High Power Testing of a 17 GHz Photocathode RF Gun *

S.C. Chen, B.G. Danly, J. Gonichon, C.L. Lin, R.J. Temkin, S.R. Trotz, J.S. Wurtele,
Plasma Fusion Center
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Abstract

We report experimental high power test results on a high gradient 17 GHz RF photocathode gun. The $1\frac{1}{2}$ cell, π-mode, copper cavity was tested with 5-10 MW, 100 ns, 17.145 GHz pulses from a 24 MW Haimson Research Corp. klystron. A maximum surface electric field of 250 MeV/m was achieved corresponding to an on-axis gradient of 150 MeV/m. The gradient was verified by a preliminary electron beam energy measurement. Conditioning with $\sim 10^5$ shots resulted in a low field emission current, less than 6 mA. Future research will concentrate on measurements of the quality of electron beams produced by ps laser photoemission.

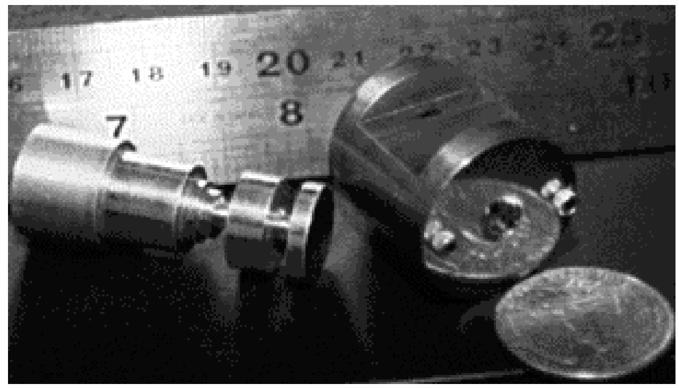

Figure. 1. RF Gun Cavity and Mandrel

I. Introduction

To meet the stringent requirements set by future applications such as high-energy linear colliders and next generation free electron lasers, efforts have been made recently to create novel electron beam sources[1]. Operation at high frequency allows for high accelerating gradient without breakdown, a compact system, and high brightness. While existing RF guns operate from 144 MHz to 3 GHz, MIT is constructing and testing a 17.136 GHz photocathode RF gun[2].

When operating with a photoemission, cathode The expected beam parameters of the MIT 17 GHz RF gun are, : output energy 2 MeV, normalized emittance 0.47π $mm{\cdot}mrad$, energy spread 0.18%, bunch charge 0.1 nC, and bunch length 0.47 ps. The experimental setup and status are described.

II. Experimental Layout

A. RF Source and Gun

Figure 1 shows the RF Gun cavity. Next to the cavity is the mandrel from which a previous version was electroformed. Later versions were constructed from machined OFHC pieces which were clamped together. Future versions will be brazed. The $1\frac{1}{2}$ cell cavity length is about 1.3125 cm. Figure 2 is a schematic of the experiment. The RF power source is a 17 GHz relativistic klystron developed by Haimson Research Corporation[3] and presently installed on the MIT High Voltage Modulator. The modulator voltage pulse is 560 kV, 95 A, and 1 μs. The klystron has a peak output power level of 26 MW corresponding to a saturated gain of 67 dB and an efficiency of 51%. Following the klystron are a dual-directional coupler, a twist, a bend, an RF window, and a second dual-directional coupler. The two couplers are used to monitor the forward and reflected power exiting from the klystron and entering the cavity. A fast Faraday cup is placed just at the exit of the RF gun cavity in order to measure the accelerated current. Lastly, the inside of the cavity can be observed optically with a prism built into the Faraday cup and a viewport in the vacuum vessel which holds the RF gun. The vessel is evacuated by a 220 l/s ion pump. A vacuum of $3 * 10^{-9}$ $Torr$ was achieved inside the RF gun chamber after a few weeks of pumping. This viewport permitted the detection of arcing and breakdowns which occurred inside the RF gun cavity. The breakdowns were characterized by flashes of light visible to the naked eye with the help of a remote television camera looking into the viewport. These flashes were coincident with shots in which a large spike of Faraday cup voltage was observed. The rectangular TE_{10} mode is coupled to the cavity through two rectangular apertures, one on each cell of the cavity, to excite the π-mode resonance. An intensive study of this waveguide sidewall coupling scheme has been conducted both theoretically and experimentally[4]. The values of Q_0, Q_l, and β are 1790, 808, and 1.22. The results of these tests and preliminary high-power gyro-amplifier operation were reported in [5].

B. Laser

An Argon-Ion pumped Ti:Sapphire laser produces a regeneratively modelocked CW train of 10^{-8} J pulses at 780 nm which enter a pulsed Ti:Sapphire laser amplifier. The amplifier is pumped by a 1 J frequency doubled Nd:YAG laser. One pulse is captured and amplified to 2 mJ. Pulse-to-pulse laser power fluctuation in the infrared is approximately $\pm$10%. To date, the amplified IR pulse has been frequency doubled using a KDP crystal with an efficiency of 50%. The pulse still must be frequency summed to generate UV using a BBO crystal. For typical quantum efficiencies of 10^{-5} in copper, the expected electron bunch charge is 0.4 nC. The design parameters of the laser system are summarized in Table I.

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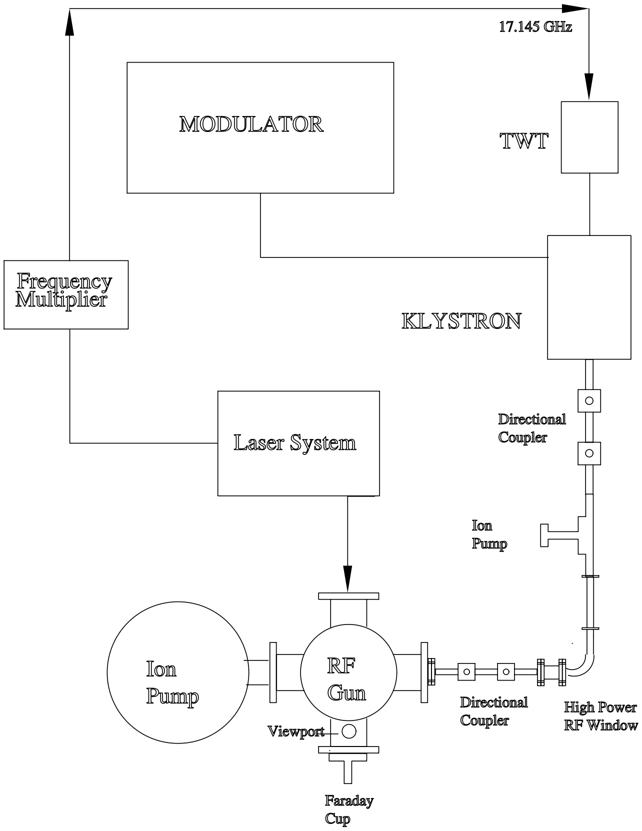

Figure. 2. Schematic of the experiment

C. Timing

Simulations have shown that the beam quality is strongly dependent on the RF phase of photoemission[6]. The phase jitter is required to be less than 1 *ps* in our experiment. The highly stable Ti:Sapphire laser system serves as the system clock in the timing chain. The modelock frequency of 84 MHz is defined by the round-trip time of the laser cavity. The laser oscillator cavity mirrors are mounted on an Invar tube to minimize length variations. The 84 MHz signal is multiplied up by a solid state frequency multiplier (x 204) into 17 GHz to drive the RF amplifier chain (see Fig. 2.

III. Results

A. Accelerating Gradients and Maximum Surface Field

For the results presented in this section, the RF gun was powered by the klystron but the laser system was not operational. Figure 3 is the record of a typical shot showing filling of the RF gun cavity and buildup of a strong electric field. The horizontal axis is time. Two of the traces are the forward and reflected power as measured by the 60 dB directional couplers just before the RF gun. The third trace, that of the electric field, is calculated from the forward and reflected power using the energy balance equation. The incident power is 7.5 MW. After the electric field builds up, the Faraday cup signal increases, remains nonzero for tens of nanoseconds, and then decays. This signal can be interpreted as partial breakdown or field emission. In addition, there

Table I
Parameters of the laser system

Wavelength	220-280 nm
Repetition rate	Single pulse and 0-10 Hz (adjustable)
Final output energy (per pulse)	0-200 μJ (adjustable)
Energy output fluctuation	$\leq \pm 10$ %
Pulse Length	<2 *ps*
Phase Jitter	<1 *ps*
Timing Jitter	<3 *ns*
Polarization	$>$ 99 %
Beam Divergence	0.5 to 1 $mrad$
Beam Pointing Error	$<$ 10 μrad
Mode-Lock Frequency	84 MHz

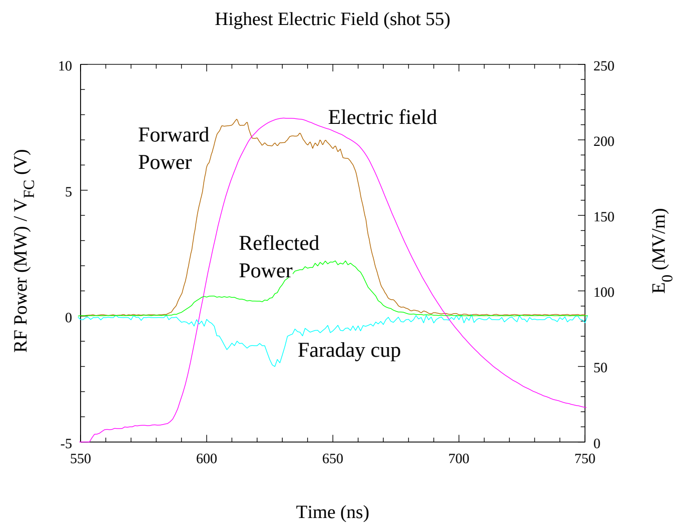

Figure. 3. Shot Number 55

is an increase in the reflected power coincident with a jump in the Faraday cup voltage. This pattern suggests a momentary true RF breakdown. However, the electric field still builds up to 210 MV/m on-axis corresponding to 250 MV/m on the cathode surface. This field gradient is the highest observed in the experiment to date.

B. Field Emission Level

Figure 4 illustrates the history of the conditioning of the RF gun cavity. As time progressed, the maximum sustainable electric field increased and stabilized. Similarly, the amount of field emission decreased with time.

C. RF Breakdown Observations

Figure 5 shows a typical shot in which RF breakdown occurred. The traces are as described in the previous shot. After an initial period corresponding to the filling time of the cavity, one observes that the cavity became mismatched and totally reflecting. This breakdown is correlated with a large spike on the Faraday cup, a pressure rise, and a visible flash inside the RF gun cavity. These four events are clearly signs of RF breakdown. This type of shot occurred frequently when the incident power exceeded 7 to 8

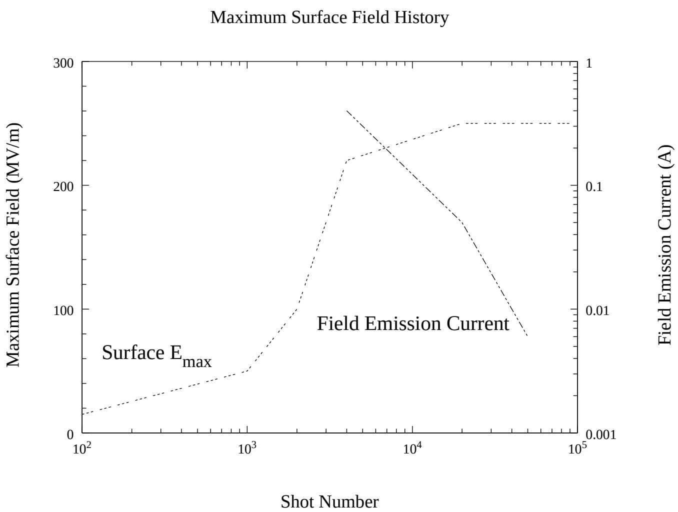

Figure. 4. Max Field History

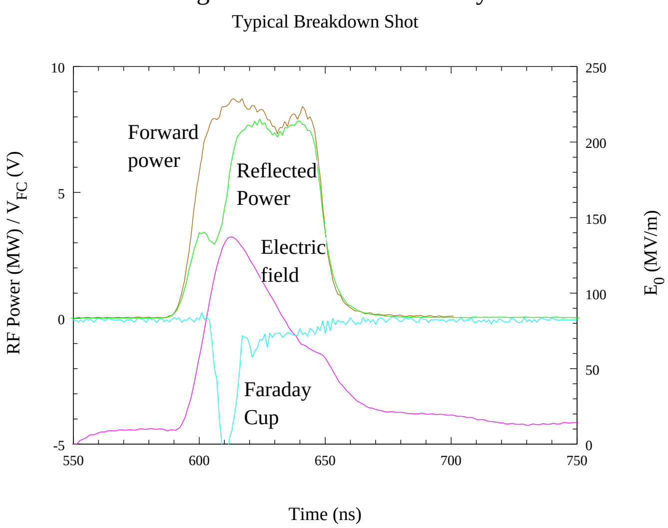

Figure. 5. Shot Number 70

MW. However, the % of RF breakdown shots decreased from 90 to 10 % during the conditioning process.

D. Preliminary Beam Energy Measurements

The current experimental setup of the Faraday cup yields the total charge emitted during a shot and the coarse time profile of the current emission. In order to gain some information about the kinetic energy of the emitted electrons, the following diagnostic was used. The ability of electrons to pass through sheets of various metals depends on the type of metal, the thickness of the sheet, and the energy of the electrons. Thus, aluminum and titanium foils of varying thicknesses were placed between the exit of the RF gun and the Faraday cup. The metal sheets act as filters allowing only electrons with an energy greater than some level to pass. Then, the integrated Faraday cup signal becomes an indication of the number of electrons to exit the gun with energy greater then this level. The thicknesses and materials of the metal sheets were chosen to stop 99% of electrons with energies below 220, 650, 1450, and 2250 KeV. Faraday cup signals were observed when the 1450 KeV sheet was in place. This result brackets the maximum electron kinetic energy between 1.45 and 2.25 MeV. Using the cavity length of 1.3125 cm, the energy gain corresponds to an average electric field between 110 MeV/m and 171 MeV/m. This measurement is consistent with the 150 MeV/m average field gradient deduced from the RF power balance calculation described above. Future experiments will employ a magnetic spectrometer for more precise determination of the electron energy spectrum.

IV. Conclusion and Future Work

A 17 GHz photocathode RF gun experiment is being performed at MIT. High power tests have been conducted at 5-10 MW power levels with 100 ns pulses. A maximum surface electric field of 250 MV/m was achieved. This peak value corresponds to an average on-axis gradient of 150 MeV/m. The gradient was verified by a preliminary electron beam energy measurement. Higher gradients are expected in future experiments utilizing a brazed cavity. To date, more than 90,000 pulses have been accumulated in the RF conditioning process.

Future plans for the 17 GHz RF gun experiment include the use of a brazed cavity design, integration of the laser to generate high quality electron beams, and improved beam diagnostics.