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Output Characteristics of a Corona-Preionized XeCl Laser

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Abstract—The output characteristics of a corona-preionized XeCl laser are described. Measurements in an He-based mixture up to 5 bars and in an Ne-based mixture up to 10 bars are presented. The maximum obtained output energy per unit volume is more than 9 J/l.

INTRODUCTION

A SELF-sustained avalanche discharge is the easiest way to excite a rare-gas halide laser system. Successful operation of such a system depends mainly on the density of the electrons formed by preionization [1] and on the rapidity with which the stored energy can be dissipated in the laser gas [2]. The latter requires as large a rising speed of current through the laser as possible. Up until now, the best performance has been obtained by constructing systems with a low circuit inductance and by the use of a waterline in series with a multispark gap, which is pulse-loaded by an additional supply like a Marx generator. If no multispark gap is used, the voltage applied to the electrodes has a small rising speed determined by the loading time of the waterline, which means that the electron density in the laser mixture, originating from a preionization source, is only slowly multiplied by avalanche. An additional multispark gap will hold the voltage until a certain predetermined level is reached, so that after breakdown, a fast voltage pulse appears between the electrodes, resulting in a small current rise time and a high output power. The use of a multispark gap has the serious disadvantages that it dissipates energy and contributes significantly to the total self-inductance of the system. In this paper a construction is described, based on the corona-preionization technique [3], [4]. In this technique the voltage is present on the electrodes and the preionization density, which is produced by the corona discharge, switches on the laser current. So the advantage of the multispark gap, viz., a small current rise time, is preserved without contributing to the circuit self-inductance. Because proper working of the corona discharge relies on a high voltage rising speed, the driving circuit for the waterline has to be as fast as possible.

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DESCRIPTION OF THE SYSTEM

The construction we used is schematically shown in Fig. 1. The waterline has a double structure with a plate separation of 15 mm, a length of 1 m, and a width of 75 cm. The total capacitance of the waterline is 70 nF. It is loaded by a low-inductance capacitor of 142 nF through a conventional spark gap. The high-voltage side of the waterline is attached to one of the aluminium electrodes by means of a solid feedthrough through the pressure vessel. The electrode gap is 15 mm and the discharge length is 40 cm. The central part of the electrodes has a Chang profile with $k = 0.02$ and $v = \arccos(-k)$. It proved to be impossible to obtain a good discharge in an XeCl mixture with an electrode construction as used in [3] for a CO₂ mixture. The main discharge took place on both sides of the electrodes instead of between the central parts. That is why we modified the electrode construction. As can be seen in the figure, both sides have been broadened and provided with a Pyrex glass plate, having a thickness of 4.2 mm. The high-voltage electrode is elongated at the inner side and the earth electrode is elongated at the outer side of the glass plate with brass plates, as is also shown in the figure. The earth electrode is connected with two springs to the vessel. This construction leads to a calculated laser-head self-inductance of about 4 nH, so that very high current rising speeds can be expected.

When the spark gap closes, the waterline will be loaded until it reaches the breakdown value of the corona surface discharge alongside the glass plates. In this corona discharge, ultraviolet light will be produced, which provides for the necessary preionization between or at the electrodes. The preionization density is multiplied by avalanche so that, within a short time, the main discharge will take over the current from the corona discharge. The preionization construction thus not only provides for the necessary preionization, but also acts as a multispark switch. However, it is not in series but parallel to the main discharge and does not contribute to the total circuit self-inductance. The breakdown voltage of the construction was on the order of 15 kV and depends somewhat on the total gas pressure in the vessel.

THE OUTPUT CHARACTERISTICS AND DISCUSSION

We performed measurements on He- and Ne-based mixtures; the first one up to 5 and the second one up to 10 bars. It appeared to be impossible to obtain good output

Fig. 1. A scheme of the XeCl laser system. The corona preionization discharge along the glass plates also acts as a multispark gap. However, it is in parallel with the main discharge.

measurement in an He-based mixture for pressures higher than 5 bars. This probably is due to instabilities in the discharge, so that arcing occurs in an early stage of the discharge. In Ne-based mixtures, no problems of that kind are found up to 10 bars of pressure. We could not try higher pressures because our filling system could not handle it. The output energy characteristics are plotted in Figs. 2 and 3. On the horizontal axis, the load voltage on the primary capacitor and on the vertical axis, the output energy per pulse, measured with a GenTec ED500, is plotted. The total pressure has been used as a parameter. In all measurements, 14 mbar Xe has been used and 6 or 7 mbar HCl. Because our vessel was not fully HCl-compatible, the HCl pressure decreases in time. By following the output energy of the laser in time, the HCl pressure could be optimized. The Xe pressure is the optimized value for a total pressure of 3 bars. We did not try to optimize the Xe pressure for higher total pressures, because the output power is only slightly dependent on the Xe pressure. Probably at higher total pressures, a somewhat higher output energy can be obtained for higher Xe pressures. For all measurements, a flat high reflecting dielectric mirror is used and a flat 70 percent reflecting dielectric mirror for outcoupling, except for the 10 bar measurements, where a 20 percent reflecting mirror has been used. From the measurements we got the impression that the amount of reflection is not very important for an Ne-based mixture with a slightly higher output energy (between 5 and 10 percent) for the lower reflectivity, indicating that absorption losses are low in that mixture. The shot-to-shot reproducibility is very good and remains within a few percent. However, for different fillings, pulse output energy changes on the order of 25 percent are found. That may have to do with degradation of optics, building up of impurities, or degradation of the surface of the preionization glass plates.

Fig. 2. The output energy per pulse as a function of the load voltage of the power supply. 14 mbar of Xe has been used and about 4 mbar of HCl. The He pressure is used as a parameter.

Fig. 3. The output energy per pulse as a function of the load voltage of the power supply. 14 mbar of Xe has been used. The HCl pressure is optimized. The Ne pressure is used as a parameter.

In order to be able to calculate the energy production per unit volume, the beam width has been measured for our measurements in an 8 bar Ne-based mixture by means of a 1 mm wide slit. An FWHM value of 14 mm has been found. If the reasonable assumption is made that the discharge width equals the width of the output beam, the discharge volume of $1.5 \times 1.4 \times 40 \text{ cm}^3 = 84 \text{ cm}^3$ produces an output energy of 650 mJ/pulse at 8 bars, which means a production of 7.7 J/l. The 10 bar mixture produced a maximum energy of 780 mJ/pulse. Assuming that it is produced in the same discharge volume, the specific energy production is over 9 J/l.

The output energy of both He- and Ne-based mixtures

Fig. 4. A plot of the peak current and breakdown voltage of the laser as a function of the load voltage of the primary capacitor for an 8 bar neon-based mixture.

tends to saturate as a function of the primary capacitor voltage. The reason for that is the fact that the voltage on the laser is determined mainly by the breakdown voltage of the corona discharge, and is only slightly dependent on the voltage of the primary capacitor. This is shown in Fig. 4, where a plot of the breakdown voltage is given as a function of the primary capacitor voltage for an 8 bar neon-based mixture. That the corresponding peak current increases as a function of the primary capacitor voltage can be explained by the rapid loading of the waterline, so that during the discharge, extra energy is transferred from the primary capacitor to the waterline. Such a rapid loading is necessary for obtaining a good preionization density. The observation that, at higher pressure, the quasi-steady-state voltage increases somewhat, means that the energy transfer rate from the electrons to the Ne at the higher concentration increases. Consequently, this leads to an increased energy transfer rate from Ne to Xe and finally to a higher output. Also, the breakdown voltage of the corona discharge increases with increasing pressure, which indicates that the breakdown voltage of the corona discharge and the steady-state voltage of the main discharge are interrelated.

In Fig. 5, the laser efficiency is plotted as a function of the load voltage of the primary capacitor. The highest efficiency was obtained for a pressure of 10 bars of neon. For 17 kV load voltage, it appeared to be over 2.5 percent. The efficiency values are the overall efficiency and related to the total energy in the primary capacitor. For a 3 bar neon-based mixture and a charge voltage of 30 kV, the discharge and output behavior as a function of time is plotted in Fig. 6. The solid line denotes the voltage in units of 4 kV/div, the dashed one denotes the current in units of 5 kA/div, and the dotted one denotes the output behav-

Fig. 5. The overall efficiency of the laser as a function of the load voltage of the primary capacitor in neon-based mixture. The total gas pressure has been used as a parameter.

Fig. 6. The time behavior of the voltage (solid line), current (dashed line), and output (dotted line) of the laser for a 3 bar neon-based mixture. The time scale is 50 ns/div.

ior in arbitrary units. The time scale is 50 ns/div. The voltage has been measured by a resistive divider. The breakdown voltage is about 16 kV in this case. Note that the voltage rise time is on the order of 75 ns, necessary for good operation of the corona discharge. Because this loading time has the same order of magnitude as the width of the current pulse, interference between the main capacitor and the waterline is present. No correction has been made for $L di/dt$ effects. The current has been measured by measuring the voltage over a one-turn self-inductance $1 \times 1 \text{ cm}^2$ in cross section and 40 cm long, attached directly to the ground electrode. This signal has been integrated by an integrator with a time constant of 1.6 μs .

It should be noted that the current rise time is slower than would be expected from the inductance of the laser

head. This increase is due to the finite avalanche time, which in our case is substantial compared to the inductive rise time. This is due to the relatively low breakdown voltage of the laser system. This effect has already been described earlier. See, for instance, [5]. The output pulse has been measured by an EG&G photodiode type FND 100/Q.

CONCLUSION

The corona preionization technique seems to be a good way to condition a self-sustained excimer laser. High output power and good efficiency can be obtained in this way. The discharge of neon-based mixtures is stable for pressures up to at least 10 bars and the output energy scales with pressure, so it can be expected that for higher pressures, higher output powers can be achieved.

Looking at the time behavior of the output and current

pulse, it can be expected that a longer waterline will produce more output energy.

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