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The Argonne Wakefield Accelerator High Current Photocathode, Gun and Drive Linac

P. Schoessow, E. Chojnacki, G. Cox, W. Gai, R. Konecny, J. Power, M. Rosing, J. Simpson, N. Barov, M. Conde

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DISCLAIMER

THE ARGONNE WAKEFIELD ACCELERATOR HIGH CURRENT PHOTOCATHODE GUN AND DRIVE LINAC *

P.Schoessow, E.Chojnacki, G.Cox, W.Gai, C.Ho, R.Konecny, J.Power, M.Rosing, J.Simpson
Argonne National Laboratory, 9700 S.Cass Ave., Argonne IL 60439
N.Barov, M.Conde
UCLA Dept. of Physics, 405 Hilgard Ave., Los Angeles, CA 90024

Abstract

The Argonne Wakefield Accelerator (AWA) is a new facility for advanced accelerator research. A major component of the AWA is its drive linac, consisting of a unique high current short pulse L-Band photocathode based gun and special standing wave preaccelerator designed to produce 100 nC, 30 ps electron bunches at 20 MeV. Commissioning on the drive linac is now underway. We report on our initial operating experience with this novel machine, including bunch length and emittance measurements.

I. INTRODUCTION

The generation of high accelerating gradients (>100 MeV/m) in wakefield structures requires a short pulse, high intensity electron drive beam. The main technological challenge of the AWA program is the development of a photoinjector capable of fulfilling these requirements. In the past year we have made considerable progress towards attaining the design goals of the AWA, and in this paper we report on the commisioning of the AWA photoinjector and drive linac. The main emphasis so far has been measurement of beam current and testing various photocathode materials. A general overview of the AWA program may be found in [1] and references therein.

II. PHOTOINJECTOR AND LINAC STATUS

The gun and drive linac are shown in fig. 1. The laser photocathode source was designed to deliver 100 nC bunches at 2 MeV to the drive linac. Some of the novel features incorporated into the gun to attain high intensities include a large (2 cm diameter) photocathode, a large accelerating field at the photocathode, the use of a curved laser wavefront, and nonlinear focussing solenoids matched to the angle- energy correlation computed for the 100 nC bunch.

Fine tuning of the gun cavity frequency was originally effected by moving the photocathode plug. To attain the desired frequency required the plug to extend past the cavity surface, causing serious arcing. This difficulty was overcome by simply installing a tuning slug on the outer radius of the gun. The cathode can then be inserted flush with the cavity surface.

The gun cavity is presently capable of operating at 80% of design field (75 MV/m on photocathode). This does not significantly impact the performance of the source.

The laser operates at a wavelength of 248 nm and can produce 3 ps pulses of energy in excess of 5 mJ. In order to monitor the position of the laser spot on the photocathode during machine operation, a mirror can be inserted which transports laser light reflected from the photocathode to a CCD camera. The laser injection mirror can be adjusted remotely to maintain proper aligment of the laser spot. For initial operations the laser pulse shaping system was not installed; all results so far have been obtained with a flat laser wavefront.

The linac tanks have performed without serious difficulties. The rf supply is currently operating at a lower power which limits the final beam energy to 15 MeV.

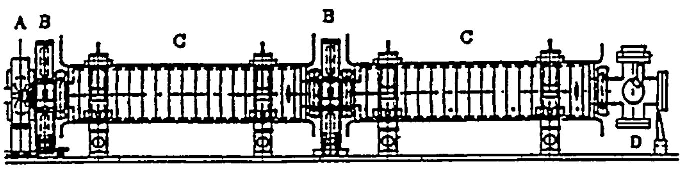

Figure. 1. Drive linac. A: High current photocathode gun, B: Focussing solenoids (bucking solenoid not shown), C: Linac cavities, D: Laser port

III. DIAGNOSTICS

A temporary diagnostic beamline is installed downstream of the linac. Insertable luminescent screens are used for beam position monitoring and beam profile measurements. Graphite/lead beam dumps are instrumented as Faraday cups for beam intensity measurements.

Transverse emittance is measured using a "pepper pot" emittance plate. A quartz Cherenkov radiator is used in conjuction with a streak camera for measurements of bunch length.

IV. INITIAL RESULTS

We tested a number of different photocathode materials. Quantum efficiencies are measured at very low laser intensities so that space charge effects are negligible.

For simplicity copper was chosen for the initial measurements. We observed a quantum efficiency of 4×10^{-5}. At an intensity of 30 nC/pulse we obtained a bunch length of 27 ps FWHM, and rms emittance 17π mm mr.

The quantum efficiency for magnesium is known to be large [4], and as a result was our primary choice as a photocathode material. Using a cathode consisting of a layer of Mg mechanically deposited on a Cu substrate we observed beam intensities of > 110 nC/bunch due to explosive emission [3] of electrons from the cathode surface when the laser intensity exceeded ~ 10 mJ/cm^2. This effect results from a discharge on the cathode surface initiated by the laser but continuing beyond the duration of the laser pulse.

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Streak camera measurements of the time structure show the beam consists of a train of bunchlets separated by one rf period (fig. 2). The length of the macropulse was measured to be < 25 ns. The total charge/macropulse is rather stable (~ 10% pulse to pulse).

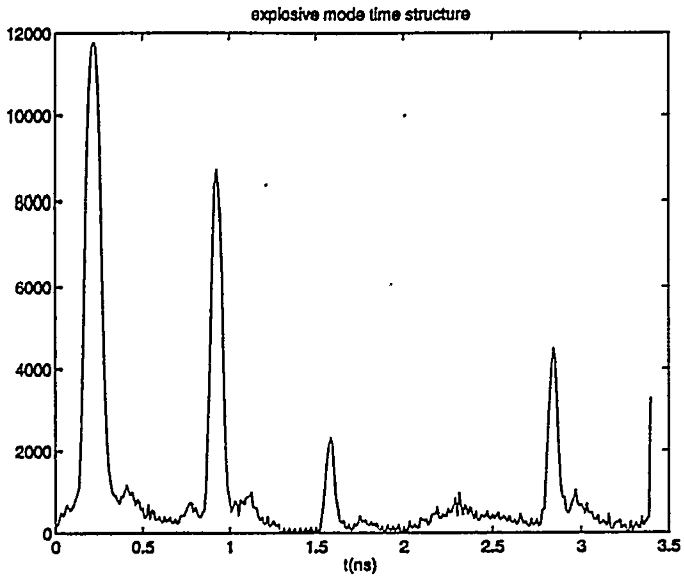

Figure. 2. Streak camera measurement of the time structure of the beam produced by explosive emission from a Mg photocathode. The bunch spacing corresponds to one rf period.

Using a solid Mg photocathode and maintaining a sufficiently large laser spot on the cathode so that the explosive emission threshold was not exceeded, we were able to study the beam produced by prompt photoemission. Up to about 40 nC/pulse the scaling of transmitted beam intensity (fig. 3) is linear with laser energy, giving a quantum efficiency of 1.3×10^{-4}. At higher laser intensities the beam charge begins to roll off to a maximum of 56 nC at 4 mJ. This is expected based on PARMELA simulations of the beam dynamics in the accelerator [2]. The shape of the fields in the focussing solenoids was optimized for the divergence angle- energy correlations computed for the beam produced by a curved laser wavefront. We do not expect to transport more than 60 nC using a flat laser wavefront.

At the highest intensities observed, the spot size at the drive linac exit is 9 mm (rms). The intensity distribution is shown in figure 4. The rms width is $\simeq$ 6%, consistent with the level of shot to shot laser energy fluctuations. We have not yet measured the energy and bunch length for the highest current beams obtained, due to reconfiguration of the diagnostic beamline for the initial plasma wakefield experiments.

A number of other candidate photocathode materials were evaluated. Yttrium was found to have a low quantum efficiency $\simeq 1 \times 10^{-5}$. The relatively low work function (2.9 eV) of Calcium made it appear a good candidate photocathode material. We observed a quantum efficiency however of only $\simeq 4 \times 10^{-5}$.

The quantum efficiency found for Y and Mg is somewhat lower than other measurements [4]. The reason for this is not yet

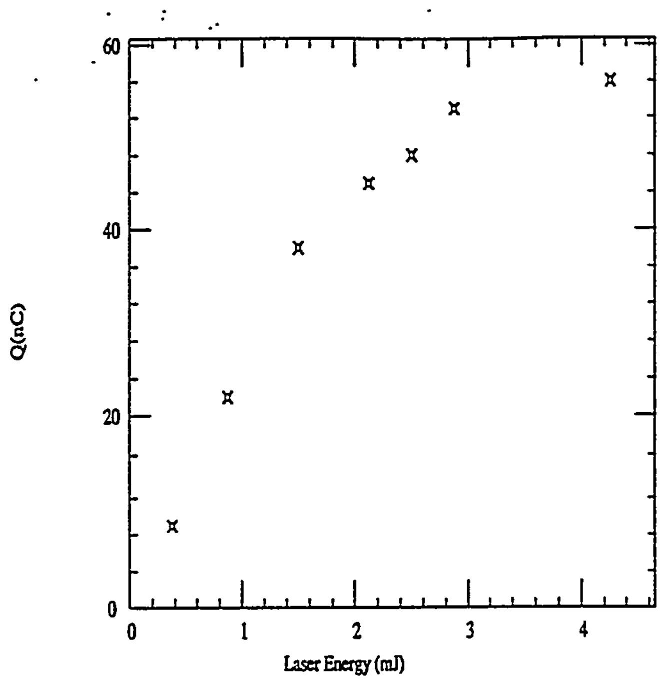

Figure. 3. Measured beam intensity as a function of laser energy. (Magnesium photocathode).

understood. Nevertheless, the observed quantum efficiency for Mg is sufficient to produce 100 nC from the drive gun as well as supply the requirements of the witness gun and thus meet the goals of the AWA program.

V. FIRST EXPERIMENTS

Experiments planned for the AWA include studies of dielectric wakefield structures and plasma wakefield acceleration. Some initial plasma measurements have been performed.

A second rf gun designed to produce witness pulses for wakefield measurements is being fabricated and is described in [6]. In the meantime, a second method for generating witness pulses at small delays has been developed using the drive linac alone and has been used for the plasma experiment [5]. Using two concentric mirrors, the center of the laser pulse is delayed with respect to the outer portion. After striking the photocathode, two bunches are produced. Drive- witness bunch separations of 30- 60 ps are obtained by this technique. Intensities delivered to the plasma source are 11 nC for the drive bunch and 3 nC for the witness.

VI. CONCLUSIONS

The AWA program has demonstrated operation of a unique, high current photoinjector. The design goals of the machine are within reach. In the near term, the laser pulse shaping system will be installed, which should permit the design intensity of 100 nC/pulse to be attained.

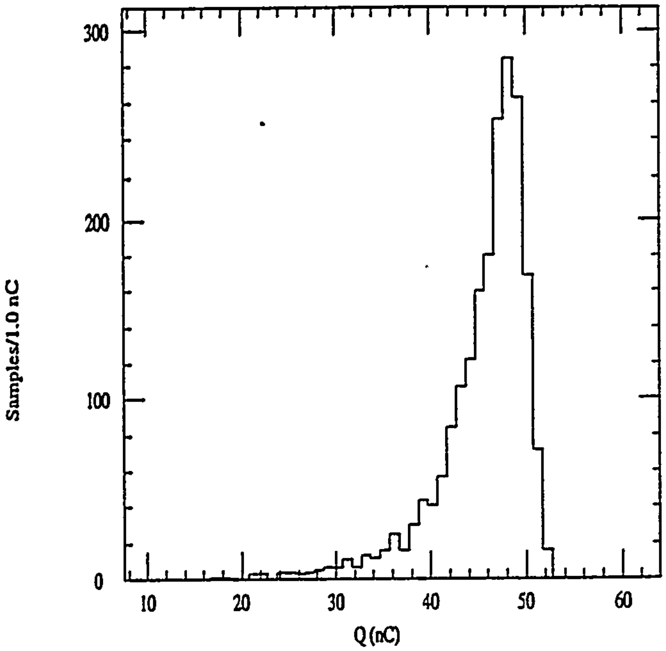

Figure. 4. Charge/pulse distribution measured over several minutes of high current running. The low tail is primarily due to laser mistriggers.

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