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LA-UR -89--972

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LA-UR--89-972

DE89 009269

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SUBMITTED TO 1989 Particle Accelerator Conference, March 20-23, 1989
Hyatt Regency Hotel, Chicago, IL

Los Alamos

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FORM NO 836 R4
ST NO 2629 5/81

PULSED 4-MeV ELECTRON INJECTOR WITH AN EXCIMER LASER DRIVEN PHOTOCATHODE*

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Abstract

The Relativistic Electron-Beam Experiment injector at the Los Alamos National Laboratory is used to generate a 4-MV pulse across an anode-cathode gap. A simple metal photocathode is illuminated by a pulsed excimer laser. Time-resolved measurements of current, voltage, and current density are made. The resulting quantum efficiencies are being used to obtain the required laser power for a multikiloampere, high-brightness electron gun to be used as an injector f r a linear induction accelerator.

Introduction

In previous work on the PHERMEX electron gun (Ref. 1), it was found that excimer lasers and simple metal photocathodes could provide a source of low-emittance electrons for injection into an rf accelerator. This paper describes experiments on the Relativistic Electron-Beam Experiment (REX) machine to provide scaling factors for a high-current photoelectron injector for potential application to the Dual Axis Radiographic Hydrotest Facility (DARHT) accelerator. A photocathode injector would provide a beam with a much lower effective temperature than the velvet cathode presently in use (Refs. 2, 3).

Experimental Set-up

An injection-locked Lambda Physik EMG 150 EST excimer laser capable of running on ArF (193 mm, 6.4 eV) or KrF (248 mm, 5 eV) was used as the source of photons.

The laser beam was directed through 8 m of air, through a quartz window at the entrance of the diagnostics chamber, and onto the metal cathodes surface (Fig. 1). The resulting photoelectrons from the cathode are then accelerated across a 15-cm anode-cathode (A-K) gap of the REX accelerator. The area illuminated on the cathode was changed by placing a lens in the path of the laser beam and varying its distance to the cathode. The area was measured using Dylux UV photosensitive film. Laser energy was measured with a Gentec ED-500 Joulemeter and was varied by placing 50-mm-thick quartz flats in the beam. The temporal shape of the laser pulse was measured with a Hamamatsu R1193U vacuum photodiode located at the quartz window and sensitive to light reflected from the cathode. The laser was synchronized with the arrival of the voltage pulse on the cathode. The REX electron beam current and voltage were measured with a series of probes described in Ref. 3.

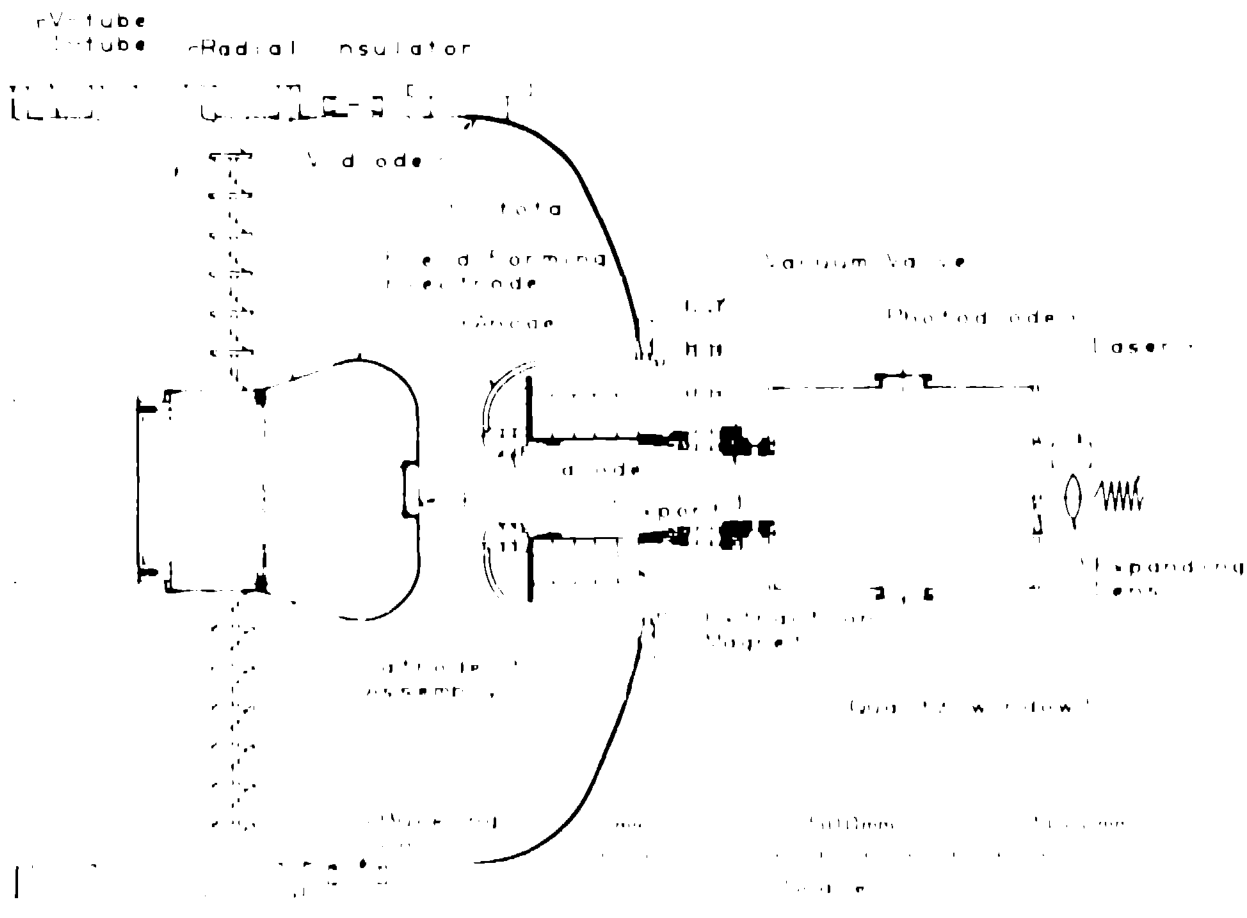


Fig. 1 REX Experimental Arrangement

*Work performed under the auspices of the U.S. Department of Energy

Results

When photoelectrons are produced at the cathode, the diode current (Fig. 2) follows the temporal pulse shape of the laser (Fig. 3) and not the voltage pulse. Figures 4a and 4b are sample REX voltage and current traces from the velvet cathode (Ref. 3). The laser power density varied from 0.77 - 8.8 MW/cm^2 for KrF, and from 0.07 – 3.5 MW cm^2 for ArF.

The quantum efficiency (QE) was computed for various cathode materials as

$$QE = J \times E/I \quad (1)$$

where J = photoelectron current density in A/cm^2,
E = energy per photon in eV, and
I = intensity of the laser in W/cm^2.

The quantum efficiency must be computed in the emission-limited region because space charge effects reduce apparent electron emission.

At laser intensities of ~ 1 MW/cm^2, plasma electrons were formed on the surface of the cathode. These electrons are accelerated across the A-K gap and the temporal shape (Fig. 5) is dramatically different from the laser pulse (Fig. 3). It was suspected that surface quality was the cause of plasma formation with the aluminum and lead cathodes. However, even when

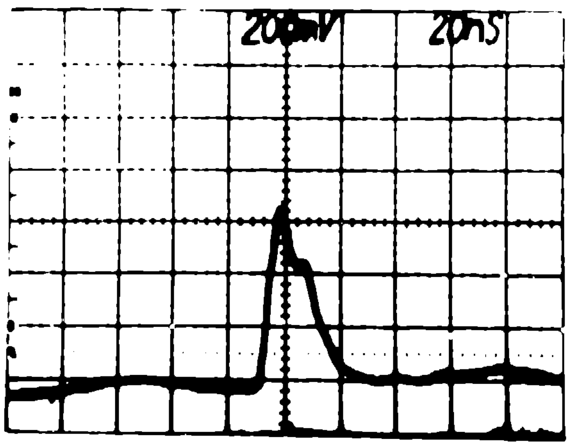
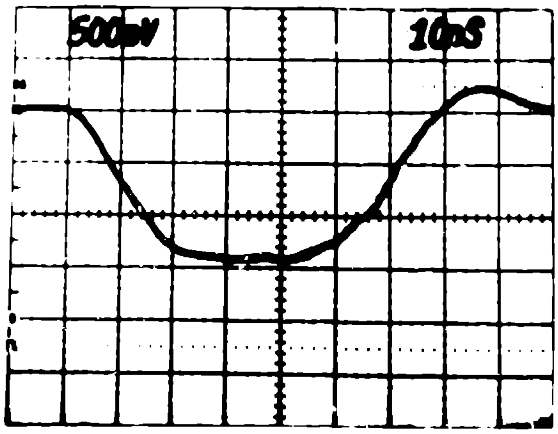
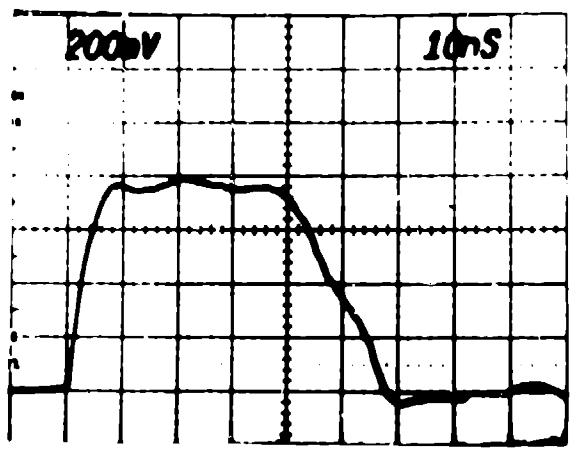


Fig. 2. Photocathode Electron Beam Current (I-diode).



4a.



4b.

Fig. 4. Diode (a) Voltage and (b) Current Waveforms with Velvet Cathode.

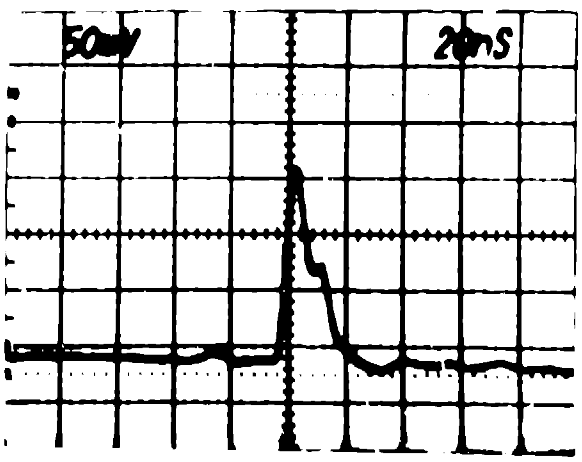


Fig. 3. Laser Temporal Pulse Shape from Vacuum Photodiode

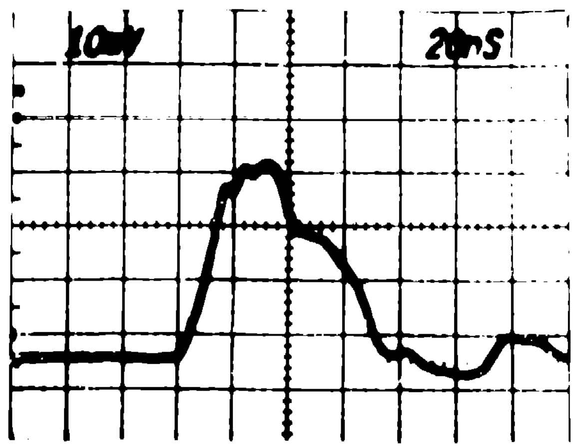


Fig. 5. Photocathode Electron Beam Current with Plasma Formation

these metals were diamond turned to a mirror finish, it was found that plasma formed on the cathode at the same laser intensity. This result is indicative of surface contamination by a monolayer of gas that forms at vacuum pressures of ~ 10^{-5} torr used in the experiment. The ultimate base pressure (5×10^{-6} torr) in REX is limited by outgassing of the large Lucite insulator and the Glyptal-coated, field forming electrode.

The KrF quantum efficiency was 5×10^{-5} for aluminum and 9×10^{-5} for lead, with corresponding maximum current densities of 6 A/cm^2 for aluminum and 10 A/cm^2 for lead. These values are approximately the same as those cited in a previous work by Saunders (Ref. 2). Quantum efficiencies for ArF were 7×10^{-4} for aluminum and 8×10^{-4} for beryllium. A maximum current density of 108 A/cm^2 was obtained from both materials, a value that is the space-charge limit of the REX diode. The maximum current of 1 kA was obtained with the ArF laser. The current was limited due to the absorption of laser energy in the 6 m of air and in the expanding optics.

Conclusions

The quantum efficiency of KrF does not look promising for developing a photocathode for a high current injector with these vacuum levels. Generation of 72 A/cm^2 would require 4 MW/cm^2 for lead and 10 MW/cm^2 for aluminum. These power densities are substantially above the plasma threshold. An aluminum photocathode capable of emitting 3.3 kA would require an ArF laser operating at 650 kW/cm^2. This would generate 72 A/cm^2, and the laser energy is well below the plasma threshold. To construct a DARHT injector (3.3 kA, 60 ns), a 1.75-J ArF laser would be required. This type of laser is within current electron-beam-pumped laser technology. Further work to increase quantum efficiency and reduce the demands on the laser is being pursued.

References

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