THE CORONA-PLASMA CATHODE:

A NEW LONG-LIFE E-BEAM CATHODE FOR X-RAY PREIONIZATION

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ABSTRACT

A new type of cold-cathode electron gun has been developed for use as an x-ray preionizer in excimer laser systems. The cathode is simple, rugged, and very reliable. Lifetime testing at an average of 175 pps shows little wear after 10^8 shots, and no decrease in e-beam current density. Current densities in the range 0.1 - 10 A/cm^2 have been demonstrated, and higher current densities appear achievable. Gas evolution at high repetition rates is minimal, reducing vacuum pump requirements. The power requirements for the corona-plasma e-gun were found to be about 4% of the input power demand of a moderate power x-ray preionized laser system.

INTRODUCTION

X-rays are quickly gaining importance as preionization sources for transverse discharge excimer laser systems.[1] When contrasted with UV preionization techniques commonly in use, x-rays provide several important advantages: (1) x-rays produce exceptionally uniform preionization, which ultimately leads to a 20-30% increase in laser output power;[2] (2) The strong penetrating power of 40 keV x-ray photons permits the x-ray generator to be modular unit located outside the discharge chamber. The preionization source is therefore non-contaminating to the laser gas, and conversely the preionizer need not be constructed to withstand chemical attack by the more corrosive excimer mixes; (3) The strong penetrating power of x-rays allows scale-up to large volumes; (4) An external x-ray source is much more easily collimated than a necessarily close-coupled UV source, and therefore can take a very active role in defining the discharge dimensions by spatially selective preionization.

E-beam requirements for x-ray preionization are relatively modest: electron energies of 60 - 100 keV, at a current density of about 1 A/cm^2, and a pulse width of 50 - 200 nS. Uniformity is not critical, due to strong homogenizing effects in the x-ray production process. The one required characteristic that is a bit stiff is that the e-beam cathode last 10^8 to 10^{10} shots without falloff in emission current.

In light of so many clear advantages over UV sources, one might wonder why x-ray preionization is not universally adopted. The reason is that conventional e-beam generators are either too bulky, complex, or short-lived to be economical candidates for small to medium size laser systems. Cold cathodes (blade geometries, carbon felt) are simple, rugged, but lack sufficient lifetime to be useful in 10^8 - 10^{10} shot laser systems. Hot cathodes (thoriated tungsten, dispenser) require high vacuums, large heater powers, and for thermionically limited emitters, lack sufficient current density capability. Plasma cathodes as a class are very interesting, but in their current forms are either too short lived (surface dielectric spark emitters) or too complex and slow (WIP guns). Motivated by the need for a simple, long-lived, and cost effective x-ray preionization source, we have developed the "corona-plasma" cathode.

THE CORONA-PLASMA CATHODE

Figure 1 shows a rather schematic corona-plasma cathode with its associated driver circuitry. The cathode consists of a fine wire helically wound around a thick-walled dielectric tube. A metal rod is inserted down the center of the tube and connected to circuit ground. When triggered, the hydrogen thyratron pulser delivers a negative 80 kV, 100 nS pulse to the helical winding. The initial load seen by the pulser is the coaxial capacitance between the cathode winding and the grounded central rod. When the electric field strength at the wire/dielectric interface exceeds about 1 MV/cm, field emission occurs which vaporizes minute quantities of metal and dielectric material and sets up a localized plasma sheath. Formation of the sheath is further driven by strong displacement currents as the cathode capacitance continues to charge. Once

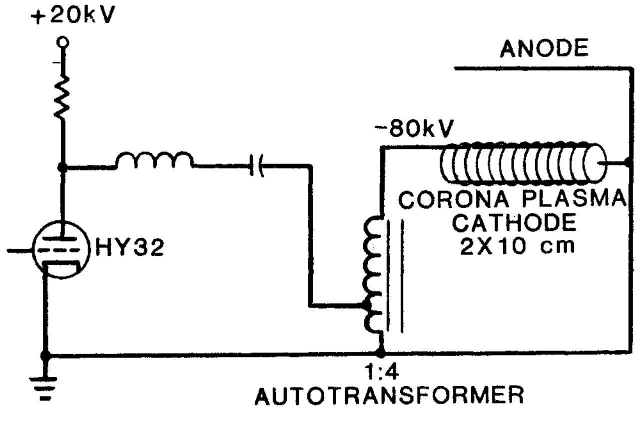

Figure 1. Schematic diagram of the corona-plasma cathode and associated H.V. driver.

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A new type of cold-cathode electron gun has been developed for use as an x-ray preionizer in excimer laser systems. The cathode is simple, rugged, and very reliable. Lifetime testing at an average of 175 pps shows little wear after 108 shots, and no decrease in ebeam current density. Current densities in the range 0.1 - 10 A/cm2 have been demonstrated, and higher current densities appear achievable. Gas evolution at high repetition rates is minimal, reducing vacuum pump requirements. The power requirements for the corona-plasma e-gun were found to be about 4% of the input power demand of a moderate power x-ray preionized laser system.

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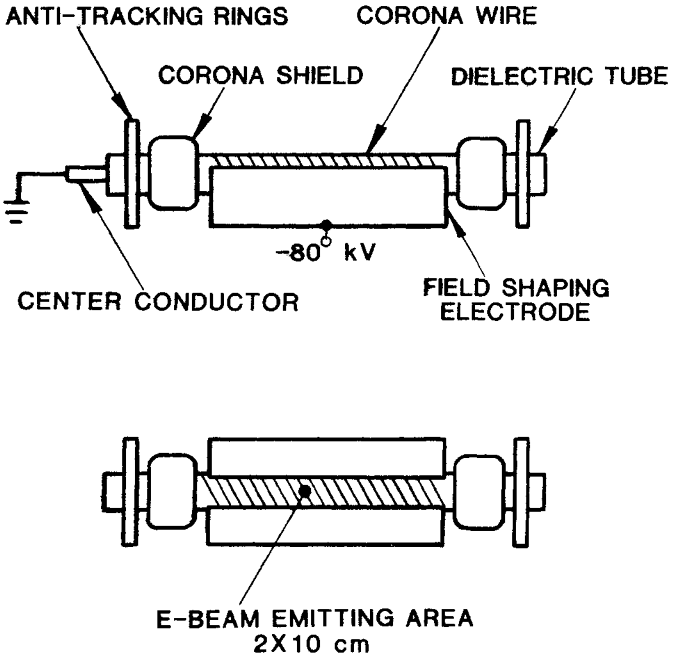

Figure 2. More detailed view of the corona-plasma cathode.

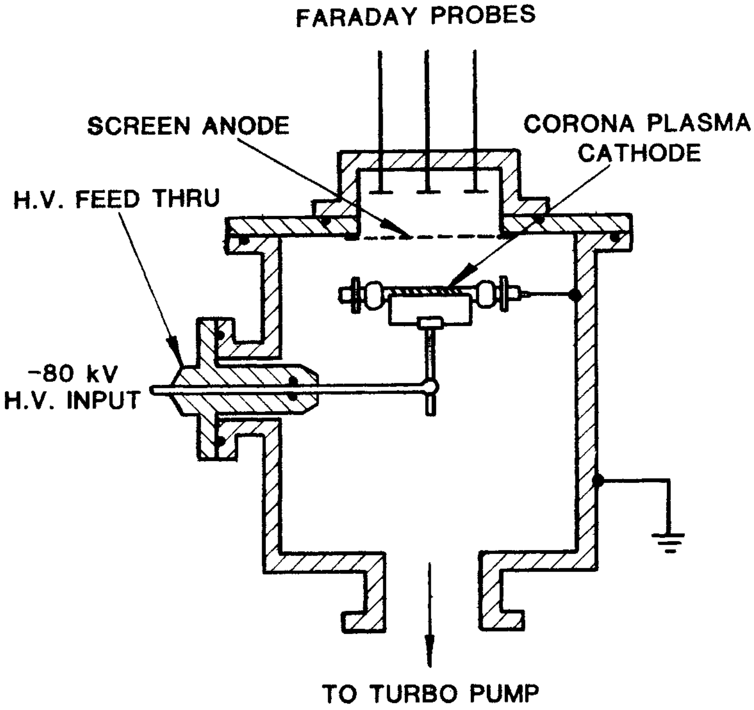

Figure 3. The vacuum chmber used for cathode performance tests.

established, the plasma sheath acts as a nearly zero work function electron emitter, and a space-charge limited e-beam current is pulled between the cathode and anode. After e-beam inception the plasma sheath is maintained by positive ion bombardment of the cathode surface.

A more detailed view of the cathode is shown in Figure 2. The emitting area for our test cathode is 2 x 10 cm. For compactness, anti-tracking rings and metal corona shields are added at either end to terminate the helical winding. A sheet metal field shaping electrode is added to define the emitting area and shape the e-beam.

CATHODE PERFORMANCE TESTS

The cathode was tested in a vacuum chamber, shown in Figure 3, which was designed for quick accessability and experimental flexibility rather than compactness. Anode-cathode spacing was set at 3 cm. A high voltage probe monitored the cathode voltage, and a set of three 1 cm^2 Faraday probes monitored the e-beam current density in the field-free region behind the screen anode. In addition, a self-integrating Rogowski-type current monitor measured the capacitive displacement current between the cathode center rod and circuit ground. For these tests, a Balziers turbomolecular pump provided a background vacuum of 10^{-5} to 10^{-6} torr.

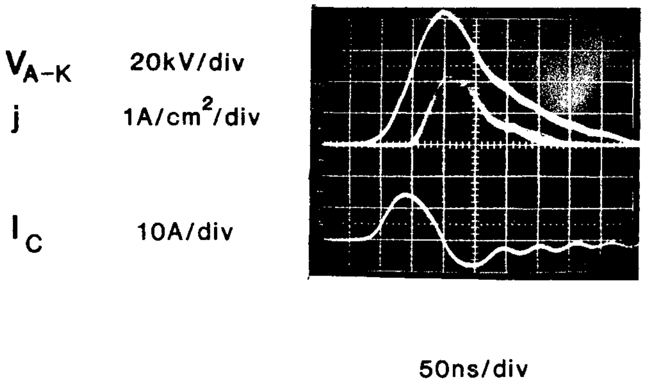

Figure 4. Current and voltage traces. Upper traces: cathode voltage (larger trace), e-beam current density. Lower trace: capacitive displacement current.

Typical current and voltage traces are shown in Figure 4. The peak cathode voltage (larger of the upper traces) was held at 80 kV. Current inception voltage was initially about 15 kV, but after 10^5 shots rose to the stable long term value of 50 kV as the cathode conditioned. After suitable correction for anode screen porosity and electron collection efficiency of the Faraday probes, the current density was found to be about 2 A/cm^2 peak. This is in good agreement with a computed value of 3.4 a/cm^2 based on space-charge limited emission. The lower trace of Figure 4 shows the current from the center rod to ground. As expected, the current is purely capacitive and proportional to dV/dt.

By varying both the anode-cathode spacing and voltage, current densities in the range 0.1 - 10 A/cm^2 have been demonstrated, at electron energies of 50 - 100 keV.

A qualitative assessment of uniformity was made by temporarily replacing the Faraday probes with a glass window coated on the vacuum side with a flourescing material, calcium tungstate. The flourescent screen showed a relatively uniform e-beam covering the entire 2 x 10 cm emitting area. However, the general character of the flourescent pattern indicates that cathode emission occurs at a large number of discrete sites, undoubtedly along the wire/dielectric interfaces. Nevertheless, the uniformity is more than sufficient for x-ray preionization duty.

A crucial test of this cathode was to lifetime test it for 10^8 shots. The cathode was run under the voltage and current conditions of Figure 4 at an average rate of 175 pps for 8 hours a day and 25 consecutive days, for a lifetime total of 1.28×10^8 shots. Virtually no falloff in current density was observed. At the end of the run, the cathode was inspected and found to have sustained surprisingly little wear. The cathode wires showed almost no erosion and had become relatively polished. The dielectric surface did show some erosion, mainly under the wires, to the point where the wires were partially embedded. Based on the amount of material lost, it seems probable that one can expect lifetimes of 10^9 shots or greater.

One unexpected and welcome characteristic of this cathode is that it is exceptionally tolerant to high system pressures. Recent tests indicate that background pressures as high as 10 microns have no detrimental effect on current density, and in fact the emission current roughly doubles at 10 microns. Furthermore, the cathode evolves very little gas: at 200 pps, the cathode evolution rate was determined to be about 15% of the outgassing rate of the vaccum vessel. Coupled together, this means that the corona-plasma cathode can be operated at a few microns pressure with nothing more than a molecular sieve and a small mechanical pump. Further testing, however, remains to be done to see if such high pressures have any impact on long-term operation.

DISCUSSION

The longevity of the corona-plasma cathode can be best explained by contrasting its operation with a conventional blade-type cold cathode. Blade cathodes emit initially by field-emission from micron size surface protrusions, or "micro-whiskers". The field-emission current is usually sufficient to explosively vaporize these micro-whiskers and form localized plasmas, which then take over as the prime electron emitters. The problem with this arrangement is that the initial population of micro-whiskers gets polished off, and the cathode emission falls, usually in less than 10^5 shots. The corona-plasma cathode by design explicitly decouples the formation of the plasma sheath from generation of the electron beam. The purpose of the central rod is to increase the macroscopic field strength at the (under) surface of the wires; the purpose of the dielectric tube is to suppress electron emission to the central rod, and at the same time to further enhance the field strength at the wire/dielectric interface. The net results is a macroscopic field strength sufficient to pull field-emission current from structures the size of the cathode wires. Since the formation of the plasma sheaths is no longer dependent upon fragile micro-whiskers, long lived operation is attained.

Scaling of this cathode to longer geometries is straightforward, and indeed has already been done. In the current design, the emitting area has been increased to 2 x 80 cm and packaged in a compact (15 x 15 x 95 cm) vacuum chamber. This e-beam generator is now in use as the x-ray preionizer in a 100 W, 1 J/pulse, 100 Hz XeCl laser system (Helionetics HLX-100). Storing 4 J/pulse, the preionizer accounts for only 4% of the input power of the laser.

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