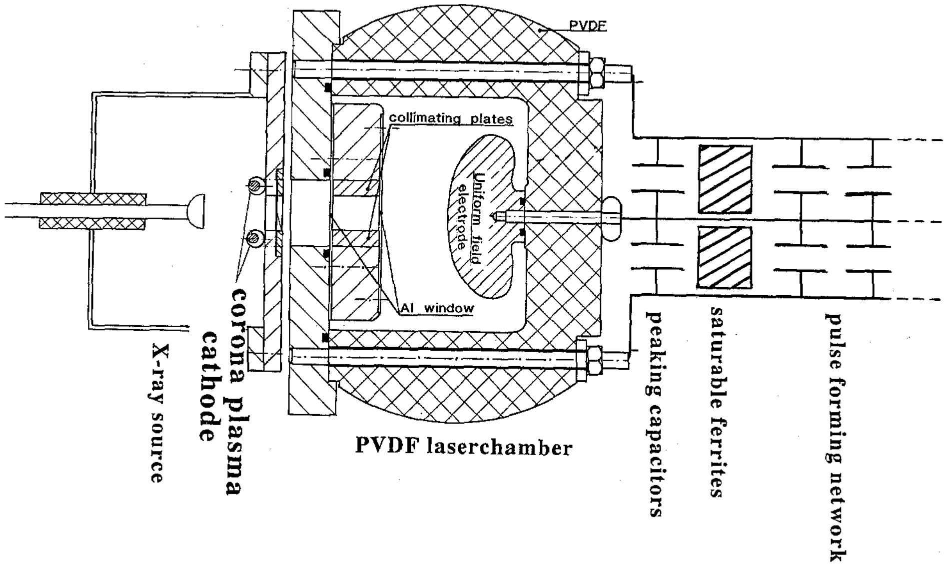


Fig. 1. Experimental setup

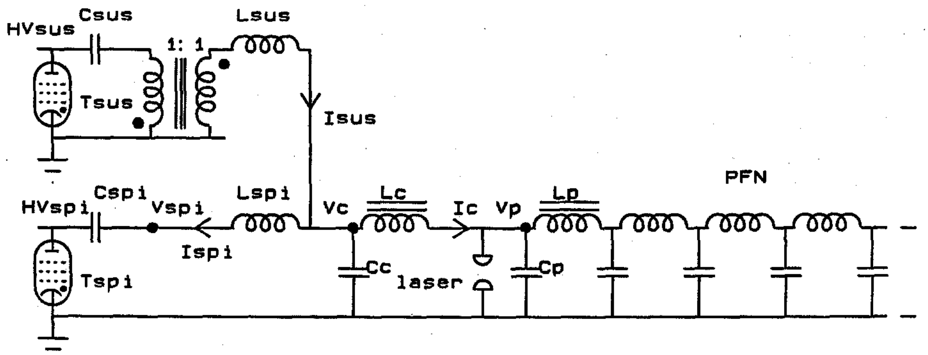


Fig. 2. Electrical circuit

one stage pulse compression network is inserted into the spiker circuit in order to decrease the thyratron stress by allowing a longer rise time for the current through the thyratron. The pulse compressor includes a coaxial saturable inductor employing 6 rings of CMD5005 high frequency ferrite from Ceramic Magnetics. The pulse forming network of the sustainer circuit consists of 8 double plate transmission lines connected in parallel at the laser head. Each line is built from 2 × 10 TDK capacitors of 2.7 nF resulting in a total capacity of 432 nF. This PFN is pulse charged up to 10 kV, which is about twice the dc-breakdown voltage. The spiker circuit is isolated from the low impedance PFN by a saturable inductor L_p. This inductor is made from 8 blocks CMD5005 ferrite of 2.5 cm × 2.4 cm × 40 cm arranged in a rectangular configuration with a 2 mm central slit for the high voltage conductor of the PFN. A total flux swing of 0.53 T has been determined by calculating the Volt-seconds integral at various values of the magnetic area which was varied in steps of 6 cm^2. Optimal performance of the laser was achieved with a cross section of 12 cm^2. Both saturable inductors in the circuit are reset by the charge current to the PFN, so no separate dc reset current supply is needed.

The laser was filled with a mixture of HCl, Xe and Ne at a total pressure of 4 bar. The HCl and Xe partial pressures were kept constant at 1 mbar and 20 mbar, respectively, by circulating the gas through a purifier (Oxford Lasers, Model GP2000) kept at a temperature of 120 K. The optical cavity consisted of a flat 70% reflective output coupler and a flat total reflector at a distance of 110 cm. The output energy was measured with a Molectron energy detector model J50. The width of the beam was determined with a burn pattern on heat sensitive paper.

During preliminary experiments the peaking capacitor, consisting of a number of 0.7 nF TDK capacitors arranged along the length of the discharge, had been varied in order to determine the optimal value. Figure 3 shows the output energy as a function of the spiker voltage for several peaking capacitors. It appeared that values larger than 2.8 nF gave no further increase of the output.

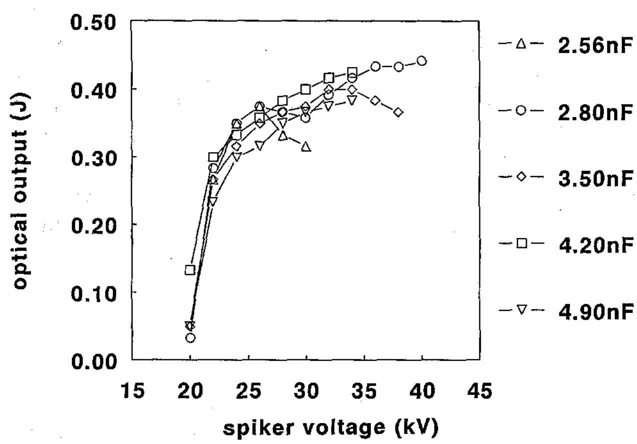


Fig. 3. Output energy at different values of the peaking capacity

2 From Resonant Overshoot Mode to Charge Mode

Two modes of operation were observed when varying the timing of the spiker thyratron together with the X-ray preionization pulse relative to the charging current of the PFN.

2.1 *Resonant Overshoot Mode*

First, when the spiker thyratron is triggered just before the charging current becomes zero, the circuit operates in the resonant overshoot mode [5]. Figure 4 shows typical waveforms of the voltage across the discharge, the discharge current and the optical output power. In this mode the spiker voltage is adjusted such that the discharge does not break down during the negative voltage swing when the peaking capacitor C_p is charged negatively. During this period the saturable inductor L_p is saturated after which the voltage rings up to a high value caused by resonant charging of C_p from the PFN. The rise time of the voltage given by $\pi(C_p L_{psat})^{1/2}$ is about 24 ns, where L_{psat} is the residual inductance with saturated ferrites.

2.2 *Charge Mode*

When adjusting the timing of the spiker and X-ray thyratrons such that triggering occurs at about 600 ns before the PFN-charging current crosses zero, the negative voltage swing disappears and the voltage rises, after a small initial drop, to a high positive voltage within a very short time. Because the prepulse is fired while the PFN is still being charged, we call this new mode the "charge mode". Typical waveforms of the laser operating in the charge mode are shown in Fig. 5. After the breakdown the inductor L_p must still be brought into saturation. This causes a delay between the breakdown of the gas and the main current through the laser, but apparently this has little effect on the output. More important are the rise time and the peak value of the voltage at breakdown. To understand how the breakdown voltage is reached, the voltages and currents have been measured at several points in the electrical circuit. The voltages V_{spi}, V_c, V_p (see Fig. 2) and the currents I_{sus}, I_{spi} and I_c are shown in Fig. 6.

When the spiker thyratron switches, the voltage V_{spi} immediately drops and a current I_{spi} starts to flow, which is built up of three branches after L_{spi}. No current can flow

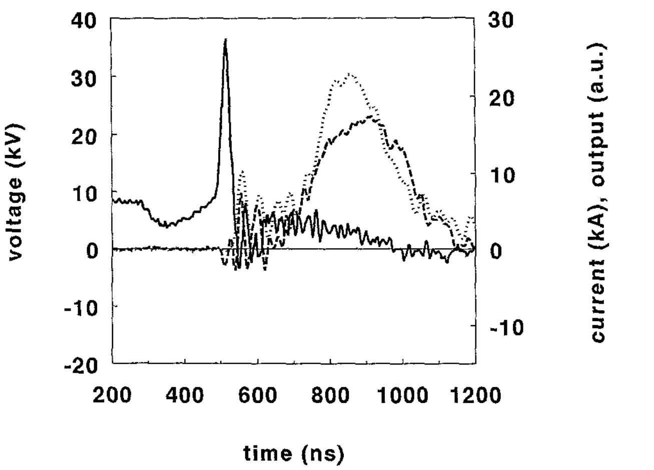
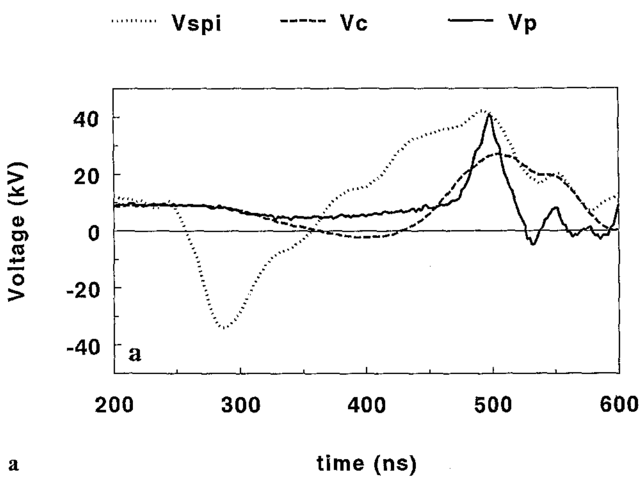


Fig. 5. Waveforms of the discharge voltage (*solid*), current (*dashed*) and optical output (*dotted*) in the charge mode



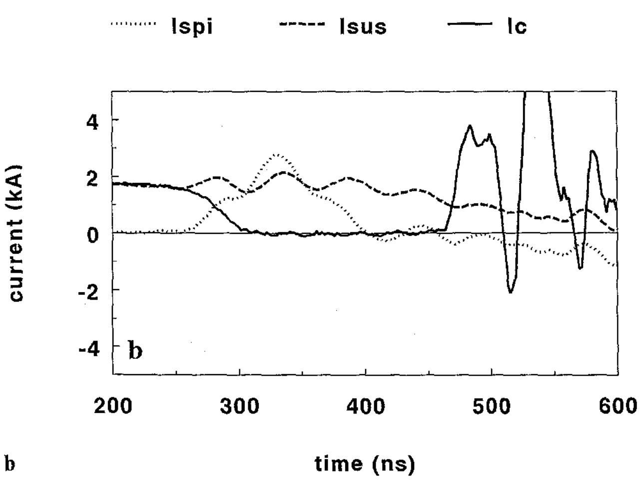


Fig. 6a, b. Voltages (**a**) and currents (**b**) at several positions in the electrical circuit in the charge mode

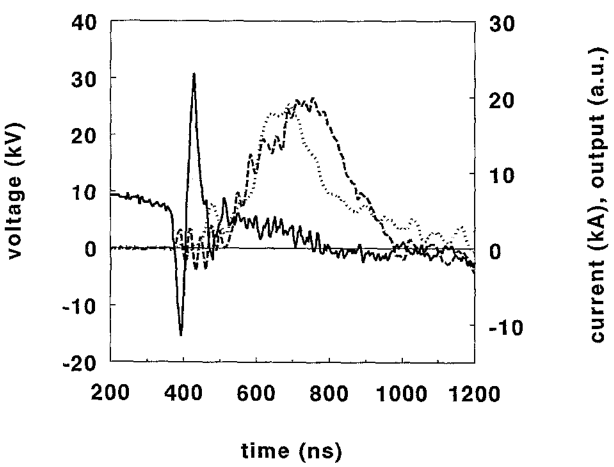


Fig. 4. Waveforms of the discharge voltage (*solid*), current (*dashed*) and optical output (*dotted*) in the resonant overshoot mode

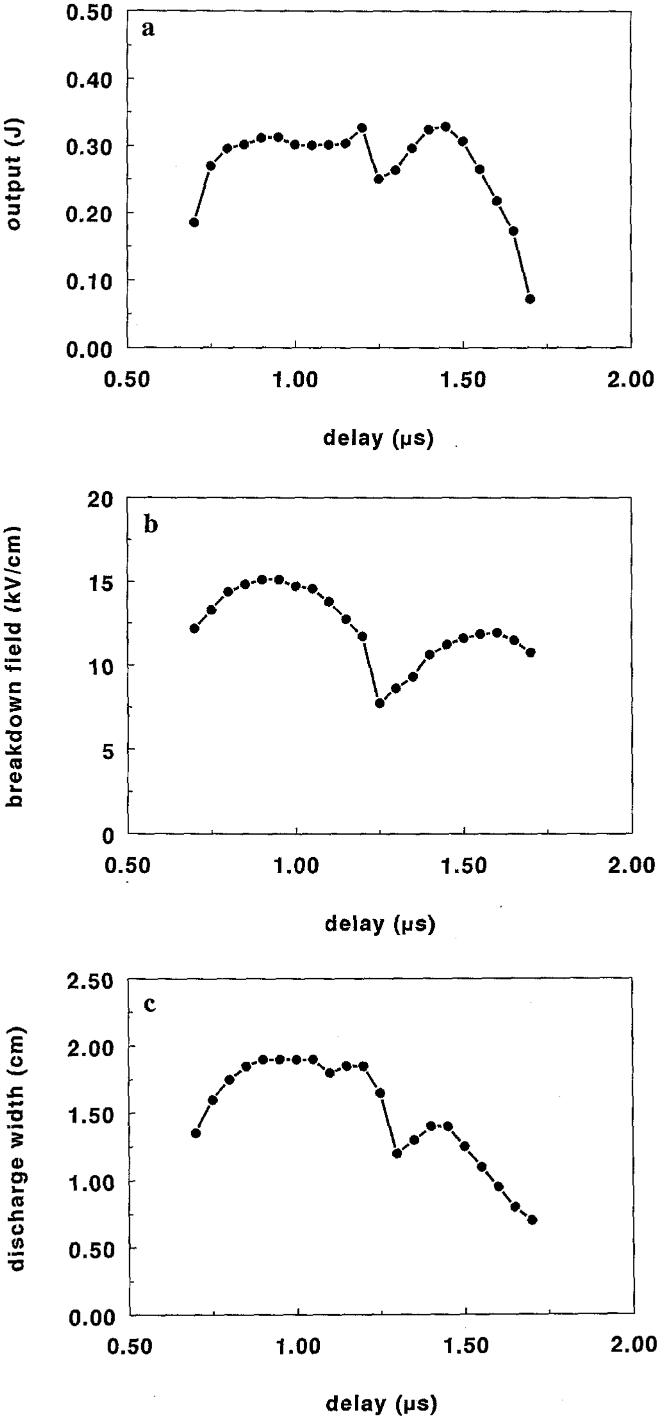


Fig. 7a–c. Optical output (**a**), breakdown field (**b**) and discharge width (**c**) as a function of the delay between the spiker and the sustainer thyratrons

through L_c because the ferrites are saturated in the other direction by the charge current to the PFN. The current I_{sus} which was originally the charge current to the PFN continues to flow since L_{sus} is a relatively large inductor. This current is now directed towards C_{spi}. There is also a current flowing from C_c to C_{spi} causing the voltage V_c to drop as shown in Fig. 6. Because C_{sus} is much larger than C_c and C_{spi}, these last capacitors are resonantly charged to high positive voltages. When V_c reaches its maximum, the inductor L_c

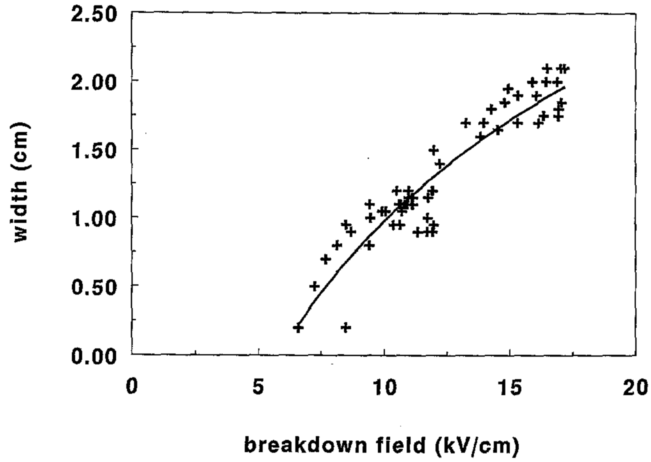


Fig. 8. Discharge width as a function of the breakdown field

saturates again and the peaking capacitor C_p is charged in 23 ns to a high positive voltage followed by the breakdown of the laser gas.

2.3 Laser Performance

To study the performance of the laser in the two modes, we monitored the laser output energy, the breakdown voltage and the beam width as a function of the timing of the spiker thyratron and X-ray preionization pulse relative to the charging current of the PFN. During the scan all other parameters were kept constant. The results are shown in Fig. 7. The delay between the start of charging the PFN and the trigger of the prepulse thyratron is plotted along the horizontal axis. The PFN is completely charged in 1.6 μs. At the left peak the laser is operated in the charge mode and the right peak corresponds to the resonant overshoot mode. In the two modes the same output energy was generated as shown in Fig. 7a, indicating that the discharge quality was good enough in both cases to transform the equal amount of electrical energy into optical output. However, as can be seen from Fig. 7b and c, the breakdown voltage and the beam width were considerably larger in the charge mode than in the resonant overshoot mode. The correlation between the breakdown voltage and the discharge width is shown in Fig. 8. Due to the high breakdown voltage in the charge mode the width of the discharge reached a maximum determined by the X-ray window (2 cm). In a wider discharge with the same total current the current density, and therefore also the electron density, is lower. It is expected that more energy can be deposited in the wider discharge of the charge mode because the discharge stability and the quenching of the upper laser level depend strongly on the electron density.

3 Conclusions

We demonstrated that a discharge excited XeCl laser using a spiker-sustainer circuit can operate in a new mode by triggering the spiker and preionization pulse before the charging of the main pulse forming network has been completed. The one stage pulse compressor in the spiker circuit, which intentionally was added to lower the thyratron electrical stress, plays an important role. Using the same charging voltages and the same capacitances the breakdown voltage can be increased resulting in a 30% increment of the discharge width, compared to the width achieved by operation in the resonant overshoot mode. Maximum efficiency was observed at high values of the breakdown field (> 12 kV/cm) obtained in the charge mode. It is expected that a larger energy deposition with the same efficiency is possible by operating the laser in the charge mode. Furthermore, the use of a pulse compressor in the spiker circuit and a magnetic switch make this circuit a suitable candidate for applications in the next generation of high repetition rate, high power excimer laser systems.

Acknowledgements. This work by the Netherlands Center for Laser Research is part of the EU213 Eureka project for the development of a 1 kHz, 1 kW XeCl laser system.

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