

MULTI-KILOAMPERE, ELECTRON-BEAM GENERATION FROM BARE ALUMINUM PHOTO-CATHODES DRIVEN BY AN ArF LASER

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Abstract

An electron-beam-pumped laser operating at ArF (193 nm) producing up to 5.0 joules in a 150-ns pulse has been used to illuminate micro-machined aluminum cathodes. The cathode was pulsed from 2.25- up to 2.95-MV across a 20-cm-AK gap producing fields up to 145 kV/cm using REX (a 4-MeV, 5-kA, 100-ns pulsed diode). Extracted current versus laser power gives a quantum efficiency increasing with power density from 0.07 to 0.11 percent. The present work is significant in that the cathode operates in the presence of out-gassing materials with a background vacuum pressure in the mid 10^{-6} torr region and 100-ns-long electron beams of up to 3 kA have been produced. Both emission limited (current follows laser pulse) and space-charge-limited (current follows pulsed power) regimes have been studied up to ~ 50 A/cm² by varying the cathode diameter. The beam temperature has been measured to be < 5 eV and directly compared in the same experimental setup to velvet based cathodes that measure ~ 100 eV.

1 INTRODUCTION

This work is a continuation of experiments reported in [1] with higher laser power illumination of the diamond turned (~ 0.5 μ m finish), 6061-T6, aluminum alloy cathodes. In addition, the measurement of the effective electron beam temperature of the cathode source has been made.

The primary advantage of a cathode utilizing the photo-electric effect from bare metals as compared to the more conventional photo-alkali or thermionic sources is the ability to have the cathode function in a modest vacuum environment ($\sim 10^{-6}$ torr). The disadvantage is that high laser energies (\sim joules) are required to drive multi-kA beams over 100-ns-long time periods as required of our present application [2,3]. Other researchers have investigated means of increasing the quantum efficiency by heating [4] or preferentially grooving [5] aluminum cathodes to increase the probability that an electron escapes the metal surface. The quantum efficiency, QE, is defined in this paper as: $QE = (I/P)(eV/\text{photon})$ where I is the emitted beam current, P is the laser power incident on the cathode, and the energy/photon is 6.42 eV. Small-scale, short-pulse, ArF studies are ongoing to address the relative QE's of other candidate metals and films, their preparation, and the effects of temperature, vacuum, and mono-layer contaminants [6].

2 EXPERIMENTAL TEST SETUP

Figure 1 shows the REX Facility [7] comprising an E-beam diode, excimer laser with beam paths, and diagnostics. The laser beam was directed by a turning mirror, focused toward a second turning mirror, through a window, and onto the cathode for beam temperature measurements. An elliptical aperture (2:1 aspect ratio) was used at the entrance window to make the beam circular on the cathode. To measure QE's at normal incidence, an alternate beam path utilized a turning mirror and lens combination that directed the laser beam through the entrance window of the test section that contained the E-beam mask and scintillator hardware.

The energy and spatial profile of the laser beam were recorded at the cathode conjugates by an Energy Monitor (Pyrex based, Scientech Inc., 10-cm absorbing calorimeter) and a Profile Monitor (Star Tech Instruments Inc., BIP-3100/Z6/F100, 10-cm, UV to CCD converter). The laser light was monitored by vacuum photo-diodes (see Fig. 1) at the source (SAM PD) and cathode (REX PD). Beam current was monitored 5 cm after the anode aperture and 125 cm from the cathode at the test section entrance with beam size controlled by the anode extraction magnet. The AK gap voltage was monitored by an array of four, integrated E-Dots flush-mounted on the anode face and were cross-calibrated by an energy spectrometer. Beam temperature diagnostics included a 3.2-mm-thick brass E-beam mask (located 160 cm from the cathode) containing an array of fifteen 1-mm-diam holes spaced on 10-mm centers except for a 2-mm-diam reference hole 2 cm on either side of center. Electrons transmitted through the array of holes drifted either 30, 50, or 85 cm to a strip of 0.5-mm-thick Bicron 422 scintillator. The resulting light was recorded on Kodak T-MAX 400 film by a Thompson-CSF, TSN-506-N streak camera located within a shielded screen room. The image was analyzed by techniques developed in [8,9] and yields both space and time resolved beam temperature of the cathode source.

3 QUANTUM EFFICIENCY

Figure 2 shows the voltage/current (VI) characteristics of a 6.35-cm-diam velvet cathode with the calculated [10] space-charge-limited (SCL) current plotted in Fig. 3. At 2.25 MV the calculation over-predicts the current by 10%: 1.360- versus 1.215-kA measured. The plot is very useful in estimating the effective beam diameter on the photo-cathode.

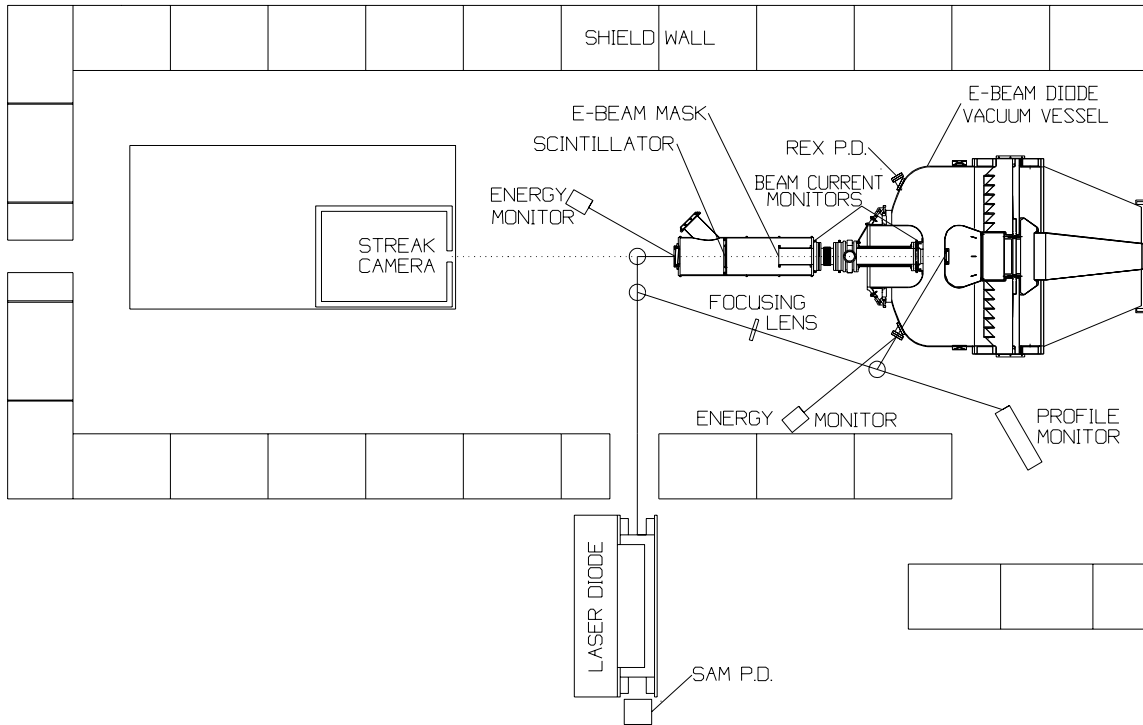


Figure 1. Layout of REX electron-beam facility with electron-beam-pumped excimer laser diode.

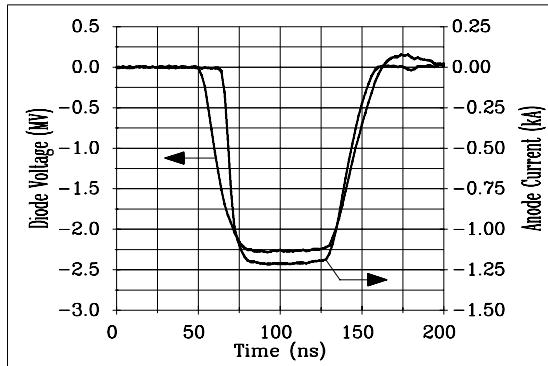


Figure 2. VI characteristics of 6.35-cm-diam velvet cathode at 2.28 MV, AK gap is 20 cm; note delay of diode turn-on.

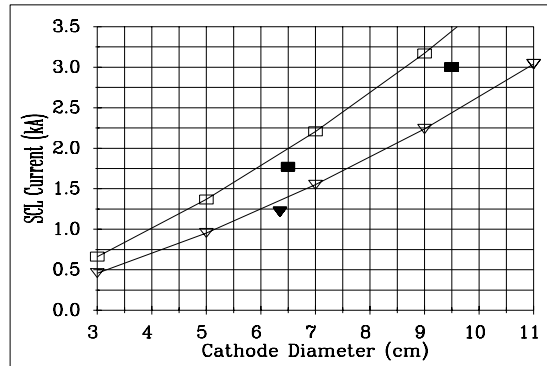


Figure 3. Calculated SCL current at 2.25- (▽) and 2.90-MV (□), AK gap is 20 cm, velvet (▼) and photo (■) SCL data.

For beam temperature and low laser power normal incidence experiments, the laser was focused to a $1/e^2$ diameter of 6.0 cm as measured by the Profile Monitor. The larger (~9.5 cm) laser beam could only be estimated by imaging the visible light emission at the cathode. ArF propagation losses experienced in our previous work [1] were greatly reduced by moving the laser close to REX. As the laser power was increased from a few- to 30-MW, the current for each beam size approached the SCL current region (current follows voltage) as indicated by the current plateaus in Fig. 4. The QE is bounded by a value of 0.07% at the lower power

densities and by 0.11% at much higher power densities which is consistent with our previous work [1]. The SCL currents for this data are 1.77- and 3-kA. The anode current, diode voltage, and REX PD for the larger-beam case are shown in Fig. 5. At 28 MW the laser power is ~50% greater than that needed for SCL conditions. At 8.6 MW the current of 1.47 kA is emission limited (current follows laser). Other measurements at lower currents from 100- to 1200-A and laser powers from 1- to 10-MW in a 6.0 cm-diam beam gave QE's of 0.07- and 0.078-% for incident angles of normal and 60 degrees, respectively.

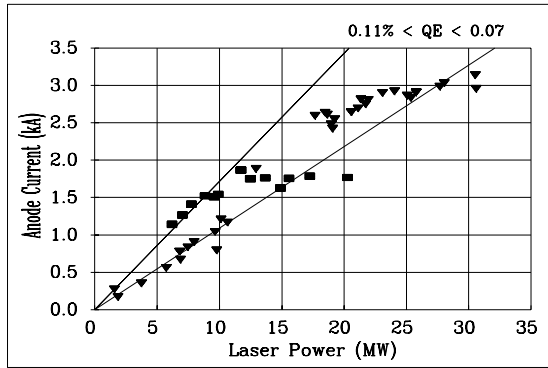


Figure 4. Anode current vs laser power at 2.95 MV, AK gap is 20 cm, 6.0- (■) and 9.5-cm-diam (▼) laser beams.

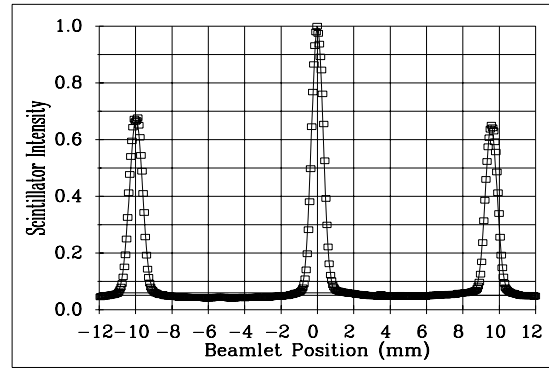


Figure 6. Gaussian fits of photo-cathode beamlet data (□) (averaged over 10 ns) at 510 A and 2.28 MV, drift is 85 cm.

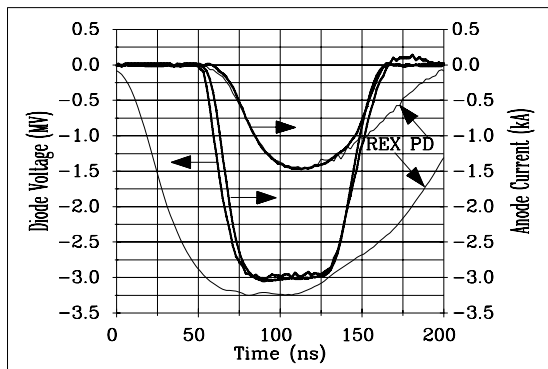


Figure 5. VI of photo-cathode at 8.6- and 28-MW.

4 BEAM TEMPERATURE

The effective beam temperature, T_{eff} , is defined as: $T_{\text{eff}} = 0.511 \times 10^6 \times (\beta \gamma \theta_{\text{rms}})^2 \text{eV}$, where θ_{rms} is the rms angle of the distribution of the electrons on the scintillator due to the transverse momentum of the electrons created at the cathode and the self space charge of the beamlet as it drifts from the E-beam mask hole. θ_{rms} must be modified by R_m/R_c which is the ratio of the electron beam at the mask to the cathode. The scintillator was placed 30- and 50-cm from the E-beam mask for the velvet and 50- and 85-cm for the photo-cathode data. The resultant T-MAX film image was scanned by a Perkin-Elmer micro-densitometer with 10- and 20- μm -square apertures for the photo-cathode and velvet data, respectively. The center three beamlets were each time averaged over a 10-ns window, the data corrected for the film density versus exposure curve, and gaussians fit to each distribution. The resultant rms radii of the gaussians were used to calculate θ_{rms} knowing the drift distance and R_m/R_c . The data were also corrected for the finite hole size in the mask; this effect is $\sim 20\%$ for a 5 eV beam drifting 85 cm with $R_m/R_c \sim 1$. T_{eff} averaged over the center three beamlets for the photo-cathode

data of Fig. 6 is 4 eV which is at the limit of the present technique. The velvet data at 1.2 kA gave 90- and 85-eV at 30- and 50-cm, respectively. The value of T_{eff} remained constant spatially and temporally across the flat-top portion of the beam.

In summary, multi-kA (~ 3 kA), 100-ns-long beams can be produced with an ArF laser at a QE $\sim 0.1\%$ on bare aluminum. The beam temperature of the photo-cathode was measured to be < 5 eV for currents ~ 500 A at 2.28 MeV.

5 ACKNOWLEDGMENTS

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6 REFERENCES

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