Time-Resolved Emittance Measurements of An Excimer-Laser-Driven Metal Photocathode

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Abstract

The velvet cathode material of a 4-MeV, electron-beam injector was replaced with a metal cathode and driven by an ArF excimer laser. Time-resolved measurements of photo electron current and effective cathode temperature were made. A streak camera and B-dot (magnetic field) probes were the primary diagnostics for the experiment. The streak camera determined effective cathode temperature in a single spatial dimension. Time-integrated photography was used to observe plasma formation in the cathode region. The results will be used to ascertain the feasibility of long-pulse (75 ns) beam generation for injection into a linear induction accelerator.

I. INTRODUCTION

Previous experiments on the Relativistic Electron-Beam Experiment (REX) injector were designed to study photo-electron quantum efficiency and to provide a basis for laser power scaling to a high-current (4 kA) photo injector [1]. Metal cathodes made of lead and aluminum were illuminated with a KrF excimer laser (248 nm). The ultimate base vacuum pressure on REX (5×10^{-6} torr) was limited by outgassing of the large plastic radial insulator in the diode region. The metal cathodes received only modest surface preparation. At 248 nm the quantum efficiency for the metals used was approximately 5×10^{-5}. To achieve space-charge-limited electron flow (>100 A/cm^2), the laser intensity must exceed 1 MW/cm^2. At greater intensities a cathode plasma is formed. This cathode plasma formation degrades beam emittance. The laser gas was changed to ArF (193 nm, 6.4 eV) and an order of magnitude increase in quantum efficiency was observed. Laser intensity was reduced, thus lowering the chance of plasma formation. This paper details experiments using an ArF excimer laser illuminating a diamond-turned aluminum cathode. Time-resolved beam-temperature measurements are made with a streak camera. In addition, integrated B-dot probes are used to measure anode and transported beam current. The streak camera film is analyzed through techniques developed to quantitatively determine emittance from a field emission velvet cathode [2]. The analysis program corrects for nonlinearities associated with the film and uses mathematical fitting routines. Comparison of photocathode and velvet cathode emittances are made.

II. EXPERIMENT

The REX experimental facility consists of a pulse power source capable of delivering a 4-MV, 55-ns flat-top pulse across a 15-cm anode cathode gap. For this experiment, the voltage was 3 MV. The vacuum vessel was modified through the addition of 4 viewing ports with Suprasil quartz windows to give line-of-site access to the cathode at 30° to the surface. The ArF laser used in the experiment was an injection-locked Lambda Physik EMG 150 EST excimer laser capable of delivering 300 mJ in a 15-ns pulse. The laser was placed 1.9 m behind the vacuum vessel and the beam turned at 45° through a negative 1.0-m-focal-length quartz lens. To illuminate a round area on the cathode, the spatial edges of the beam were clipped by placing a 22-mm by 13-mm ellipsoidal mask at the entrance of the viewing port as shown in Fig. 1. The combination of lens and mask projected an area of 13 cm^2 (4-cm diam) at the cathode surface. Laser light reflected from the cathode was monitored with a Hamamatsu R1193U-02 vacuum photodiode positioned on the opposite viewing port. The phototdiode was calibrated against a Gentec ED-500 joulemeter to obtain laser power on each shot and monitor laser temporal shape. Through the use of delay generators, the laser was synchronized with the arrival of the voltage pulse on the cathode. Time-resolved measurements of the cathode voltage, beam current, and the laser temporal pulse were made on 1-GHz-bandwith Tektronix R-7103 oscilloscopes with a digital-camera-system (DCS). The diode voltage (V-tube of Fig. 1) was measured with a self-integrated E-dot probe. Extracted beam current was measured with calibrated, 4-way-summed, integrated B-dots located at the anode aperture. Transported current was measured before the emittance mask 2.5 m from the cathode.

Accelerated electrons were transported by a solenoidal magnetic field to a brass emittance mask 2.53 m from the cathode. A peak magnetic field strength of 509 G was used to produce a nearly parallel beam at the mask. The mask contained a linear array of 1-mm holes spaced on 10-mm centers. Electrons passing through the holes are drifted 406 mm to a 0.5-mm-thick Bicron 422 scintillator. Electrons striking the scintillator produced light that was then imaged on the photocathode of the Thomson streak camera with an 89-

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mm-diam Questar telescope. A schematic of the optical path is shown in Fig. 2.

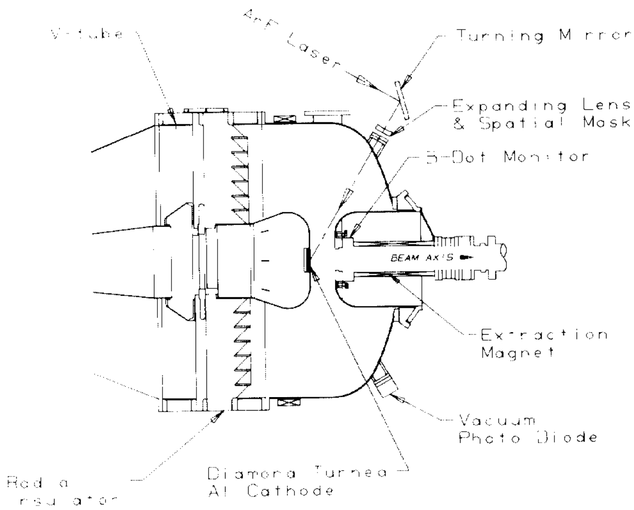

Figure 1. Schematic of REX Diode Region

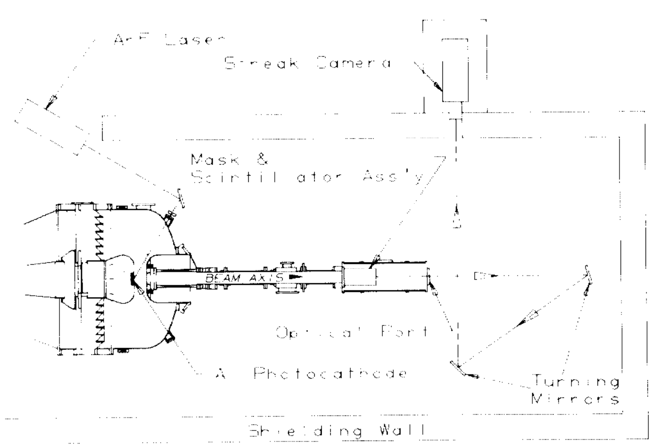

Figure 2. Experimental Layout

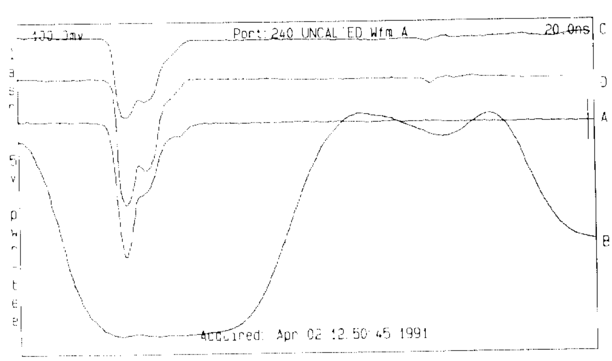

Figure 3. Tek 7103 Oscilloscope Waveforms
Laser Pulse (A)
Diode Voltage (B)
Transported Current (C)
Extracted Current (D)

III. MEASUREMENT AND ANALYSIS

Oscilloscope waveforms from DCS are shown in Fig. 3. Waveform A is the voltage pulse with a peak amplitude of 3 MV. Waveform B is the laser temporal pulse corresponding to a laser intensity of 0.59 MW/cm^2 (8.8mJ/cm^2). Waveform C is the transported current at 720 A. Waveform D is the anode current at 1120A. When the laser illuminated the cathode, electrons were produced, and so the current pulse shape followed the laser pulse shape. Tests were done timing the laser pulse to arrive before the voltage pulse on the cathode. No current was measured unless the laser and the voltage pulses were synchronized. The magnitude of the transported current was consistently 25% less than the anode current. To increase the current emitted from the cathode, the laser intensity was adjusted. When the intensity was increased to more than 0.6 MW/cm^2, plasma formed on the cathode surface and plasma electrons were emitted degrading the overall beam emittance. The REX injector perveance was 0.6μP, which at 3 MV yields space-charge-limited current flow of approximately 95 A/cm^2. The area illuminated during the experiment was 13 cm^2, and 89 A/cm^2 was obtained. This arrangement gave a quantum efficiency of 9.7 x 10^{-4}, which is in reasonable agreement with previous experiments [4].

A streak image of the beam is shown in Fig. 4. The streak speed was 3.8 ns/mm; the temporal resolution was limited by the 1-ns decay time of the scintillator.

Figure 4. Streak Photograph of Emittance Mask

The film used to record the image was Kodak T-MAX 400. A Perkin-Elmer microdensitometer was used to scan the film. Square apertures were inserted on both the top and bottom objectives to obtain a 50-um-diam spot on the film plane. The film was scanned in 50-um steps, and the pixel data stored on a computer for detailed analysis. Correction for film response was made by using results from a sensitometer. The sensitometer exposed film to light and characterized film density vs light exposure (D-log E curve). A corrected plot of beamlet intensity vs space is shown in Fig. 5. A 2-ns slice of the center beamlet was fit to a gaussian function to determine the rms width. To insure a good fit, the beamlet was magnified by inserting two Questar optical doublers between the telescope and streak camera. A plot of the magnified beamlet and gaussian fit is shown in Fig. 6. Correction was made for the finite hole size of the mask to find the "true" rms beamlet scatter. To obtain effective cathode temperature, we must take into account the expansion in the radial profile between the cathode and emittance mask. The expansion was modeled with ISIS [5]. Combining results of the temperature at the mask (3.5 mrad) with the ISIS calculation produces $\beta\gamma\theta$ rms = 7.5 mrad at the cathode surface. The corresponding effective cathode temperature is

$$T_{eff} = 0.511 \times 10^6 (\beta\, \gamma\, \theta \text{ rms})^2 = 28 \text{ eV}. \quad (1)$$

The corresponding Lapostolle emittance at the cathode is

$$\varepsilon_L = 2 \times \text{cathode radius} \times \beta\, \gamma\, \theta \text{ rms} = 0.029 \text{ cm-rad} \quad (2)$$

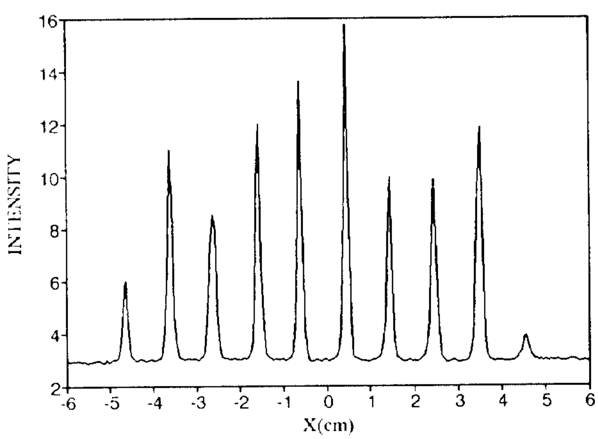

Figure 5. Beamlet Intensity Distribution

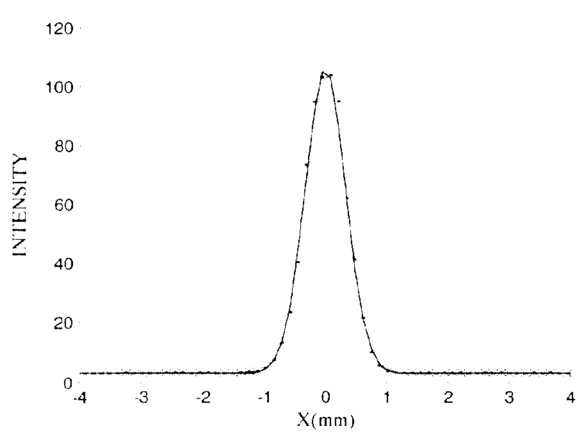

Figure 6. Magnified Beamlet

The measurement was made at the maximum photoelectron current (750 A) and the corresponding time history of the temperature was examined. Temperatures ranged from 20 eV at the front of the current pulse to 45 eV at the back.

IV. CONCLUSION

The flow of current produced by photo-electrons is not space charge limited. Measurements of transported current show that only about 65% of the extracted current reaches the downstream monitor. Measurements with a 31-cm ^{2} (6.4-cm diam) field emission cathode show similar beam losses at 3 MV. The streak camera data indicates that the emission from the cathode is not spatially uniform. Therefore, the ArF laser photon distribution must also be non-uniform. There may be areas of space-charge-limited flow adjacent to areas of emission-limited flow. Calculations by Lau [5] indicate that emission-limited flow would produce a higher emittance beam and this could possibly account for the current lost in transport. The effective temperature of the peak transported-current (750A) is lower (30%) than that of the 570A secondary peak which was highly emission- limited. The beam that is transported has a substantially lower effective temperature (28 eV) than the 117 eV measured from a field emission cathode with similar geometry.

V. REFERENCES

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