Appl. Phys. B 48, 55–58 (1989)

Applied Physics B Photophysics and Laser Chemistry

Large Area X-Ray Preionizer for Electric Discharge Lasers

T. Letardi, P. Di Lazzaro, G. Giordano, and C. E. Zheng*

ENEA, Dip. TIB, U.S. Fisica Applicata, Centro Ricerche Energia Frascati, C.P. 65 I-00044 Frascati, Rome, Italy

Received 19 July 1988/Accepted 2 August 1988

Abstract. A pulsed X-ray source with a pulse duration of 250 ns (FWHM) which uses plasma cathodes to supply sufficient electrons for emission is described. It is simple to construct and requires low energy input. Less than 14 J of energy can produce up to 10^7 electron-ion pairs/cm^3 in a 10 l volume of neon at 1 atm.

PACS: 52.80 Vp, 52.25 Ps

Stable homogeneous pumping discharge requirements in excimer lasers have been extensively studied, either in connection with the preionization electron density number or as a function of the applied electric field characteristics [1–3].

The initial electron density is currently produced by UV light sources (derived from RGH lasers [3], corona discharge [4] or spark arrays [5]) or by X-ray sources [1, 6, 7]. The latter solution is more suitable for large volume high pressure and/or high repetition rate excimer lasers because of the well-known advantages (greater mass generation depth, better preionization homogeneity, flexibility of the system and small gas contamination) of X-rays compared to UV light [7].

Among the various schemes used to generate X-rays for laser preionization, relatively little attention has been devoted to the *reflection-geometry* diode with a surface plasma cathode [8, 9]. In such a system, cathode-emitted electrons impinge on the anode, producing bremsstrahlung radiation toward the active medium along directions very different from those of the incident electrons [8]. The system core is the surface plasma cathode [9], where the field-emitted electrons desorb neutral gas atoms from the cathode surface itself. This evolved gas is rapidly ionized, forming a plasma that expands away from the cathode.

Based on the experience gained from an X-ray preionized self-sustained discharge 1 l XeCl laser successfully operated in our laboratory [8], a simple and inexpensive X-ray preionizer with plasma cathodes has been constructed for preionization of a $10 \times 10 \times 100\,\mathrm{cm}^3$ active volume XeCl discharge laser. In this paper we present the characterization of this preionizer. The preliminary laser experiment shows that the design of the system is successful. Over 10 J of laser energy has been extracted using this pulsed X-ray source for preionization of a 10 l active volume XeCl discharge.

1. Apparatus

Figure 1 shows the vertical section of the X-ray preionizer system. The X-ray source is located in a vacuum chamber ($p < 10^{-5}$ Torr) and consists of two plasma cathodes, each one providing an electron emission with good uniformity over the 100 cm length. Figure 2 shows the mechanical design of the plasma cathode. It is a laminate consisting of an insulator plate, a copper sheet with an electric connection to the trigger voltage (20 kV–30 kV), and a sheet of grounded cladding copper on which there is a matrix of isolated discs. Each disc is separated from the grounded cladding copper sheet by an annular gap where the copper material has been etched off.

* ENEA Guest on leave from the Shanghai Institute of Optics and Fine Mechanics, the Chinese Academy of Sciences, China

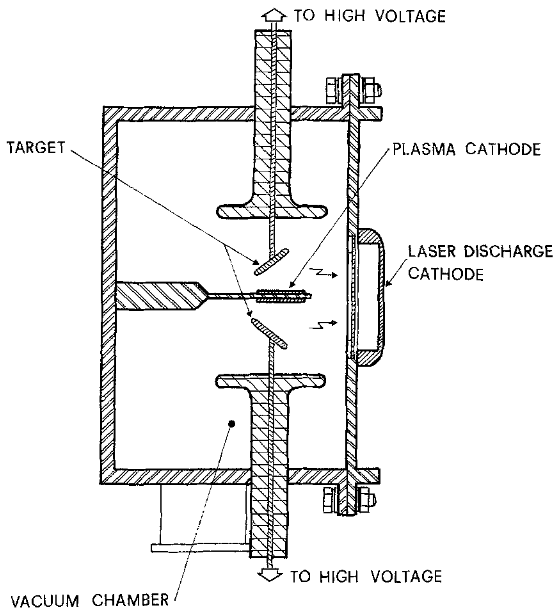

Fig. 1. Vertical section of the X-ray preionizer

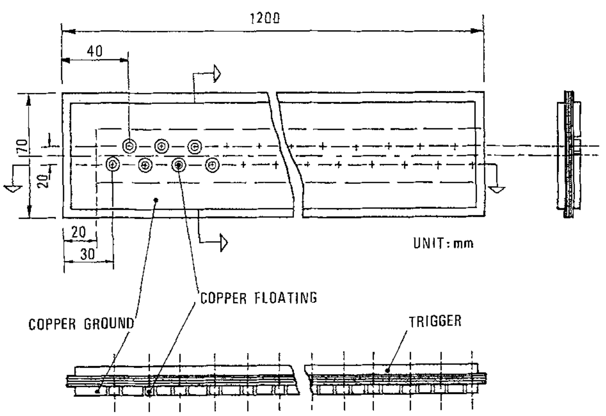

Fig. 2. Plasma cathode diagram

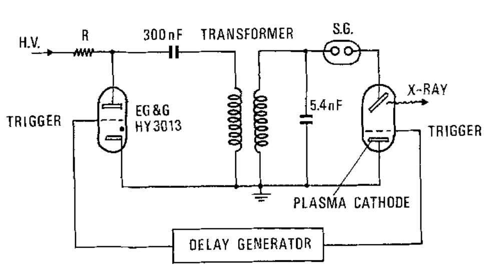

Fig. 3. X-ray preionizer circuit

When a trigger voltage pulse is applied to the cathode, a high electric field across the annular gap generates a vacuum breakdown, and a plasma is produced [9]. The plasma propagates to cover the entire cathode surface and provides plenty of electrons for emission. The plasma trigger voltage is supplied by a 1.3-nF capacitor connected in series to a thyratron. The electric energy of each plasma spark across the annular gap is 0.3–0.4 mJ on average. The diode has two anodes wrapped in lead sheets. The anode planes are arranged at 45° with respect to the cathodes. The middle line of each cathode is $\sim$5 cm from the corresponding anode and the distance between the anode and X-ray window separating the vacuum and the laser discharge chamber is $\sim$15 cm.

The circuit we used for the discharge of the X-ray diode is shown in Fig. 3. A spark-gap switch is used to improve the rise time of the diode voltage. After the spark-gap switch breakdown, a high voltage pulse is applied to the two anodes in parallel. When the diode voltage reaches its maximum value, the plasma cathodes are triggered. The plasma electrons driven by the diode voltage impinge on the lead target anodes, producing bremsstrahlung radiation. The X-rays leaving the anode planes at an angle of $\sim$45° penetrate a 0.5 mm thick aluminium window and a 0.5 mm thick aluminium laser discharge cathode and preionize the gas in the laser discharge chamber. The system outlined above can operate at a repetition rate of up to 30 Hz.

2. Experimental Results

Figure 4 shows the typical waveforms measured for the X-ray diode voltage and the upper cathode current. The lower cathode current has almost the same peak value and time behaviour.

The diode current flow is limited by space charge as shown in Fig. 5, where a plot of the total current for the two plasma cathodes vs the measured diode voltage is given. The magnitude of the current is fairly consistent with the values predicted by Child-Langmuir's Law: $I \propto V^{3/2}$. Thus the current does not appear to be source limited and a higher current density can be expected at a higher electric field.

The X-ray intensity waveforms have been measured using a scintillant plastic (type NE102) combined with an optical signal recording system consisting of a 1P28 photomultiplier and a Tektronix 7834 storage oscilloscope, as shown in Fig. 6. From Figs. 4 and 6 it is evident that the X-ray intensity and the diode current have a similar shape and the same FWHM of $\sim$250 ns. However, the full width of the X-ray waveform is a little less than that of the current because the soft component of the X-ray spectra, especially below $\sim$25 keV, suffers very heavy losses when the X-rays pass through the aluminium X-ray window and the aluminium discharge cathode into the laser discharge region [10].

Our results show that for the anode-cathode geometry of the X-ray diode developed here, the bremsstrahlung radiation, leaving the anode planes at

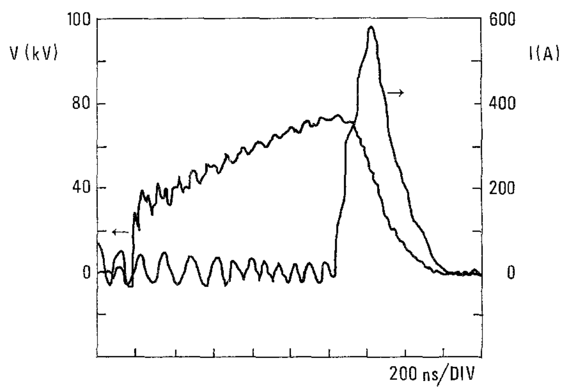

Fig. 4. X-ray diode voltage V and upper cathode current waveforms

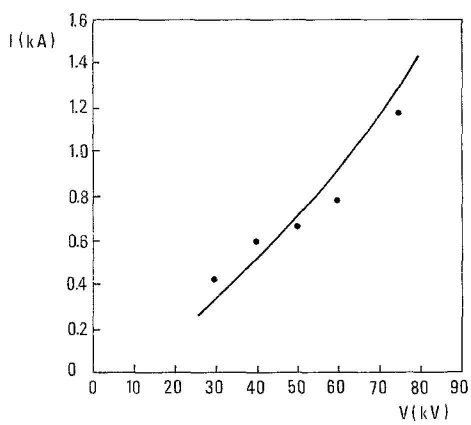

Fig. 5. Total peak current I of the plasma cathodes (the upper cathode plus the lower cathode) vs the X-ray diode peak voltage. Solid points: measured. Continuous line: calculated according to the Child-Langmuir power law

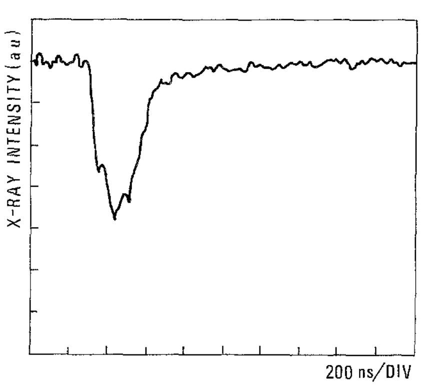

Fig. 6. Typical X-ray waveform

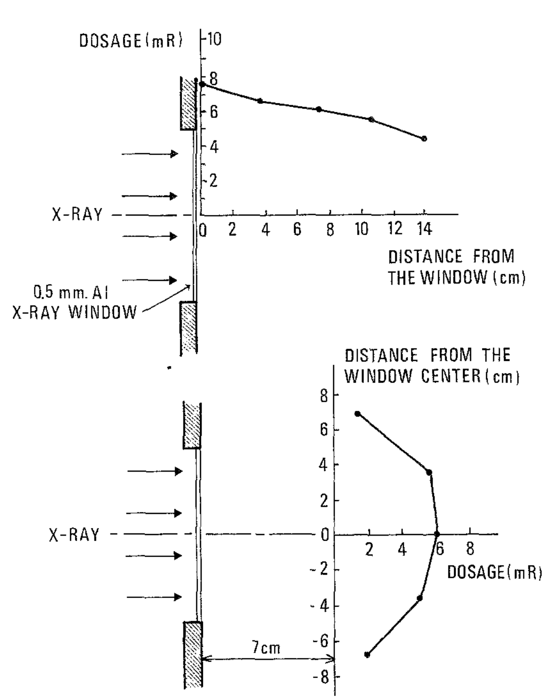

Fig. 7a, b. X-ray dosage distribution (a) along the direction perpendicular to the laser discharge cathode, (b) along the direction perpendicular to the laser optical axis and X-ray propagation direction

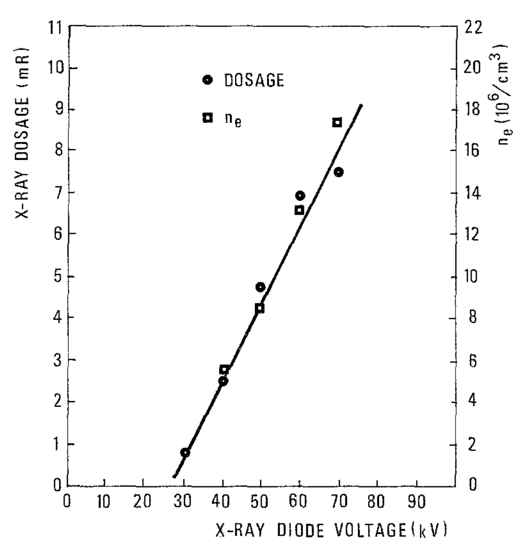

Fig. 8. X-ray dosage and the resulting preionization electron number density in neon as a function of the voltage of the X-ray diode. X-ray plasma cathode trigger voltage: 26 kV. Neon pressure: 1 atm

angles of ~45°, propagates into the discharge chamber with a better uniformity than that of the forward X-ray type diode described in [7, 11]. As shown in Fig. 7, the decrease of the dosage in air is less than 40% at a distance of 14 cm from the central line of the laser discharge cathode.

Figure 8 shows the X-ray dosages (D) measured near the middle of the discharge cathode and the preionization electron number density (n_e) measured by collecting electron charge in a 10 l volume ($10 \times 10 \times 100\,cm^3$) of 1 atm neon as a function of the X-ray diode voltage (V) [12, 13]. In the range of the diode voltage we used in this work, both D and n_e are approximately linear with V, and each milliroentgen of the absorbed X-ray dosage can generate 2×10^6 electron-ion pairs/cm^3 in 1 atm neon. It is also interesting to note that less than 10 J of electric energy in this system are sufficient to produce more than 10^7 preionization electron-ion pairs/cm^3 in the aforementioned conditions (Fig. 8).

3. Concluding Remarks

We have developed a large-area pulsed X-ray source with a two-plasma cathode that is suitable for the preionization of large aperture discharge lasers. Compared to other X-ray preionization sources with cold cathodes, the compact, low divergence X-ray diode described here does not require a very high voltage in order to operate stably and meet the preionization requirement for pumping large volume, high energy RGH lasers. In this way, shielding problems are greatly reduced, allowing safer handling of the system.

The experiments show that when the diode voltage is ~60 kV, a fairly homogeneous discharge can be stably obtained in a 10 l active volume XeCl laser, pumped by a dc charged 0.64-μF commercial capacitor bank and switched by a multichannel spark-gap switch. Using a non-optimized optical cavity consisting of an aluminium-coated flat mirror and an uncoated silica plate, over 10 J of a spatially uniform laser output energy with a pulse duration of ~130 ns (FWHM) has been achieved from a 3-atm XeCl laser mixture under a very low dc charging voltage (~70 kV).

These results support the conjecture that a good energy extraction and efficiency can be obtained with a relatively low X-ray dosage, even in large volume systems. Further details on the laser performances obtained will be presented in a forthcoming paper.

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