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PLASMA CATHODE FOR E-BEAM LASERS

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Hughes Research Laboratories

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The objective of this program is to develop the plasma cathode electron gun and to demonstrate that it has properties which make it suitable for application to e-beam lasers. The source of electrons in this device is a plasma generated within a low-voltage, cold surface, hollow cathode discharge. The device is characterized by durability, low cost, low power consumption, small size, and fast turn-on in comparison with thermionic e-guns. Previously reported results of this program have shown that the

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) plasma cathode e-gun is capable of producing large scale e-beams (625 cm^2) at 150 keV with a current density extracted through a thin foil window of 1 mA/cm^2 (cw) and 75 mA/cm^2 (pulsed). A pulsed, lower voltage configuration delivered a pulsed 1 A/cm^2 beam. Furthermore, larger scaling has been demonstrated in a 200 cm long cylindrical discharge device. A compact high-voltage feedthrough has been perfected which is applicable to large scale devices. A compact 5 cm x 125 cm gun has been used successfully with a cw CO_2 high pressure laser.

Recent studies have been made to optimize the performance characteristics and improve the reliability of the gun. Studies of the spatial uniformity of the electron beam for a 4 cm x 40 cm gun, in cw operation, included (1) measurement of the plasma density of the hollow cathode discharge in a low voltage configuration, (2) analysis of an extracted 75 keV beam by means of current probes mounted on a solid collector plate, and (3) measurement of the current density of a 100 keV beam extracted through a thin foil window by means of a single, moving probe. The effect of placing auxiliary electrodes in the gun structure has been studied. The best results indicate an output beam which is uniform to within $\pm$ 5% except for a 5 cm transition region at the ends of the long dimension (40 cm). Reliable operation of the gun has been demonstrated when proper attention to vacuum cleanliness is maintained.

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I. INTRODUCTION

The plasma cathode electron gun concept has been developed to the level of large area, operating, cw electron guns during previous periods of this contract (N00014-72-C-0496). The objectives of the current program are (1) to continue the development of the plasma cathode electron gun to optimize the performance characteristics and to improve reliability, and (2) to investigate the possibility of an "integral plasma gun laser" in which a low pressure laser may be incorporated into the plasma cathode electron gun and eliminate the need for a foil window. In the preceding semiannual report,[1] analytical results on this integral plasma gun laser were presented with the conclusion that, for noble gas ion lasers, the concept allows scaling to large size, but with no increase in efficiency over conventionally excited ion lasers. During this reporting period (January 1975 through June 1975) the effort has concentrated on testing the 4 cm x 40 cm electron gun to determine and improve the uniformity of the output electron beam in cw operation. A 100 keV beam from this gun has been extracted through a thin foil window and the spatial distribution of the current density studied.

The basic concepts of the plasma cathode electron gun and a summary of previous accomplishments are reviewed in Section II for completeness. Section III of this report describes the recent experimental results on the 4 cm x 40 cm electron gun. In Section IV a lower pressure version of the plasma cathode electron gun, which was built for another contract-funded program, is described to show an important possible extended use of this kind of gun. Section V is a summary of the conclusions of the results from this reporting period.

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II. PLASMA CATHODE CONCEPTS AND PREVIOUS ACCOMPLISHMENTS

This section describes the basic concept of the plasma cathode electron gun and outlines the experimental program performed up to the beginning of the subject reporting period.

A. Basic Concept

A schematic diagram of the plasma cathode electron gun is shown in Fig. 1. The device consists of three major regions: (1) the plasma generation region in which the beam electrons originate, (2) the extraction and control region where electrons are extracted from the plasma and transported in a controlled manner into the acceleration region, and (3) the high-voltage acceleration region where the electrons are accelerated to high energies prior to passing through a thin metal foil window and into the laser medium. These regions are comparable to the thermionic cathode, control grid, and grid-to-anode space of a conventional triode.

The plasma generation region in the present device consists of a low-pressure glow discharge struck between the cold, hollow cathode surfaces and the anode grid, G1. This type of discharge has been chosen because of its stability, reliability, simplicity, and ability to operate at the low gas pressures required to preclude gas breakdown in the acceleration region. In the present application, the discharge operates at a voltage, which is approximately independent of current, of typically 400 to 700 V with helium at pressures typically in the range of 30 to 50 mTorr. Helium is used because He^+ ions have relatively low sputtering yields and because it has high-voltage breakdown characteristics which are superior to those of other gases.

The major characteristic of the hollow cathode discharge is that most of the plasma volume is surrounded by the cathode surface. The discharge, which is sustained by secondary electron emission due to ion bombardment of the cathode surface, is operated in a region where the rate of ion generation by ionization in the discharge volume is

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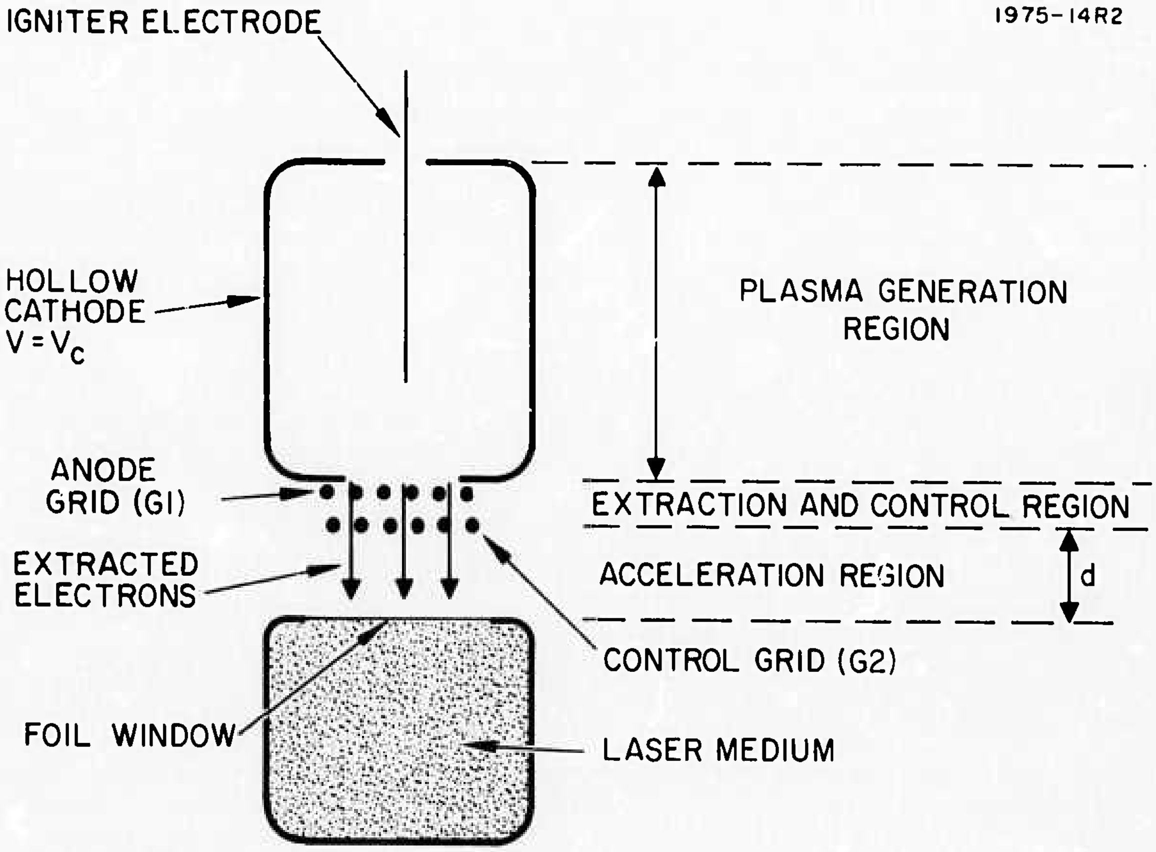

Fig. 1. Schematic of the plasma cathode electron gun.

sufficient to maintain the plasma potential slightly above anode potential. Because of the large cathode-to-anode area ratio, most ions leaving the discharge are accelerated through the cathode sheath, and utilized with maximum efficiency for secondary electron production, thus minimizing the rate of ion generation required per emitted electron. Furthermore, the secondary electrons accelerated back through the cathode sheath are repeatedly reflected from opposing cathode surfaces. This results in a high probability for making ionizing collisions at low gas pressures where the electron ionization mean-free path exceeds the dimensions of the discharge. At sufficiently low pressure, however, the ionization probability drops to a level for which the discharge cannot be maintained. This determines the minimum working pressure.

Electrons are extracted from the discharge plasma through the anode grid, G1, and pass through the control grid, G2, into the acceleration region. Voltages of typically 0 to -100 V relative to G1 are applied to G2 in order to control the beam intensity from maximum to near cut-off. Grid G2 also serves to provide isolation between the low-voltage discharge region and the high-voltage acceleration region. Alternately, control of the beam current is possible through variation of the hollow cathode discharge current through the potential of G1.

Width d of the acceleration region is critical to the successful operation of the plasma cathode electron gun, since the entire electron acceleration voltage is applied across this gas-filled gap. In order to avoid breakdown in this region, width d must be maintained at a value larger than that which would result in vacuum breakdown, and smaller than the value which would result in Paschen breakdown. Figure 2 illustrates this situation for a helium gas pressure of 50 mTorr. Both breakdown curves represent conservative values based on data generated in our experiments and quoted in previous literature.

As seen from Fig. 2, there is a region between the two breakdown characteristics where high-voltage operation is possible without incurring breakdown. In the present work, d is chosen for a given maximum operating voltage (150 to 200 kV) to have the operating point nearer to

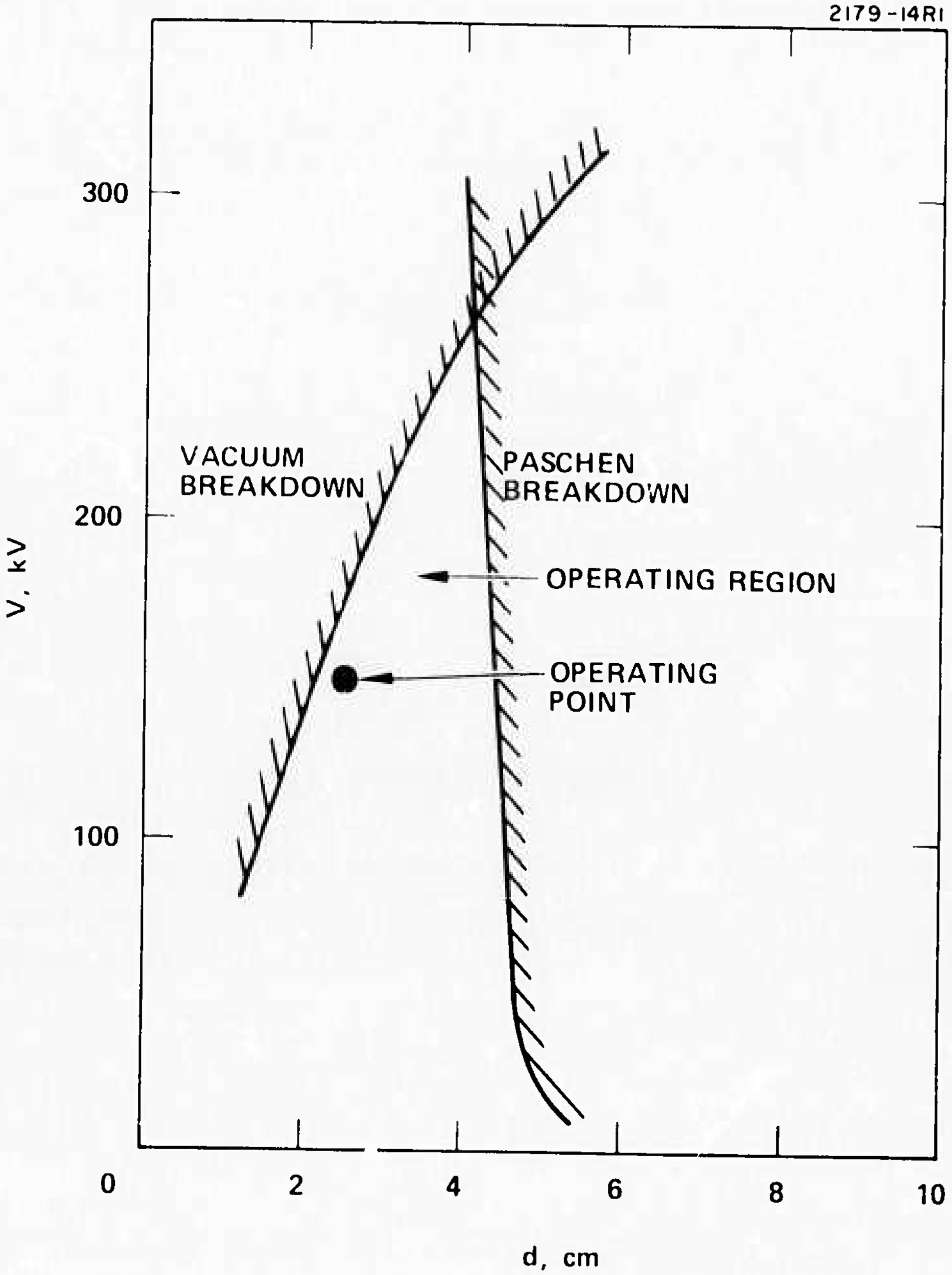

Fig. 2. Low pressure breakdown voltage in the plasma cathode accelerating region as a function of the gap width, d. The Paschen curve is for a pressure of 50 m Torr of helium.

vacuum breakdown characteristic than the Paschen breakdown curve. This is desirable since this characteristic is expected to be more stable in time than the Paschen curve which is sensitive to the presence of outgassing products. As can be seen from the figure, this design is conservative and accelerating voltages of up to 250 kV may be possible with a helium pressure of 50 mTorr; even higher voltages may be possible at lower pressures.

Figure 3 summarizes the voltage and current requirements for the plasma cathode e-gun which are based on data obtained under typical pulsed and cw operating conditions. The current level of 2 I_B supplied by the high-voltage source assumes a transmission of 50% for the foil window assembly. Measurements on existing plasma cathode devices indicate that the discharge anode current is about equal to the beam current incident on the foil window structure. Therefore, the discharge power supply also operates at 2 I_B in either pulsed or cw mode, depending on the desired application. As is shown, the control grid operates at a slightly negative potential relative to the anode and collects a current of ~15% of the extracted current. The igniter, which provides the background ionization to permit initiation of the hollow cathode discharge without requiring excessive voltages, operates cw at typically 10 mA and 300 V.

B. Previous Development

The basic ingredients of the plasma cathode e-gun development program prior to the subject reporting period are outlined below.[1]

1. Beam Generation – Electron beams 625 cm^2 in area (5-cm x 125-cm gun), have been extracted through a thin foil window, with a beam energy of 150 keV, an average current density of up to 1 mA/cm^2 with operation of 1/2 sec. A 20 cm^2 beam at 100 keV and 75 mA/cm^2 current density has been extracted through a foil window in pulsed operation (30 to 50 μsec pulsewidth). In other tests, at lower voltages and with a solid collector plate in place of the foil window, a pulsed current density of 1 A/cm^2 has been measured.

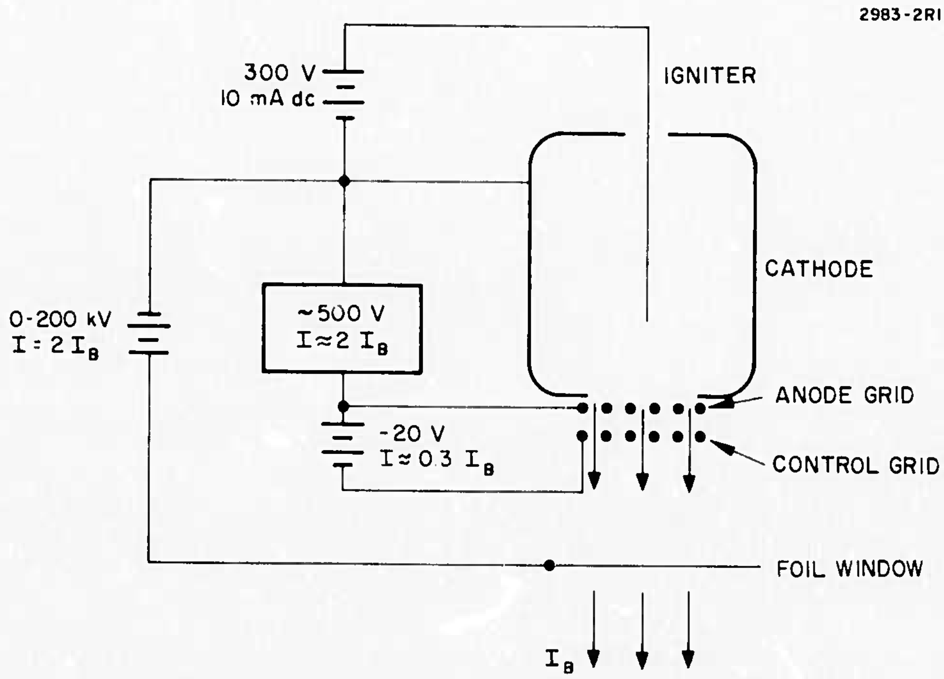

Fig. 3. Plasma cathode power supply schematic.

2. Current Density Distribution — Measurements obtained with a 10 x 15 cm plasma cathode e-gun demonstrated current density distributions uniform to ±5%. Similar measurements, under both pulsed and cw operating conditions, with a low-voltage 4 x 40 cm device indicated uniformities of ±5% and ±10% in the long and short dimensions respectively. Various designs for field shaping electrodes and discharge partitions to influence the distribution were evaluated.

3. Electron Energy Distribution — A retarding Faraday probe was used to measure the electron energy distribution of a small portion of the beam. The energy spread was measured to be monoenergetic to within ±1.4%. The actual energy spread is expected to be less than these measurements indicate on the basis of instrumentation effects. In addition, transmission measurements through a 0.00125-cm thick titanium foil, in combination with calculated transmissions as a function of electron energy, verify that the beam is monoenergetic.

4. Development of Scalable Designs — A coaxial e-gun configuration was developed which readily permits scaling to large dimensions. A 15-cm diameter, 200-cm long cylindrical hollow-cathode discharge with four electrically isolated anode sections was operated. These tests indicate that good (better than ±5%) macroscopic uniformity is achievable provided the anode sections are separately ballasted with resistors of equal value which consume less than 10% of the total low-voltage discharge power. A compact high-voltage feedthrough, which operates under the simultaneous constraints of vacuum, Paschen, and dielectric bulk and surface breakdown, was developed and successfully tested at up to 200 kV.

5. High Voltage, Large Area Plasma Cathode Electron Guns — A 4 cm x 40 cm and a 5 cm x 125 cm plasma cathode electron gun were designed and fabricated in compact designs suitable for incorporation into laser systems. Operational results of the 5 cm x 125 cm plasma cathode e-gun were reported in the preceding semiannual report[1] and this gun is presently being used with a large scale, cw, e-beam sustained CO_2 laser. Results of the studies of the 4 cm x 40 cm^2 gun are presented in Section III.

III. PLASMA CATHODE ELECTRON-GUN 4 cm x 40 cm

The 4 cm x 40 cm plasma cathode e-gun was designed and built to provide an intermediate size, practical e-gun suitable for evaluations relevant to large-scale devices. During this reporting period, efforts on this device have been directed to studying and improving the current density distribution. The previous work with the low voltage version of this device[2] demonstrated a uniformity in the long dimension of ±5%, but beam uniformity measurements on the high voltage gun, operating with a solid collector plate instead of a foil window, indicated a variation of ±20% even under the same low voltage conditions.[1] Recent measurements of the uniformity of the beam when extracted through a foil window indicate better uniformity (±5% over the long dimension) than that obtained with a solid collector plate. A brief description of the gun is given below, followed by the description and results of recent experiments.

A. 4 cm x 40 cm E-Gun Design

The design of the high-voltage 4 cm x 40 cm plasma cathode e-gun has been described previously.[3] It is based on two proven components — the low-voltage 4 cm x 40 cm device and the compact high-voltage feedthrough. Figure 4 shows a schematic cross section of the basic coaxial design, and Fig. 5 illustrates the layout of the e-gun. The hollow-cathode discharge runs at a voltage, typically 400 V, which is largely insensitive to the discharge current. The operating voltage depends on the helium gas pressure and the presence of contaminants. The anode grid is formed from square, 52% transparent stainless steel mesh having a 0.014-cm wire diameter. The control grid serves to provide electronic beam control and to ensure isolation between the hollow-cathode discharge and the acceleration region. In the present experiments a square stainless steel mesh with the same geometry as that of the anode grid is used. It is spaced 0.8 cm from the anode grid, a distance which is mechanically convenient and which should not be

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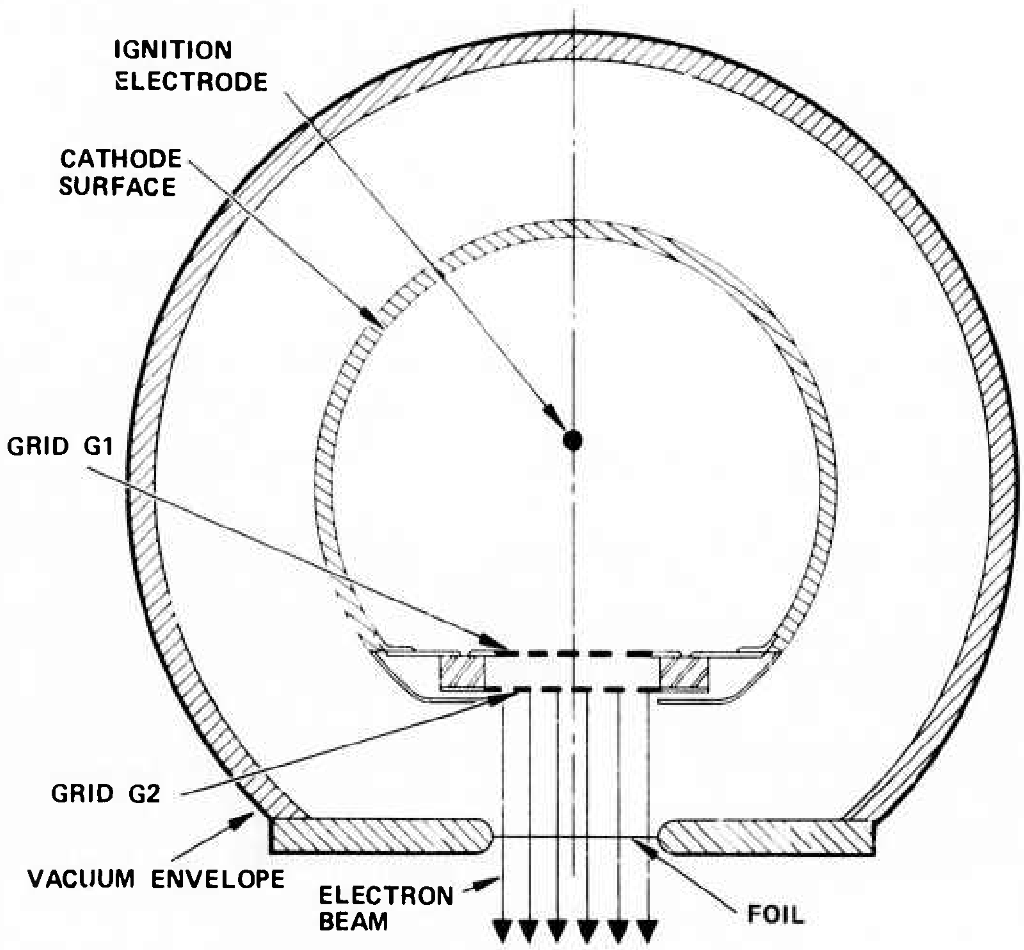

Fig. 4. Cross section of the coaxial e-gun design.

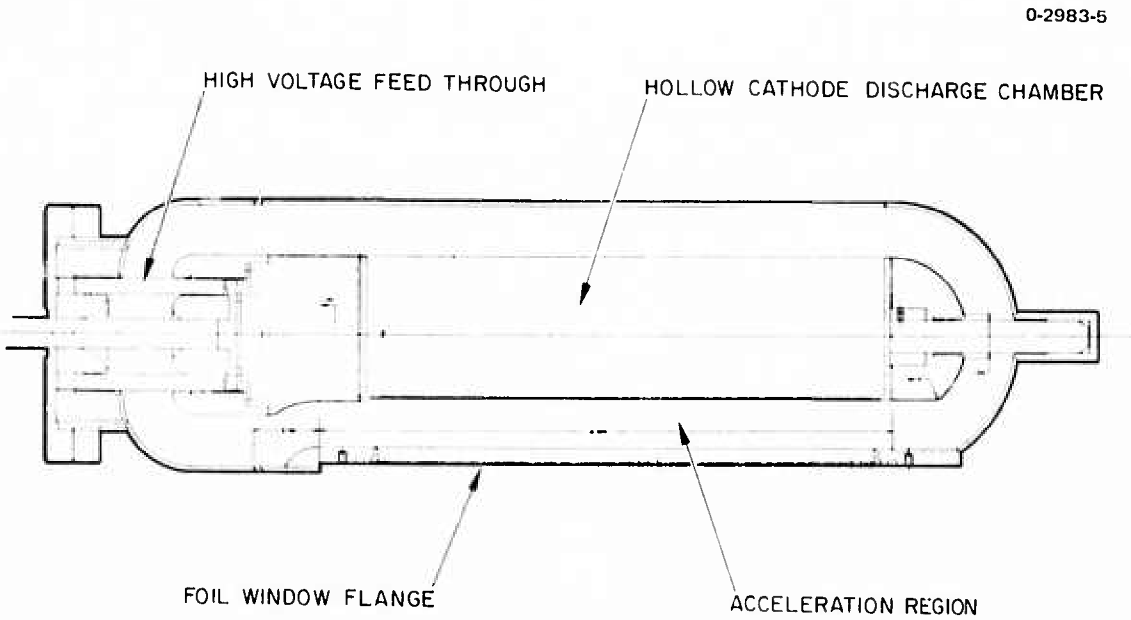

Fig. 5. High energy 4 x 40 cm e-gun.

critical. The hollow cathode discharge supplies an emission limited beam and control is achieved by reverse biasing the control grid so as to retard electron motion through it.

The inner and outer cylinders (refer to Figs. 4 and 5) are contoured so that a spacing of approximately 4 cm is maintained at all points between the two cylinders. This spacing is chosen assuming a 200 kV operating voltage. With reference to Fig. 2, a smaller gap would result in excessive field strengths which could cause vacuum breakdown. A larger gap would reduce the gas pressure range for which operation would be possible. Maintenance of this spacing is accomplished by the use of field shaping electrodes. Electrodes are provided which extend the plane of the control grid, G2, smoothly into the cylindrical cathode surface. Contoured electrodes are also provided at each end of both the inner and outer cylinders in which to minimize electric field concentrations. All parts of both cylinders are formed from nonmagnetic 304 stainless steel which is electro-polished in order to minimize sharp surface protrusions.

Electrical power is supplied to the cathode, anode grid, control grid, and igniter electrode through the high-voltage feedthrough (refer to Fig. 5). This component must operate under the constraints of Paschen breakdown in addition to those associated with the other forms of electrical breakdown usually encountered in vacuum high-voltage feedthroughs.

A coaxial cable passes through the center of the assembly to a four-pin connector located within the innermost field shaping electrode. The center conductor of this cable is a copper tube which facilitates routing of four conductors to the connector. The copper tube carries current to the cylindrical discharge cathode. The field shaping electrodes within the ceramic tube are designed so that the electric field lines merge smoothly from the 4-cm gap into the co-axial cable.

The 4 cm x 40 cm plasma cathode e-gun, which is capable of both cw and pulsed operation, has been operated under cw conditions for these studies (operating times of 0.5 to 10 sec have been typical). High-voltage stand-off tests, which were performed without beam extraction, demonstrated the capability of the present design to operate at beam voltages up to 200 kV. Although average cw beam current densities of 1 mA/cm^2 have been extracted from the 5-cm x 125-cm gun (a gun of similar design to the 4-cm x 40-cm gun) and from the low voltage configuration of this gun, the present tests were limited to lower current densities, due to limitations in the high-voltage power supply and due to inadequate cooling of the foil window.

B. Experimental Results

The 4 cm x 40 cm plasma cathode e-gun has been studied in three different experimental configurations in order to determine and improve the uniformity of the output electron beam. In the first set of experiments, the gun was placed in a bell-jar and the uniformity of the plasma cathode discharge measured by means of a single, movable Faraday cup ion probe. Next the e-beam current density distribution was studied by means of 21 Faraday probe current collectors, placed at different positions in the 4 cm x 40 cm e-beam pattern and mounted on a solid collector plate bolted to the e-gun. Finally, a 100 keV e-beam was extracted through a thin foil window and probed by means of a single Faraday cup current collector which could be moved continuously along the 40-cm gun dimension in the center of the pattern. In all three experimental arrangements, small endplates were placed within and near the ends of the hollow cathode chamber as a means to alter and improve the observed beam uniformity. These endplates could be biased at a fixed voltage, allowed to float, or connected electrically to the hollow cathode. A more complete description of each experiment and the obtained results follows.

1. Low Voltage Bell-Jar Experiments

In order to provide an opportunity to study the effects on the expected current density profile due to structural modifications to the e-gun, the 4-cm x 40-cm e-gun was placed in a vacuum bell jar. In this configuration, the plasma density of the hollow cathode discharge was studied by measuring the spatial variations of an extracted ion beam. The justification for the validity of this experimental approach is based on two assumptions:

a. The spatial variation of the extracted e-beam is dependent primarily upon the electron density in the hollow cathode discharge which in turn equals the ion density for a neutral plasma.

b. The control grid (G2 in Fig. 1) and the plasma, with a Debye length of ≈ 0.5 mm,[4] isolates the conditions in the hollow cathode region from the acceleration region so that the operation at high voltages with an extracted beam does not affect the conditions within the hollow cathode.

The ion density in the hollow cathode discharge was monitored by a modified Faraday cup probe which was mounted on a rod located ≈ 0.7 cm from the control grid and which could be moved continuously along the 40 cm dimension of the structure. The Faraday cup had a collecting aperture of 0.32 cm^2 (6.35 mm diameter), and a suppressor grid in front of the collector which was operated with a negative bias of about 20 V, with respect to the collector, to minimize the effects of secondary emission from the collector plate. The collector was run at a negative potential of 20 V relative to the cup and aperture. The sliding contact for an 8.5 Ω potentiometer was connected to the rod which moved the probe and this allowed the position of the probe to be continuously monitored. A continuous analog recording of the ion current versus position (as determined by the voltage across the potentiometer) was made using an x-y recorder. Over fifty such recordings were made under many different conditions and configurations of the gun.

The gun structure was modified by placing two 0.012 in. thick stainless steel plates normal to the axis of the gun, in the hollow cathode can, and at the ends of the 40 cm aperture of the gun. These endplates were circular, of 4.5 in. diameter, except for a segment cut off to clear the screen grids (G1 and G2). This size provided a 3/16 in. clearance with the interior of the hollow cathode and grid surfaces and the endplates were therefore electrically isolated from the rest of the cathode parts. Tests were run with and without endplates. The endplates were allowed to float, were connected to the cathode, or were maintained at a fixed voltage (50 to 400 V) with respect to the cathode in separate tests.

The results of these experiments showed that the plasma density in the hollow cathode discharge could be modified in a predictable manner due to the presence of the endplates. Without the endplates, the plasma density (and the e-beam current density as seen in previous measurements)[1,2] falls off, from the uniform midgun value, to near zero at the ends of the gun aperture, with a transition region of 4 to 8 cm. Operation with the endplates biased to 250 to 300 V, or floating (where the potential floats up to the plasma potential which is near the anode grid voltage of 400 V), gave an increase in the plasma density near the ends of the 40-cm aperture, so that the fall-off region was approximately halved. In the best cases, the uniformity of the observed ion density was ±5% over the central 80 to 85% of the longitudinal aperture. Variations of ±10% to ±20% were more typical.

The observed increase in plasma density near the ends of the beam aperture is believed to be due to changes in the potential near the walls, which the plasma species experience. In the normal case, when the edges of the aperture are at cathode potential (which is also the case when the end plates are operated at cathode potential) a sheath on the order of a centimeter thickness develops which reflects electrons back into the interior of the hollow cathode and causes the plasma density in the sheath region to be low. When the positively biased or floating end plates are present, electrons no longer experience the reflection of the sheath near the end plates and the plasma density increases.

It was observed that contamination effects played a major role in determining the uniformity of the plasma density. The bell-jar is not a clean environment in which an electron gun is meant to run. Usually after a couple of data runs, the gun was so badly contaminated that the observed plasma density became grossly nonuniform (even for fresh gas fills) and the gun would have to be disassembled and cleaned. This occurred even when the diffusion pump line was LN trapped. A micro-probe analysis of the contaminated parts was not conclusive in showing that the contamination was due to pump oil or vacuum grease from the bell-jar seals. Nevertheless, due to these contamination problems, it was decided to continue tests of the endplate configurations with the gun in a clean, high vacuum environment at high voltage and observing an extracted e-beam.

2. Experiments with Fixed Probes on a Solid Collector Plate

In these experiments the 4-cm x 40-cm e-gun was placed in its normal high voltage configuration including the high voltage feed-through. The diffusion pump was trapped with both an LN and a molecular sieve trap to guard against contamination and the gun was only pumped on when a new fill of helium was needed. Based on the results of this and the following set of experiments, no pump oil or vacuum grease contamination effects in the gun on the observed electron beam uniformity were seen. A solid collector plate was bolted to the output flange of the gun and imbedded in the plate were 21 individual Faraday probe collectors, each with a diameter of 1 cm.

To take data, the gun was turned on by turning on the anode voltage, the high voltage being on continuously, and the output of the various probes as measured by a current meter was recorded sequentially on a storage scope. Due to power supply constraints at the highest beam voltage studied (75 kV) a maximum beam current of 40 mA (250 $\mu A/cm^2$) could be drawn. Data were taken with and without endplates, and with the endplates at the same voltages as described above.

The results of the experiment, without endplates, were similar to the results taken a year ago, with the same probe plate, in that the beam was uniform to ±15 to 20% over the central 70% of the 40 cm dimension. The positions of individual peaks or valleys in the observed probe current were not the same, however, although these positions were consistent in the present case from run to run. (Run-to-run consistency also existed in the previous experiments.) Numerous sets of data were taken with different igniter, anode grid, control grid, and beam voltage and current conditions. Changing these parameters did not consistently nor significantly alter the observed results. It is not known whether or not the presence of the high and low current density points is a real effect or an artifact of the measurement. In both cases of data taking, presently and a year before, the probe plate was turned around. This changed some, but not all, the apparent details of the observed current distribution so that no firm conclusions, as to the influence of the probes on the experiment, can be made. The apparent run to run consistency of the two sets of data seems to indicate that on the short term the gun operates the same but in the long term, after frequent times of cleaning, repairing, reprocessing, etc., the details of gun operation do change. In all this, the gross behavior of the gun, i.e., ±20% uniformity over 20 to 25 cm, seems to stay the same.

Operation with endplates was accomplished by connecting the two grids (G1 and G2) together electrically and using the third lead in the high voltage feedthrough to bias the endplates. Within the estimated accuracy of the experiments, and taking into account the scatter in the observed data, the endplates did not change the observed current density distribution in a significant way. The averaged results for the various endplate operating conditions tend to show the same results as observed in the bell-jar data. In particular, operation with floating or biased (250 to 300 V) endplates increases the current density at the ends so that the region of ±20% uniformity is increased by ≈5 cm.

The apparent beam uniformity data observed in the transverse (4 cm) dimension were less consistent. In fact, the scatter of the data was much larger near the edges of the aperture, in both the longitudinal and the transverse dimensions, than near the center of the aperture. This may indicate that random or nonreproducible edge effects are present or that the hollow cathode discharge may be flickering in some way near these edges.

The best results obtained in these experiments do not match the (best) results obtained in the low voltage tests of the 4-cm x 40-cm gun, i.e., the bell-jar data and the data presented in Ref. 2. The presence of floating endplates helps some in extending the flatter portion of the beam, but does not make the uniformity in the central portion of the beam better.

3. Extracted Beam Measurements with a Single Moving Probe

Operation of the 4 cm x 40 cm plasma cathode e-gun in the same configuration for which it would be useful to pump e-beam sustained lasers was accomplished. In this configuration, the e-beam was extracted through a 4 cm x 40 cm thin foil window which was Kapton coated on both sides with a thin layer of aluminum with a total thickness of 0.0005 in. The chamber downstream of the foil was evacuated and housed the moving Faraday cup probe which was used in the bell-jar experiments. This probe was grounded through a low input impedance current to voltage converter and thus acted as an electron collector. As before, the position of the probe was monitored by putting a known voltage across a potentiometer, the moving contact of which was connected to the moving rod and probe, and reading the voltage on the contact. The probe diameter was 6.35 mm. Since, in these experiments, a single, moving probe was used to monitor the extracted current density, the possible probe to probe artifacts observed in the previous experiments were eliminated.

There was no attempt made to cool the foil so that operation at low current density and of short duration at 100 to 120 kV was required. Satisfactory operation at $\approx 100\ \mu A/cm^2$ for ≤ 1 sec was obtained, although the current density distribution data were taken at $\approx 30\ \mu A/cm^2$. At each probe position the received probe current signal was displayed on a storage scope along with a signal proportional to the total beam current drawn so that a reference for each probe position reading could be maintained. Data were taken with endplates both floating and connected to the cathode.

In Fig. 6, the results for the case where the endplates are floating are shown. This included the data from two runs, taken on different days and with different helium gas fills. Good reproducibility of the data is seen and the beam is uniform within ±5% over about 15 to 20 cm and ±10% over 25 cm. This can be compared with the similar data taken for the case in which the endplates are tied to the cathode as shown in Fig. 7. A comparison of the two sets of results is shown in Fig. 8 in which the averaged results for each operating condition are plotted. A small change between the two sets of data is apparent. This change, a slight increase in the density nearer the edges of the beam, is consistent with the results of the other two sets of experiments.

These results show that the extracted beam of the plasma cathode electron gun is very uniform, ±5%, over the central region of the gun aperture. Near the edges, 5 to 10 cm away, the current density decreases, probably due to sheath effects and potential gradients present at the gun in those regions. For a larger gun, of 100 cm to 200 cm length, these end effects represent a nonuniformity over a small fraction of the aperture and are tolerable. Endplates could be installed to help decrease these edge effects if operated either with a fixed potential (250 to 300 V) or allowed to float toward plasma potential. The latter case is to be preferred because no additional lead in the high voltage feedthrough is required.

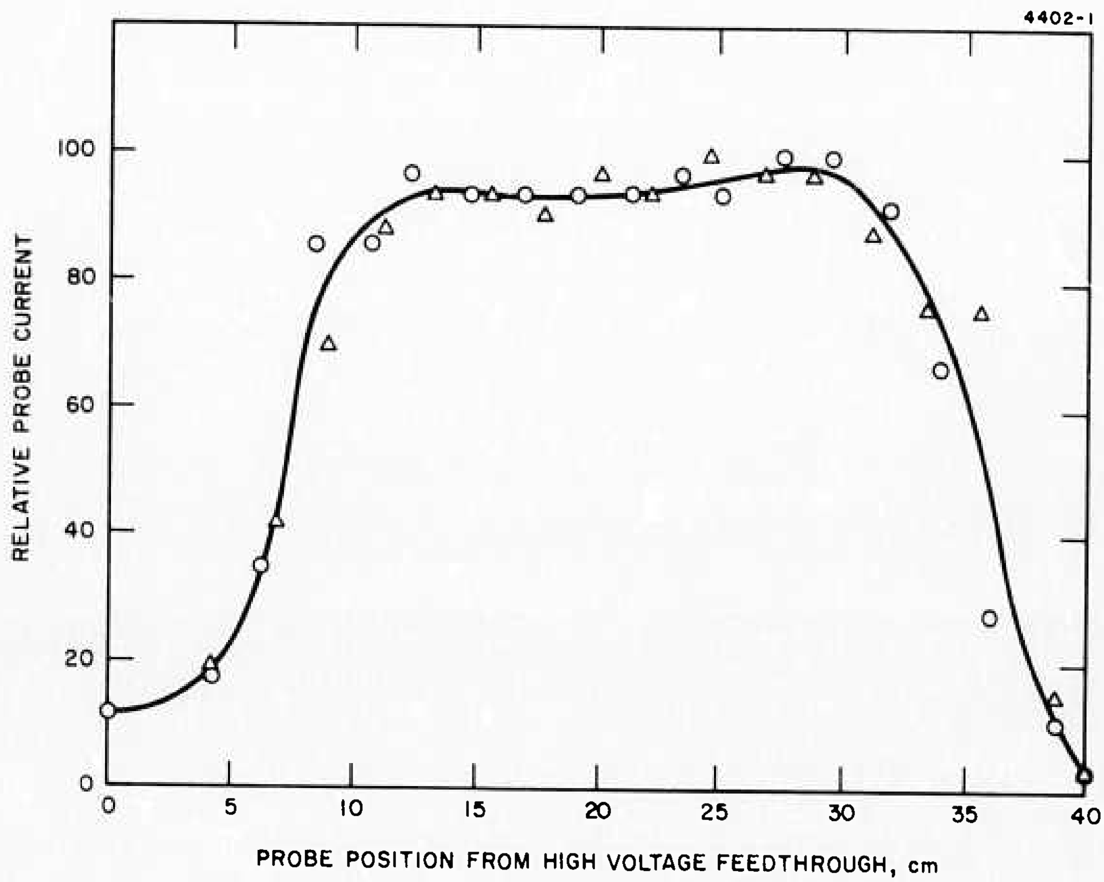

Fig. 6. Relative transmitted beam current versus probe position with endplates tied to the cathode and with a beam voltage of 100 kV and an average current density of 30 $\mu A/cm^2$.

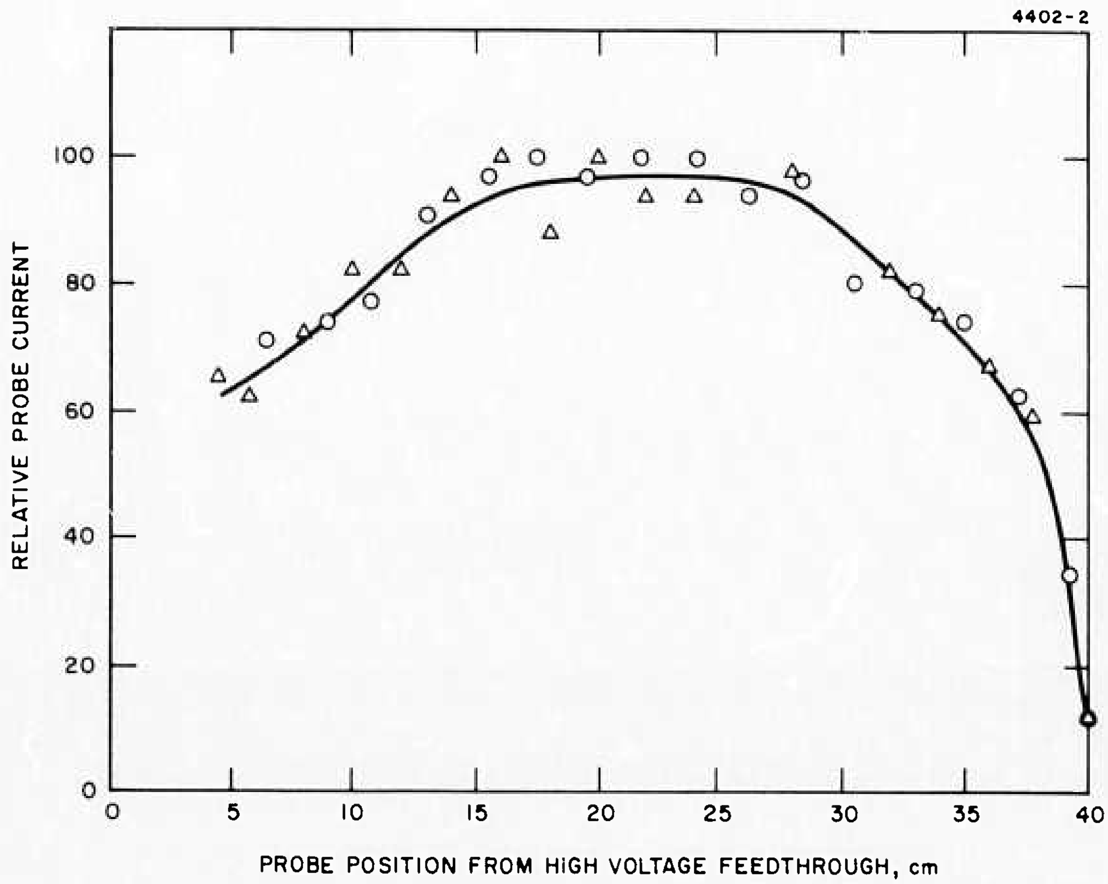

Fig. 7. Relative transmitted beam current versus probe position with endplates floating and with a beam voltage of 100 kV and an average current density of 30 $\mu A/cm^2$.

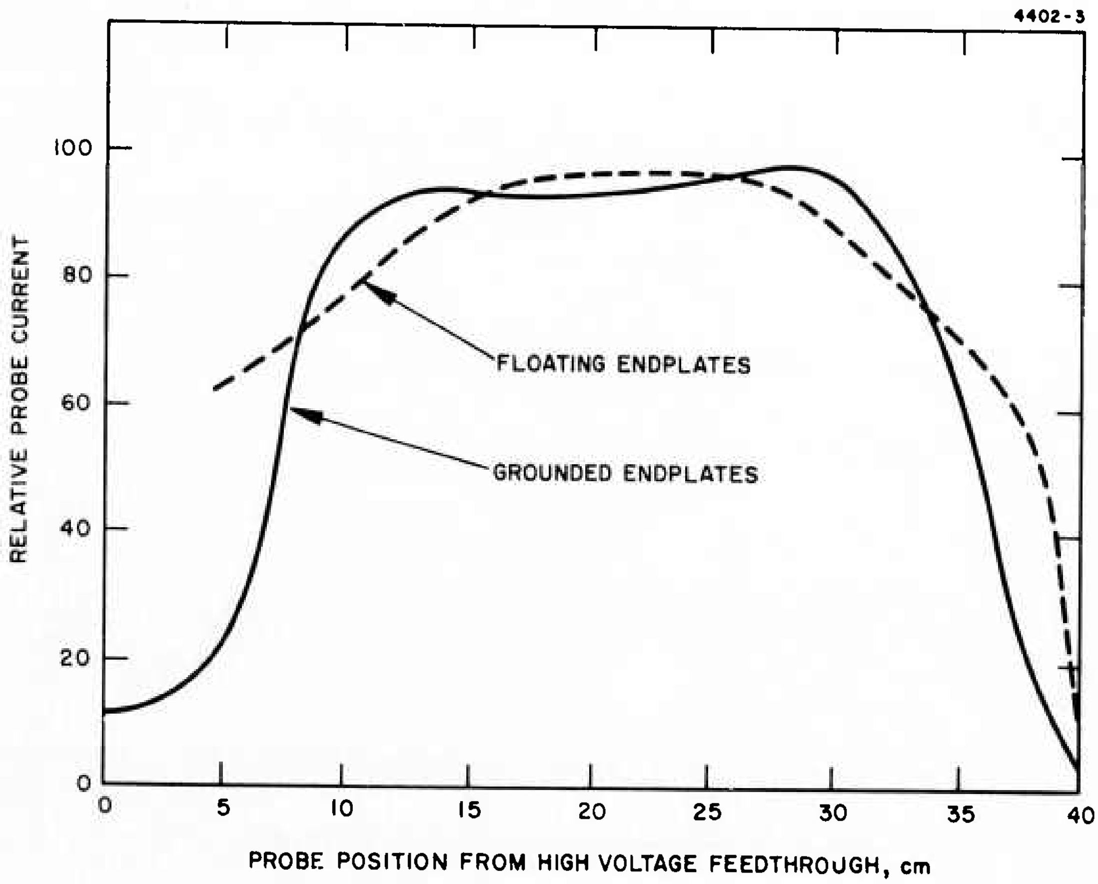

Fig. 8. Comparison of spatial distribution of output current.

IV. LOW PRESSURE PLASMA CATHODE E-GUN

When operating at high voltage and extracting the e-beam through a foil window, the plasma cathode e-gun is susceptible to Paschen breakdown arcs which occur to the foil and rupture it. These arcs are brought about due to an accumulation of poor Paschen characteristic gas contaminants which are released by the foil as it is heated by the electron flux. The foil cannot be heated or baked in the normal way to clean out these contaminants so that the operation with the beam is often the only cleaning procedure. These contaminants, as they collect, dominate the helium in determining the breakdown characteristic of the system and arcs occur. To circumvent these problems it has been suggested that a plasma cathode e-gun be constructed to operate at lower helium pressure than 30 mTorr, the approximate operating pressure for the 4 cm x 40 cm and 5 cm x 125 cm guns, so that the released contaminants would be less severe in affecting breakdown.

On another program at Hughes Research Laboratories, such a lower pressure plasma cathode e-gun has been constructed and is presently in operation. Although built for the program, "High Pressure Chemical Laser" funded by ARPA/MICOM, Contract DAAH01-75-C-0412, the details on this gun are included here because they are of general interest in gaining a better picture of the present state of development of the plasma cathode e-gun concept.

To obtain lower pressure operation of the plasma cathode e-gun it is necessary to increase the ratio of the hollow cathode surface area to the extracted beam area. In the gun built for the chemical laser project this surface area aspect ratio is about 125, whereas for the 4 cm x 40 cm gun the ratio is about 25. In the low pressure gun the extraction area is 2 cm x 4 cm and is located at one end of a 6 in. diameter by 6.7 in. long cylinder. This gun operates at less than 10 mTorr helium pressure. To further reduce the possibility of Paschen breakdown, the region of minimum pd across which the high voltage is applied (which is the region of minimum breakdown probability), is at the foil so that Paschen arcs, if they occur, should tend to occur elsewhere. In the present coaxial gun designs, like the 4-cm x 40-cm gun, the pd is nearly constant throughout so arcs can, and do occur often to the foil.

The new, lower pressure gun has been operated successfully for several months at 140 kV, with an average extracted beam current density (through a 0. 0005 in. aluminum foil window) of 900 $\mu A/cm^2$ and with an operating time of 100 msec. The foil window is mounted on an aluminum ribbed structure to aid heat conduction away from the foil during operation but no gas cooling of the window is provided. No detailed beam uniformity measurements have been taken. Some difficulty in obtaining reliable gun operation due to contamination of the cathode surface with diffusion pump oil and contaminants from the chemical laser mixture have been encountered.

V. CONCLUSIONS

During the past six months, efforts have been directed to study and improve the output e-beam uniformity of the 4 cm x 40 cm plasma cathode electron gun. To this end three experiments have been performed.

a. Low voltage tests of the hollow cathode structure in a bell-jar to determine the spatial variation of the plasma density in the hollow cathode discharge.

b. High voltage tests using a solid collector plate, in place of a thin foil window, and fixed Faraday collector probes to study the extracted current density spatial distribution.

c. Determination of the spatial distribution of a 100 keV e-beam, extracted through a thin foil window, by means of a single, moving current probe.

The best results of these experiments show that the output beam of the e-gun is uniform to within ±5% over the central 50 to 60% of the gun aperture. A uniformity of ±10 to ±20% extends over 70 to 80% of the aperture. The current distribution drops toward zero near the edges of the aperture, with increasing scatter in the observed data, and with a transition region of 4 to 7 cm. This transition region may be decreased by placing endplates, normal to the axis of the hollow cathode and at the ends of the 40 cm dimension of the aperture, and allowing these endplates to either float up toward plasma potential ($\approx$400 V) or biasing them at 250 to 300 V relative to the cathode. This decrease in the width for the transition from high to low current density at the edges means that the "flat" portion of the current distribution is extended by about 5 cm or 12% of the aperture. This decrease in the edge effects is believed to be due to the fact that an anode type sheath probably surrounds the endplates and is calculated to be only a few mm thick, whereas the cathode sheath which is present when no endplates are in place, is several centimeters thick.

It was also found that contamination of the hollow cathode surfaces by diffusion pump oil or other hydrocarbon or silicon impurities seriously degrades the performance of the gun. In particular, this leads to localized peaks in the output current density which may rupture the foil window during operation. These contamination effects may be circumvented by carefully trapping the pumping lines or probably by using an oil free pumping system such as a turbomolecular pump.

This program demonstrates that the plasma cathode e-gun is a practical gun for use with large scale cw e-beam lasers. Large scale guns (5 cm x 125 cm) with cw current densities of up to 1 mA/cm^2 have been demonstrated. The output current density is uniform to within ±5% except for a 5 cm region near the ends (using endplates). For large scale devices this represents a small loss in beam aperture. Some attention to pumping cleanliness is necessary but satisfactory solutions are well within the capabilities of modern technology. When necessary, lower pressure operation of the plasma cathode e-gun is also possible with some sacrifice in compactness.

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