A 10 cm APERTURE, HIGH QUALITY TEA CO_2 LASER

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Received 20 September 1982

Experiments have been performed on a corona preionization type 10 cm aperture TEA CO_2 laser. For a $CO_2:N_2:He$ = 1 : 1 : 7 mixture an output energy of 34 joule per liter and for a 1 : 1 : 10 mixture 40 joule per liter could be obtained. The overall efficiency is about 18%. The time behaviour of the current and voltage of the system shows a delay of several hundreds of nanoseconds after the preionization peak, which indicates a relatively low initial electron-density level. Never-the less, it proved to be high enough to obtain a very homogeneous discharge and reproducible output energy.

1. Introduction

Because there is a need for high-energy CO_2 laser pulses for different kinds of applications, such as plasma heating, and because the output energy per unit volume is limited as a consequence of gas heating and photoionization of the laser medium, large-aperture systems have to be developed. To meet that goal electron-beam preionized systems are most commonly used. Those systems are very complicated, but have the advantage of operation below the break-down voltage where a stable discharge is possible. In comparison self-sustained discharges are much easier to build, but are inherently unstable. That is why it is difficult to build large-aperture self-sustained discharges. Several excitation schemes have been tried out to overcome this difficulty. The most successful ones were those employing initial preionization produced by UV radiation from an array of spark gaps behind a mesh electrode [1].

In this paper we will report on a 10 cm aperture, self-sustained discharge with a corona-type preionization [2,3], which has the advantage of a very simple construction and which produces a high preionization level.

2. Construction details

In fig. 1 the laser construction is shown. It consists of two electrodes profiled according to the Chang publication [4]. For our 10 cm system a k-value of 0.015 and a v-value of arccos $(-k)$ is used. This should give an almost square discharge for the normally used mixtures and discharge voltages. For out-coupling a plane-parallel uncoated germanium flat is used. The high-reflecting aluminium mirror has a radius of curvature of 7 meter. The length of the discharge is 60 cm. Fig. 2 shows a cross-section of the laser system. At the upper and lower side a glass-plate is glued and the right profile is extended by a copper plate, which is bent against the glass-plates. When the Marx generator is fired, a high field-strength between the left electrode and the copper plate ap-

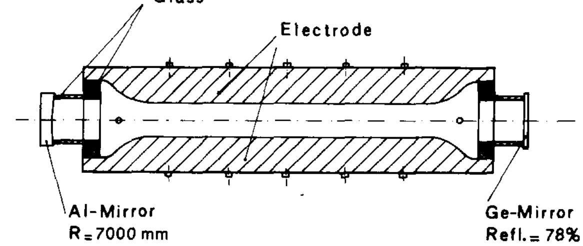

Fig. 1. Cross-section of the electrode construction.

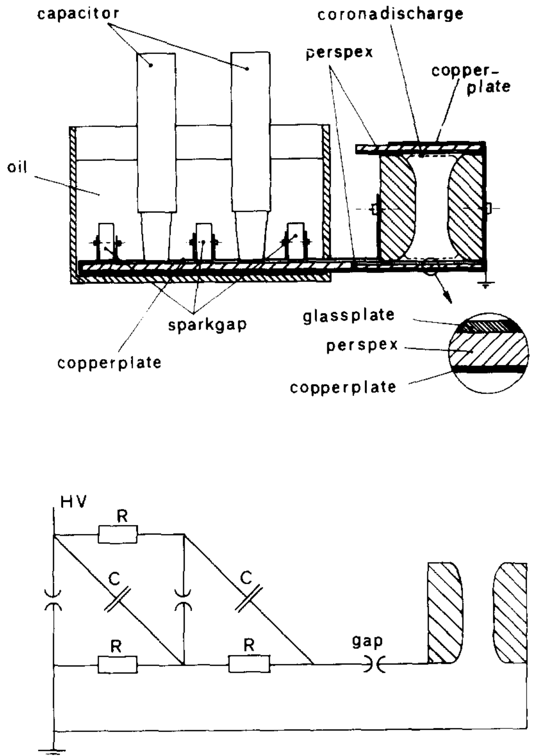

Fig. 2. a. Scheme of the construction of the system and details of the side-wall construction of the laser. b. Electrical scheme of the laser system.

pears. This causes a corona-type discharge to flow alongside the glass-plates. In this discharge the UV light is produced, which provides for the needed pre-ionization. The thickness of the glass-plates depends very much on the width of the electrodes. The smaller the width of the electrodes, the thicker the glass-plates have to be. If the glass-plates are too thin, the corona discharge degrades into a spark alongside the glass-plates; if they are too thick, the UV production is insufficient and the laser will spark between the electrodes. For our 10 cm laser two different widths have been used: 364 mm and 346 mm. The larger width has an optimum value for the thickness of the glass-plates of 13 mm; the smaller width had an optimum value of 23 mm.

Since the amount of UV produced in a surface discharge depends on the rise-time of the current, a Marx generator has been constructed width low self-inductance. The electrical scheme is shown in fig. 2b, It has two stages and an additional gap, which provides for insulation of the laser head from the Marx generator when only the first stage is working. When the discharge sparks, the oscillation frequency of the current through the laser can be used to roughly estimate the self-inductance of the system. It appeared to be about 200 nH.

3. Experimental results

Fig. 3 shows the output energy of the system with the larger electrode width of 364 mm for a $CO_2 : N_2 : He = 1 : 1 : 10$ mixture as a function of the capacity of the Marx generator. The maximum output energy we measured was 148 J (accuracy 10%), for a Marx-generator voltage per stage of 50 kV. For a voltage of 45 kV the maximum output energy was 135 J. The capacitance per stage of the Marx generatoı for that case was 360 nF. We also measured the output beam diameter by moving a 2 mm slit over the

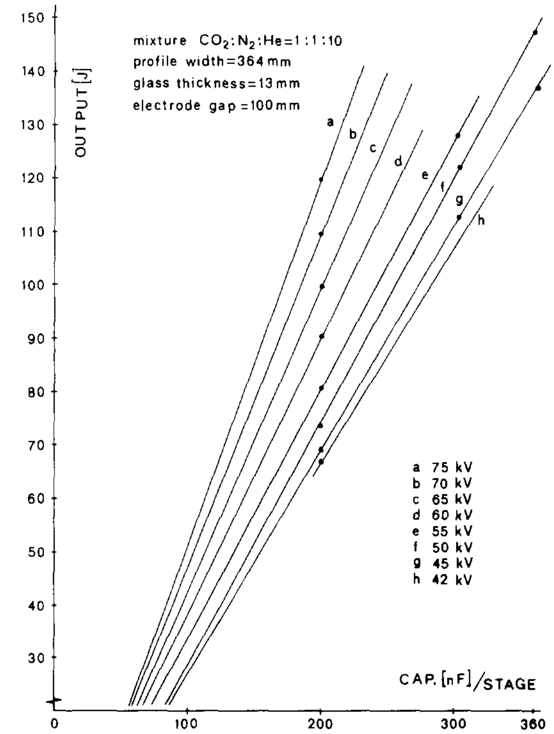

Fig. 3. Output energy as a function of the capacity per stage of the Marx generator for a $CO_2 : N_2 : He = 1 : 1 : 10$ mixture. The voltage per stage of the Marx generator has been used as a parameter.

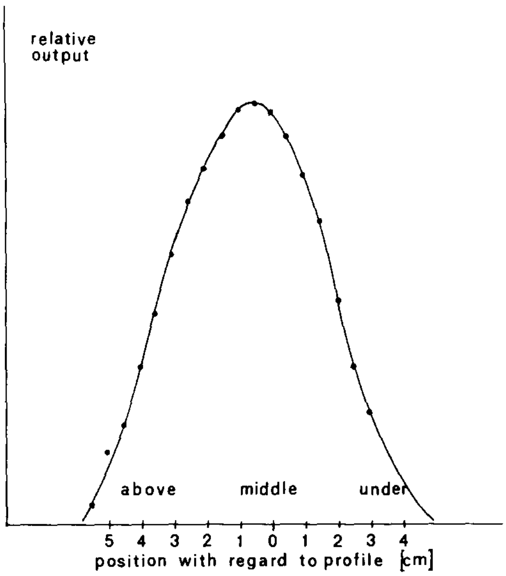

Fig. 4. Output energy density as a function of position between the electrodes for a 1 : 1 : 10 mixture, a capacity per stage of 360 nF and Marx generator voltage of 45 kV per stage.

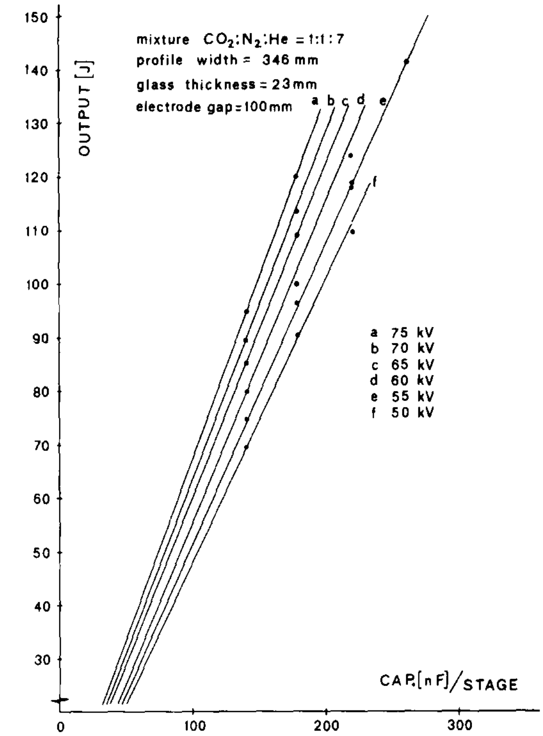

Fig. 5. Output energy as a function of the capacity per stage of the Max generator for a $CO_2 : N_2 : He = 1 : 1 : 7$ mixture. The voltage per stage of the Marx generator has been used as a parameter.

beam. Fig. 4 shows a plot of the output energy as a function of the position of the slit. The width of the output beam appears to be 55 mm, which means an active volume of $5.5 \times 60 \times 10\ cm^3 = 3.3$ liter. This results in an output energy per unit volume of 40 J per liter. For the efficiency it follows: 135 J output divided by 729 J input energy makes 18.5%. The output-energy measurements have been performed with a Scientech model 38-0402 laser power meter. The response of this meter has been calibrated with a Gen Tec model ED-500 joulemeter (accuracy 10%) and a laser pulse from a 2 cm CO_2 laser system.

We also performed measurements with the system with the smaller electrode width of 346 mm. Although the optimum thickness of the glass-plates is now 23 instead of 13 mm, the output characteristics are essentially the same, so that it can be concluded that the electrode width is not a critical parameter provided that the thickness of the glass-plates has been adapted. Output-energy measurements on a $CO_2 : N_2 : He = 1 : 1 : 7$ mixture were carried out as well (see fig. 5). The maximum output energy we obtained was 142 J at a Marx generator voltage of 55 kV. Also for this case we measured the width of the output beam (see fig. 6). It appeares to be 70 mm, which means an ac-

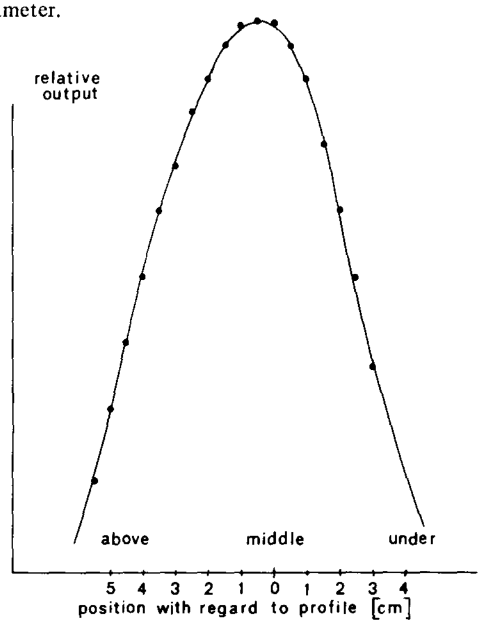

Fig. 6. Output energy density as a function of position between the electrodes for a 1 : 1 : 7 mixture, a capacity per stage of 260 nF and Marx generator voltage of 55 kV.

tive volume of 4.2 liter; this results in an output energy per unit volume of 34 J/liter. The efficiency in this case is 142 J output divided by 786 J input energy makes 18%. From the discharge-width measurements it can be seen that it is much smaller than the electrode gap. Comparison with the results of our 2 and 5 cm systems, having both a k-value of 0.02, it must be concluded that the k-value of the electrodes, which is a measure for the width of their flat part, is not directly scalable; this means that for increasing electrode gap the flat part of the electrodes must increase more than proportionally.

An important check on the proper working of the system is the time behaviour of its voltage and current. Compared to the 2 cm and 5 cm system our 10 cm system had a different time behaviour. Fig. 7a shows the current as a function of time of our 5 cm system. The first peak is due to the peaking capacitor and it represents the corona discharge. Immediately

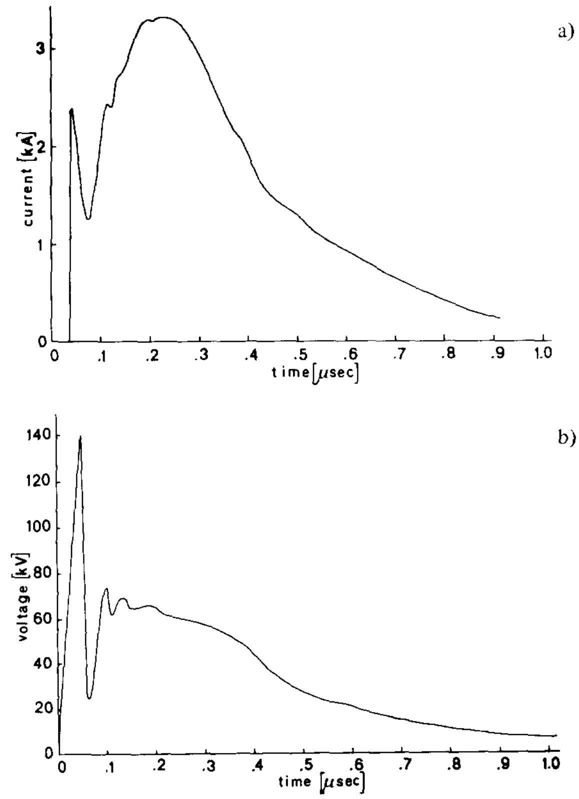

Fig. 7. Current (a) and voltage (b) as a function of time of a 5 cm CO_2 system for a Marx generator voltage of 97.5 kV and a 1 : 1 : 3 mixture. For details see [5].

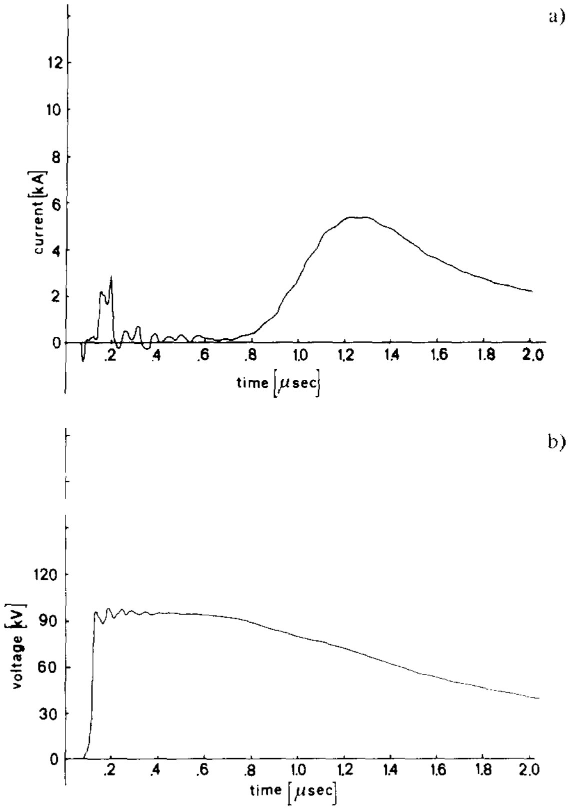

Fig. 8. Current (a) and voltage (b) as a function of time for the 10 cm CO_2 system for a total Marx generator voltage of 95 kV and a 1 : 1 : 10 mixture.

thereafter the main discharge starts. Fig. 7b shows the voltage as a function of time. The total Marx generator voltage was somewhat less than 100 kV. A voltage overshoot, caused by the peaking capacitor, can clearly be seen, and after some oscillations the voltage drops to the so-called "stabilization voltage", where the electron ionization rate balances the electron attachment rate. These figures can be compared with the ones from our 10 cm laser. Fig. 8a shows the current as a function of time for a $CO_2 : N_2 : He = 1 : 1 : 10$ mixture. The first peak must be attributed to the corona discharge, where the UV production takes place. It starts immediately after the voltage appears at the electrodes. However, it takes a long time before the main discharge sets to work. The voltage as a function of time, shown in fig. 8b, has a corresponding behaviour. There is only a small overshoot and after that, the current being zero, the Marx generator voltage persists. However, the voltage does not drop down to the "stabilization value" as soon as the main discharge current appears; instead, the voltage gradually decreases from the Marx generator voltage down to zero or some low value. To check if this behaviour is due to the insufficient preionization we tripled the value of the peaking capacity. However, only a small improvement of the delay between corona and main discharge could be seen.

4. Conclusions

A 10 cm aperture TEA CO_2 laser has been constructed with the following features: a high power output, i.e. 34 J per liter for a 1 : 1 : 7 and 40 J per liter for a 1 : 1 : 10 mixture; a simple construction and simple electrical circuit, as no separate UV source is present; a low self-inductance of the circuit, resulting in a high small-signal gain; a high overall efficiency of the order of 18%; a very homogeneous discharge, resulting in a homogeneous output energy distribution and good shot-to-shot reproducibility.

From current and voltage measurements we have the impression that improvement of the system must be possible. Probably a detailed study of the corona discharge is necessary.

References

[1] M.C. Richardson, K. Leopold and A.J. Alcock, IEEE J. Quant. Electron. QE-9 (1973) 934.
[2] G.J. Ernst and A.G. Boer, Optics Comm. 27 (1973) 105.
[3] G.J. Ernst and A.G. Boer, Optics Comm. 34 (1980) 221.
[4] T.Y. Chang, Rev. Scient. Instr. 44 (1973) 405.
[5] G.J. Ernst and A.G. Boer, Optics Comm. 35 (1908) 249.