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PULSED WIP ELECTRON GUN

MASTER

FINAL REPORT - FABRICATION PHASE

1 x 40 cm and 1 x 70 cm COOLED WIP ELECTRON GUN

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I. INTRODUCTION

Presented here are test results of a full scale (70 cm) WIP electron gun system capable of long-run operation with the following specifications:

Foil area	$\sim 70 \times 1$ cm
Electron beam current density	~ 1 A/cm ²
Pulse length	<200 ns FWHM
Pulse tail	<25% f pulse energy
Average current	~ 2 ma/cm ²
Voltage	~ 150 kV
Voltage droop	<10%
Rep rate	~ 10 KHz
Power	~ 20 kW
Run time	~ 30 min
Jitter	~ 10 ns

This report details the fabrication and test phase of a 40 cm uncooled and a 70 cm cooled WIP electron gun system. For a detailed description of the theory of operation of the WIP electron gun refer to Contract No. 78-73-09176. The design details for the 40 cm and 70 cm WIP guns are described in Contract No. 79-73-00775.

II. SUMMARY

An electron gun capable of long-run operation at 10 KHz and 1 A/cm^2 has been fabricated and tested. Pulse widths of 200-600 nsec and a total life of greater than 10^7 shots have been demonstrated.

During the acceptance tests, the electron gun was operated at a total average power of 20 KW for 30 minutes. This basically satisfied the contract requirements. To establish some upper limit of the gun's capability, the device was operated at a repetition rate of 3.5 KHz at a total average power of 54.5 KW for greater than 10 minutes. During these tests, no high voltage breakdown occurred after the device was processed. The beam uniformity at high repetition rates is $\pm 10\%$ and the efficiency is 50%.

III. ABSTRACT

WIP-TYPE ELECTRON GUN

The wire ion plasma (WIP) electron gun consists of an ion source, an extraction grid, and a high voltage cold cathode. Positive ions extracted from the plasma strike the high voltage cathode and produce secondary electrons which are then accelerated through the ion source to the thin metallic window. The electron beam distribution is thus the same as that of the ion beam falling on the cathode. Therefore, the ion source can be applied to generate, control, and regulate the electron beam. This is unique and advantageous because it can be accomplished at ground potential rather than at 200 kV.

In the high voltage region, a coaxial design with a 4 cm spacing allows operation on the left of the Paschen minimum. For 1-5m Torr Helium pressure, the Paschen breakdown is over 400 keV and vacuum breakdown is approximately 310 keV for this spacing. Hence, the probability of a Paschen breakdown is minimal after this region is processed for high voltage operation.

The grid assembly shields the ion source from the high fields in the acceleration region. Here, ions may be generated by a hollow cathode ion source, a thin wire discharge, or by various other thermal mechanisms. For long CW operation, the thin wire discharge is advantageous because it provides moderate currents and operates at reduced gas densities. A thin wire in 1 to 5m Torr He biased positively induces a potential well that traps electrons and causes them to spiral around the wire. This results in increased electron collisions with gas molecules and hence allows operation at extremely low pressures. It is thus possible to operate at near-vacuum characteristics where lower voltage stress levels increase the overall gun reliability. Figure 1 illustrates a schematic diagram of the wire plasma electron gun.

Approximately 25 percent of the ions produced in the source region are injected into the high voltage region. When they strike the molybdenum cold cathode, 14 electrons are liberated per incident ion. These electrons emerge with a preferential direction (normal to

cathode surface) and thus allow focusing by shaping the cathode with a concave contour. The electron beam now travels through the ion source and exits the electron gun through a thin foil window.

IV. SPECIFICATIONS

The design parameters for the electron guns are shown below. The 40 cm device was delivered 7 months ARO and the 70 cm gun was assembled and tested 12 months ARO.

Electron Gun Specifications

<u>Item</u>	<u>E-Gun 1</u> <u>Uncooled 40 cm</u>	<u>E-Gun 2</u> <u>Cooled 70 cm</u>
Foil area	1 x 40 cm	1 x 70 cm
Electron beam current density	1 A/cm ²	1 A/cm ²
Pulse length	200 ns FWHM	200 ns FWHM
Pulse tail	N/A	>25% of peak
Average current density	N/A	2 ma/cm ²
Voltage	150 KV	150 KV
Voltage Droop	N/A	<10%
Rep rate	10 KHz burst	10 KHz
Power deposition	N/A	20 KW
Run time	N/A	>30 min
Jitter	N/A	10 ns
Foil	Al	Al, cooled

V. FABRICATION MATERIALS

The design of the 40 cm and the 70 cm electron guns are based on data established in Contract No. 78-73-09176 and detailed in Contract No. 79-73-00775.

40 cm WIP GUN

The 40 cm WIP gun incorporates nickel-coated aluminum in the high voltage field shaping region, the plasma chamber, the extraction grid, and the foil support plate. All other materials, including the vacuum vessel and the pump manifold, are stainless steel.

70 cm WIP GUN

The cooled 70 cm WIP electron gun utilized stainless steel, molybdenum and copper in all structures except the foil support plate which is aluminum. These materials were chosen to minimize outgassing problems.

Both guns utilize 125 LPS turbomolecular pumps to establish the proper Helium pressure in the plasma chamber. The cross section of the 40 cm design is illustrated in Figure 2. The 70 cm cross section is similar but incorporates cooling in the foil support, grid, and cathode regions. This is illustrated in Figures 3 and 4.

Figure 2. Modified WIP Gun

Figure 3. Cross Section High Voltage Emitter

Figure 4. Foil Backup & Cooled Blankoff Plate

VI. TESTS

EXPERIMENTAL PROCEDURE

The test procedure was similar for both the 40 cm and the 70 cm WIP electron guns. A 125 l/sec turbomolecular pump provided a constant pressure throughout in the electron gun housing. Once the pump was up to speed, Helium was admitted through a fine leak valve until the pressure (calibrated thermocouple gauge) reached the desired value (2-60 mtorr). The plasma chamber is now fired several times by discharging a 5400 PF capacitor charged to 10 KV into the center wire electrode through a spark gap. This cleans the chamber wall by ion bombardment. The device is now ready for high voltage. When the voltage on the cathode secondary emitter has reached the operating value (150 KV minus), the capacitor circuit described above is triggered and the resulting plasma generates an electron beam that is measured with a Faraday cup. All current density measurements either in air or vacuum were conducted through a 0.5 mil aluminum foil.

HIGH VOLTAGE CIRCUITRY

The high voltage cold cathode is connected to the high-voltage power supply as shown in Figure 5. This arrangement was utilized previously for C.W. applications and does not represent an optimum circuit for high repetition rate applications.

PLASMA CIRCUITRY

For the single shot and two pulse experiments the pulse circuit consisted of the elements illustrated in Figure 6. Several versions of the same circuit were built and tested. Best results were obtained when the circuitry was located in close proximity to the electron gun. Attempts to connect the plasma chamber and driver circuit via 50 ohm coaxial cable resulted in longer pulse widths.

A 10 KHz thyatron pulse circuit was also built and tested. The pulse width of this circuit was 0.5 sec. Although this is not adequate for short pulse operation, it is useful in long run average

Figure 5. High Voltage Schematic

power tests. This circuit is shown in Figure 7.

TEST MEASUREMENTS

During the testing of both devices, the following currents could be monitored with the methods described below:

1. Total Cathode Current

This current, which is the sum of the ion current impinging on and the electron current leaving (due to secondary emission) the cathode, was read using a Pearson current transformer and an scilloscope readout. The current transformer was placed around a portion of the RG19 high-voltage cable and inside the outer conductor (which connected the high-voltage supply to the gun cathode).

2. Total Thin-Wire Current

The sum of the currents in the thin-wire discharges was also monitored via a Pearson current transformer.

3. Faraday Cup Probe Current

For the quasi-dc current measurements, this current was small. To measure the current, the voltage drop across a $10\ \Omega$ resistor placed between the cup and ground was read and amplified (gain, 10^3) for display on an oscilloscope. For the short pulsed measurements, in which current levels were much higher, a Pearson current transformer could be used. In both cases the Faraday cup collector was not biased. The collected current measured in such an arrangement has been estimated to be about 50% less than the actual e-beam current entering the cup aperture. The amplifier display system was carefully calibrated.

4. Collector Plate Current

Apart from the e-beam current collected by the Faraday cup, this current represents the total transmitter e-beam and was read via a Pearson current transformer in the ground return lead.

Figure 7. Thyatron Pulse - Circuit

VII. TEST RESULTS

40 cm WIP E-GUN (1/2 mil aluminum foil)

- Single Shot Beam Uniformity - A 1 cm² Faraday cup was placed in the center, +10 cm. and -10 cm from the center. The results are shown in Figure 8.
- High Rep Rate Beam Uniformity - At 2 to 5 KHz, a .3 to .5 sec electron beam burst was deposited on a tinted plastic film and optically scanned. The intensity variation was less than $\pm 10\%$ over 35 cm. A 20% edge effect roll-off was evident within 2.5 cm of each end.

Faraday Cup

- 1 cm²
- 25 ohm load
- 1/2 mil aluminum
- 150 KV
- single shot
pulser

+10 cm

center

-10 cm

Figure 8. 40 cm WIP Electron Gun
Single Shot Tests

70 cm WIP E-GUN

Single Shot Beam Uniformity

- A 1 cm^2 Faraday cup was placed in the center, +20 cm, and -20 cm from the center. The results are shown in Figure 9.

High Rep Rate Beam Uniformity

- A tinted plastic film was irradiated for several hundred shots at 1 KHz rep rate. The results were optically scanned and revealed less than $\pm 10\%$ uniformity for the center 60 cm. A 5 cm roll-off was evident at each end.

Faraday Cup

- 1 cm²
- 25 ohm load
- 1/2 mil aluminum
- 150 KV
- High rep rate pulser

+20 cm

center

-20 cm

Figure 9. 70 cm WIP Electron Gun
Single Shot Uniformity Test

LONG LIFE TESTS

The following tests were conducted with a water cooled copper blank-off plate in place of the foil window. The input power was measured at the high voltage power supply and the output power was measured as a temperature rise at the inlet and outlet of the blank-off plate. The total power in the gun can be expressed as follows:

$$P_T = P_S + P_A + P_B + P_I$$

where $P_T = 100\%$ = total internal beam power ($V \times I$)

$P_S = 40\%$ = interrupted power by both grids

$P_A = 25\%$ = absorbed in copper blank-off plate (Δt)

$P_B = 25\%$ = backscattered electrons from copper blank-off plate

$P_I = 10\%$ = ion beam internal to gun

The efficiency of the device is thus approximately 50% since backscattering is negligible with 1/2 mil aluminum foil. The following two tests were part of the acceptance tests supervised by Lawrence Livermore Laboratory personnel.

C.W. TESTS

The following C.W. test was conducted to process the gun after it had been opened to air. This illustrates in real time the processing procedure.

Time	Run Time (min)	Voltage	Current (ma)	Power In (KW)	Comment
10:00		92	20	1.8	
10:03		125	40	5.0	
10:07	7				Overcurrent
10:08		143	40	5.7	
10:10	2				"
10:11		155	40	6.25	
10:12	1				"
10:13		155	40	6.25	
10:14	1				"
10:15		155	60	9.3	
10:17	2				"
10:28		155	105	11.0	
10:30	2				"
10:37		155	125	19.4	
10:52	22				"
10:53		155	160	24.8	
11:14	21				Manual turn-off Gun is processed

PULSED TEST

The following high repetition rate pulsed test was conducted with a plasma pulser whose pulse width was approximately 0.5 μ sec. This test followed the C.W. test by 14 minutes.

Time	Run Time (min)	Rep Rate (KHz)	Voltage (KV)	Current (ma)	Power In (KW)	Comments
11:28	8	1	155	80	12.4	Start
11:36						Overcurrent
11:43		1	155	80	12.4	Start again
11:48		2	155	140	21.7	Increase current
11:54	36	2	155	160	24.8	Increase current
12:19						Terminate run
12:20		3.5	155	350	54.3	Start
12:40	10					Terminate run

During the pulsed tests the high voltage cathode potential was monitored and found to vary less than 10% of its nominal value. The average electron beam current versus operating voltage and plasma current is shown in Figure 10. Figure 11 illustrates the relationship between total high voltage power and output electron beam power.

Figure 10. Average Current vs. Operating Voltage As A Function Of Plasma Current

Figure 11. Total Internal Beam Power
Versus Output Electron Beam
Power

VIII. CONCLUSION

It should be emphasized that these two devices were designed for operation at 10 KHz. During single shot operation the statistical variation in the temporal development of the plasma leads to poor electron beam uniformity. Thus, at low repetition rates, auxiliary ionization sources are necessary to achieve the required background plasma essential to initiate a uniform electron beam profile. At high repetition rates, the residual plasma from the previous pulse provides the background ionization that achieves uniform plasma ignition.

It has been demonstrated that the gun can be processed in about 30 minutes after being opened to air. This is a significant result since it indicates that baking is not necessary and standard alcohol cleaning procedures suffice when cleaning the internal gun assembly.

During the entire test phase over 10^7 shots were accumulated on the device without any component damage whatsoever. It is important to note that during the last 45 minutes of the acceptance tests more than 6×10^6 shots were generated without any breakdown. During the last 10 minutes of the same test, thermal equilibrium was established at an average electron beam output power of 27 KW. The test was deliberately terminated due to inadequate x-ray shielding.