LEGIBILITY NOTICE

A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although portions of this report are not reproducible, it is being made available in microfiche to facilitate the availability of those parts of the document which are legible.

3

CONF 870302-61

LA- UR-87-810

LA-UR--87-810

DE87 007499

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.

TITLE: A PULSED ELECTRON INJECTOR USING A METAL PHOTOCATHODE IRRADIATED BY AN EXCIMER LASER

AUTHOR(S): T. J. Kauppila, L. A. Builta, J. K. Crutcher, J. C. Elliott, and D. C. Moir

SUBMITTED TO: IEEE Particle Accelerator Conference
Washington, DC
March 16-19, 1987

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

A PULSED ELECTRON INJECTOR USING A METAL PHOTOCATHODE
IRRADIATED BY AN EXCIMER LASER*

T. J. Kauppila, L. A. Builta, J. K. Crutcher, J. C. Elliott, and D. C. Moir
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Abstract

The hot cathode of an electron gun is replaced by a metallic photocathode driven by an excimer laser. The current, current density, and emittance of the 500-kV electron beam produced by the photoelectron source are presented. In addition, the temperature of the photocathode is varied to study the possibility of a hybrid source.

Introduction

Laboratory experiments have been performed to assess the feasibility of an excimer laser-driven photocathode as a high-current electron source.[1-3] This paper describes experiments using an 800-mJ, 20-ns pulse width, KrF excimer laser to generate an electron beam in a full-scale electron gun. The gun is a standard PHERMEX hot cathode source[4,5] that has a spherical Pierce geometry. The 100-mm-diam dispenser cathode is replaced with a simple metal cathode that is illuminated at a 45° angle. Because the cathode can be heated, a hybrid (hot/photocathode) source was also studied. The electron beam produced by the photocathode has the temporal shape of the laser pulse and is independent of the voltage source. The eventual photo-cathode application is an injector for PHERMEX that can produce a train of electron beam pulses, synchronized with the 50-MHz rf accelerating fields. This new injector could minimize energy dispersion between micropulses, maximize beam transport, and simplify pulse power requirements for multipulse generation (i.e., electron bursts separated by greater than the characteristic cavity accelerating cycle of 20 ns).

Experiment

The experimental apparatus included a standard PHERMEX electron gun[4,5] modified to accept laser illumination of the cathode. Changes for laser beam entry included a 25-mm-diam, suprasil window, entrance port in the vacuum wall and a 25-mm-diam hole in the anode. Corning 7940 +50-mm focal length uv grade optics were installed between the entrance port and anode to expand the beam across the cathode as shown in Fig. 1. The laser used for illumination of the cathode was a Lambda Physik EMG-150EST, injection-locked, unstable resonator. The 100-mm-diam cathode had a radius of curvature of 225 mm and total area of 8100 mm^2. The experiments reported here were with an aluminum (6061 T) photocathode.

Cathode voltage was produced by a Femcor 200-ns, 500-kV, Marx generator. Voltage was monitored with a 0.1-Ω, 500-Ω, voltage divider in parallel with the gun. A schematic of the experimental arrangement is shown in Fig. 2. Current generated from the photocathode was monitored with a self-integrating, magnetic-sense, B-dot loop in the drift space.[6]

A BNC Model 7102 delay generator in the laser trigger line was used to synchronize the laser pulse with the center of the voltage pulse. Both gun voltage and current were monitored with Tektronix Model 7103, 1-GHz-bandwidth oscilloscopes. Voltage on the gun was varied by changing the charge voltage on the Marx. Laser intensity was selectively varied by insertion of calibrated beam splitters into the laser path and adjustment to the laser discharge voltage. An open-shutter camera was used to photograph the time-integrated beam pattern transmitted through the emittance mask. Emittance was then measured as in Ref. [4].

*Work performed under the auspices of the U.S. Department of Energy by Los Alamos National Laboratory under W-7405-ENG-36.

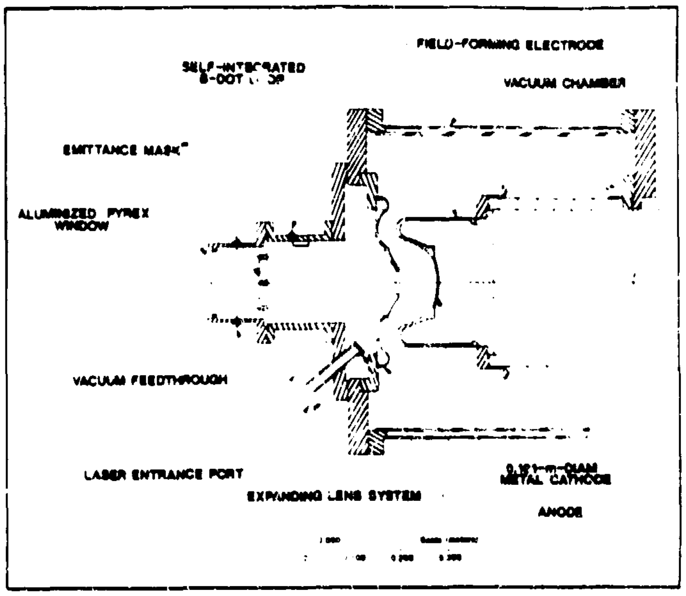

Fig. 1. Standard PHERMEX gun modified for photocathode experiment.

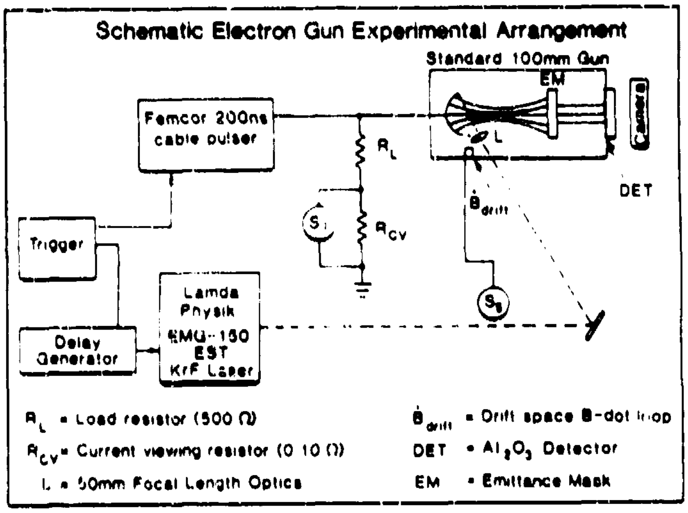

Fig. 2. Schematic electron gun experimental arrangement.

Results

The illumination area of the photocathode determines the perveance of the electron gun[7] and therefore total electron beam current. Illumination of the entire cathode area would produce a perveance of 1 μP. With the available optics this was not possible. The illumination area of the cathode was 1974 mm^2 or approximately one-fourth the total cathode area. This constraint limited the peak current but did not affect the current density. The laser energy on the cathode was limited to a maximum of 150 mJ because of the aperture on the laser entrance port.

Waveforms representative of the electron gun voltage, the electron beam current pulse, and the laser pulse are shown in Fig. 3, demonstrating that the beam current tracked the laser and was independent of the voltage pulse on the electron gun. Current rise-times of 7.0 ns were measured but may have been less due to cable inductance.

The peak photoelectron current density vs voltage is shown in Fig. 4 for various laser powers. For all of the laser powers and gun peak voltages ≤420 kV, the current density is space-charge limited. The data fit the function

$$J = (0.21 \pm 0.02)\ V^{3/2} \quad , \tag{1}$$

where $J = I/A$, I is the total current measured by the self-integrated B-dot loop, and A (the illumination area) equals 1974 mm^2. At the lowest laser power, the beam is emission limited at 420 kV; at the highest power the emission limit increases to 600 kV. The maximum current density achieved in the experiment was 7.6 A/cm^2.

The emission-limited data can be used to derive a quantum efficiency as was done in Ref. [3]. For the aluminum photocathode, the quantum efficiency was found to be 7.5×10^{-5} electrons/photon. This number is five times the value obtained in Ref. [3] for aluminum; however, there was a vast difference in surface preparation. That may explain the discrepancy. Heating the cathode to approximately 400° C produced a rise in quantum efficiency to 1.5×10^{-4} electrons/photon. The

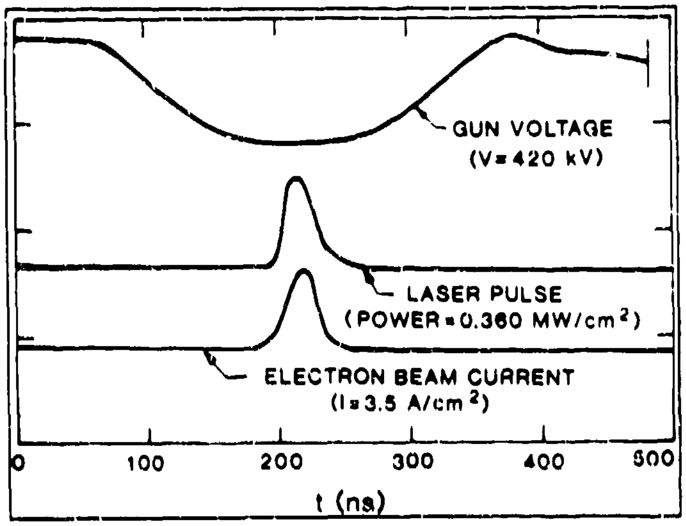

Fig. 3. Waveforms of the electron voltage, laser pulse, and electron beam current.

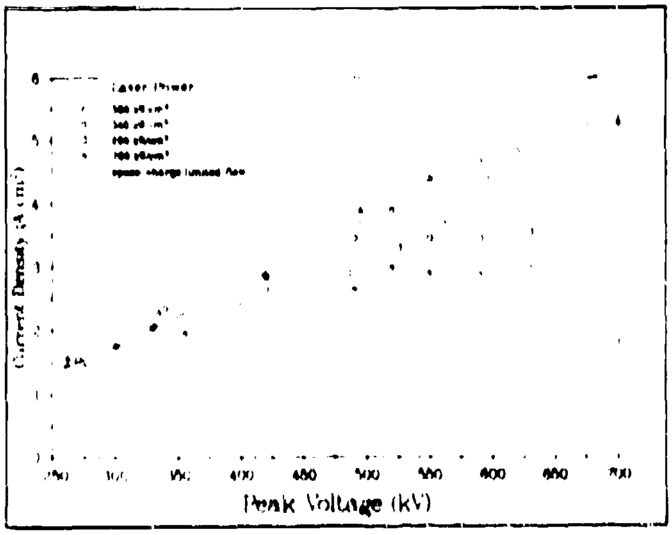

Fig. 4. Peak photoelectron current density vs voltage.

cause was likely a natural cleaning of surface contaminates because the quantum efficiency did not change after the cathode was recooled. As was observed in Ref. [3], the quantum efficiency was roughly independent of laser power.

Figure 5 is a photograph of the space-charge limited beam distribution beyond the emittance mask. The time-integrated emittance taken from Fig. 5 is plotted in Fig. 6. For emission-limited flow, there was evidence of nonuniform (hot spot) emission, as is typically seen in the conditioning of dispenser (hot) cathodes. The FWHM emittance was found to be 50 π mm-rad for a gun voltage of 355 kV, a total beam current of 45 A, a current density of 2.25 A/cm^2, and a pulse width of 20 ns. The normalized emittance of $\epsilon_n = \epsilon\beta\gamma$ is found to be 68 π mm-rad. Normalized time-integrated emittance value obtained for a standard electron gun with hot cathode is ϵ_n = 160 π mm-rad for a gun voltage of 440 kV, a current of 280 A, a current density of 3.5 A/cm^2, and a pulse width of 200 ns. The primary difference between the emittance measurements is the energy dispersion due to the 30 ns rise and fall time in the hot cathode measurements.

Conclusions

The normalized emittance of electrons produced by an excimer-laser-driven photocathode for space-charge limited flow has been determined. The emittance is less than the value obtained for a hot cathode. However, because of the temporal differences of the beam current pulses, an absolute comparison would require a time-resolved measurement of hot cathode emittance over a corresponding 20-ns period of the laser.

Extrapolation of these results to a 5-MV, 5-kA planar cathode injector with a 30-cm, anode-cathode gap and an aluminum photocathode indicate that a laser energy of 3.3 J would be required to obtain space-charge limited flow. According to Ref [3], use of a Pb photocathode would reduce the laser energy requirements to less than 1 J, well within the energy range of commercially available excimer lasers.

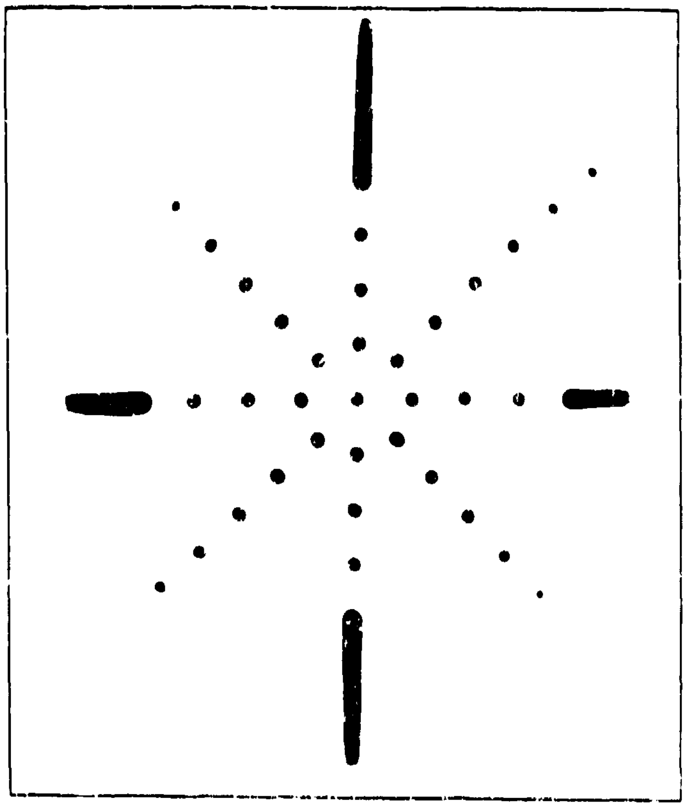

Fig. 5. Typical emittance record.

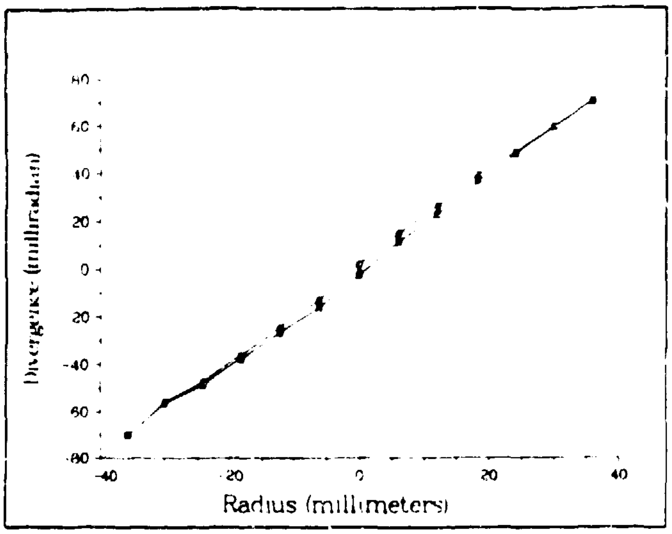

Fig. 6. Emittance plot.

References

[1] Y. Kawamura, K. Toyoda, and M. Kawai, "Generation of Relativistic Photoelectrons Induced by Excimer Laser Irradiation," Appl. Phys. Lett. 45, p. 307, 1984.

[2] S. W. Downey, L. A. Builta, and D. C. Moir, "Simple Laser-Driven, Metal-Photocathode Electron Source," Phys. Lett. 49, p. 911, 1986.

[3] J. D. Saunders, T. J. Ringler, L. A. Builta, T. J. Kauppila, D. C. Moir, and S. W. Downey, "Simple Laser-Driven, Metal-Photocathodes as Cold, High-Current Electron Sources," Proc. of IEEE Part. Acc. Conf., Washington, DC, March 16-19, 1987, to be published in this issue.

[4] J. C. Elliott, R. J. Faehl, H. J. Fullbright, D. C. Moir, and C. E. Swannak, "Intense Low-Emittance Electron Gun Development at PHERMEX," IEEE Trans. Nuc. Sci. NS-28, p. 2699, 1981.

[5] L. A. Builta, J. C. Elliott, D. C. Moir, T. P. Starke, and C. A. Vecere, "PHERMEX Electron Gun Development," IEEE Trans. Nuc. Sci. NS-30, p. 2728, 1983.

[6] R. L. Carlson, R. N. Ridlon, and L. E. Stout, "Multigigahertz Beam Current and Positron Monitor for Relativistic Electron Beams," Rev. Sci. Instrum. 57, 2471 (1986).

[7] J. R. Pierce, Theory and Design of Electron Beams, Van Nostrand Co., Inc., p. 183 (1954).