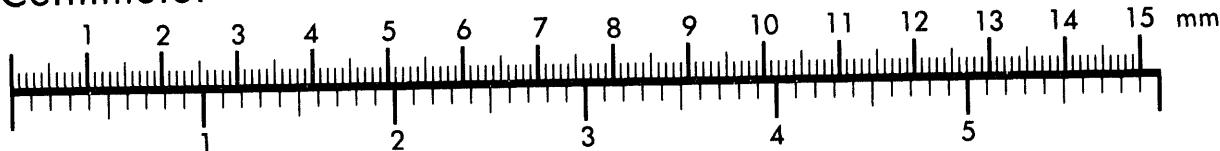




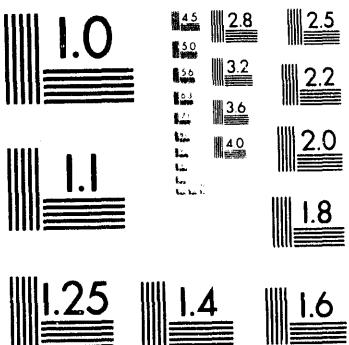
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*Title:*

PERFORMANCE OF CESIUM TELLURIDE PHOTO-CATHODES AS AN ELECTRON SOURCE FOR THE LOS ALAMOS FEL

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PERFORMANCE OF CESIUM TELLURIDE PHOTOCATHODES  
AS AN ELECTRON SOURCE FOR THE LOS ALAMOS ADVANCED FEL\*

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The Los Alamos Advanced FEL was successfully operated with a  $\text{Cs}_2\text{Te}$  photocathode driven by a frequency quadrupled Nd:YLF laser as the electron source. Lasing was achieved at 5-6 microns.  $\text{Cs}_2\text{Te}$  photocathodes with quantum efficiencies of 12-18% at 254 nm were fabricated in an ultrahigh-vacuum chamber and transferred under high vacuum to the FEL. 263 nm light from the drive laser was focused to an 8 mm spot on the center of the photocathode. We estimated that the operational life time of  $\text{Cs}_2\text{Te}$  photocathodes to be at least 20 times that for  $\text{K}_2\text{CsSb}$  photocathodes. The measured dark current of 0.3 mA in an electric field of 22-24 MV/m is well within the acceptable level. The maximum amount of charge extracted was observed to be limited by space charge to about 3.5 nC per micropulse. The emittance of the beam was estimated by fitting the data from a quadrupole scan. We measured an emittance that is comparable with the emittance measured with a  $\text{K}_2\text{CsSb}$  photocathode in our system. A pulse length of  $9.3 \pm 2$  ps for  $1.3 \pm 0.2$  nC electron micropulses and a pulse length of  $7.1 \pm 0.7$  ps for the laser pulses were measured with a streak camera. Therefore, the response of the  $\text{Cs}_2\text{Te}$  photocathode to the laser pulse is sufficiently fast for FEL applications.

\* Work supported by LANL Laboratory Directed Research and Development under the auspices of the U.S. Department of Energy.

## **1. Introduction**

Recently, we have fabricated and tested cesium telluride photocathodes. Cesium telluride,  $\text{Cs}_2\text{Te}$ , is known for its application in high quantum efficiency UV photocathodes for solar blind photomultiplier tubes. The important question is whether it can be adapted for application as a good electron source for FELs or other systems based on an electron accelerator. We have successfully lased with the Los Alamos advanced FEL with a  $\text{Cs}_2\text{Te}$  photocathode. This result dismisses any major flaws with this photocathode. However, we still need to consider several other issues: operational lifetime, shortest pulse that can be extracted, maximum current that can be extracted, quality of the extracted electron beam, and the level of dark current. Any deficiency in these areas may adversely affect the operation of the FEL. The issues of lifetime, maximum current, and dark current have been studied by CERN for a  $\text{Cs}_2\text{Te}$  photocathode in a 10 MV/m dc gun. They have observed a 60 hour half-life for continuous running, a negligible dark current, and a maximum current limited only by the saturation of the gun due to space charge effects.

## **2. Description of the photoinjector and rf linac**

The source of high current electron pulses for the Los Alamos Advanced FEL is a photoinjector that forms the first half-cell of a high gradient rf linac. The klystron-powered linac consists of ten and a half on-axis coupled rf cavities with a single rf feed. The linac is 1.2 m long and capable of accelerating electrons to a maximum energy of 25 MeV. The surface of the photocathode is flush with the wall of the first half cell. The maximum electric field on the surface of the cathode when operating at 16 MeV is about 20 MV/m.

The drive laser is made up of a Nd:YLF oscillator modelocked at 108.33 MHz (12<sup>th</sup> subharmonic of the rf) and a double-pass amplifier. A Pockell cell switches out variable length macropulses to be frequency quadrupled by using a LBO crystal followed by a BBO crystal. A typical 10  $\mu$ s macropulse consists of 1080 micropulses, each 7-14 ps in duration. Typical operations require 1-3 nC of charge per micropulse. A calibrated toroid is used to measure the current, and OTR (Optical Transition Radiation) screens are used to measure the beam profiles.

Further detail on the instrumentation can be found in Refs. 1 and 2.

### **3. Operation of the Cs<sub>2</sub>Te photocathode in the Los Alamos Advanced FEL**

#### **3.1 Lasing with a Cs<sub>2</sub>Te photocathode**

The Los Alamos Advanced FEL has successfully lased at wavelengths of 5-6 microns with cesium telluride photocathodes. We observed no qualitative difference in the quality of lasing when using a Cs<sub>2</sub>Te photocathode in place of K<sub>2</sub>CsSb photocathode except a deterioration in lasing stability caused by increased fluctuations in the drive laser beam. The necessity of frequency quadrupling the output of the Nd:YLF laser is the one disadvantage in switching to a Cs<sub>2</sub>Te photocathode since it magnifies the instabilities in the drive laser system and requires working with UV radiation. However, the instabilities can be remedied by upgrading to a diode-pumped and amplifier laser system.

### 3.2 Operational lifetime

The operational life time of  $\text{Cs}_2\text{Te}$  photocathodes in the Los Alamos Advanced FEL has not been well established at this time since the life times are long. The initial 263-nm QE of new photocathodes when operating beam at low charge is 8-12%. A small amount of QE degradation from small air leaks sometimes occurs during the transfer of the photocathodes from the fabrication chamber to the photoinjector. The pressure in the linac was in the low  $10^{-10}$  torr range without beam and rose into the high  $10^{-10}$  torr to low  $10^{-9}$  torr range when beam was on. With degradation from the transfer process and initial arcing in the linac, the QE of PC2 stabilized at about 3-5% while operated in the linac. We have observed that after 100 hours of operating beam, no significant loss in QE was observed beyond the initial drop. This behavior is similar to that observed when we exposed PC1 to air at levels of  $10^{-7}$  torr for several days and noticed that the rate of degradation slowed drastically when the QE dropped to about 3-5%. If we consider the photocathode dead when the QE drops below 1%, the lifetime is probably well beyond 100 hours. We can also conclude that the lifetime of  $\text{Cs}_2\text{Te}$  is much greater than that of  $\text{K}_2\text{CsSb}$ .

## 4. Characterization of the electron beam

### 4.1 Emmitance of the electron beam

The quality of an electron beam is typically characterized by the emittance, brightness, and energy spread. Driving a cathode with photons well above threshold results in a spread in the transverse and longitudinal components (relative to the linac axis) of the photoelectron kinetic energy. However, this energy spread is on the order of an eV, so is not expected to noticeably

affect the energy spread of the electron beam. Single pulse measurements yielded a fwhm energy spread of 0.13%, which is limited by the rf system

The emittance of the electron beam was estimated by measuring the waist of the electron beam core at the first OTR screen as a function of the field strength of a magnetic quadrupole that is 27 cm upstream. The data was fit to a theoretical curve to extract a value which represents the emittance of an electron beam with an ellipsoidal distribution in phase space. However, since the electron beam generated do not have such a distribution, the extracted value is not the true rms emittance. Nevertheless, these values can be used as a figure of merit to compare the quality of electron beams obtained from  $K_2CsSb$  and  $Cs_2Te$  photocathodes. The emittance value measured for  $Cs_2Te$  divided by the value measured for  $K_2CsSb$  gives a ratio of  $1.2 \pm 0.2$ . Therefore, we see no significant difference in the measured emittance.

#### 4.2 Pulse length

The pulse lengths of the electron micropulses were measured by using a Hamamatsu model M1955 streak camera to look at the OTR light generated promptly by electrons striking a metal screen. The streak images were processed on a computer to extract the fwhm pulse lengths by generating an intensity profile versus time. The broadening from the finite resolution of the image was removed by subtracting in quadrature,  $(\tau_{\text{actual}})^2 = (\tau_{\text{meas}})^2 - (\tau_{\text{res}})^2$ . The pulse length of the drive laser beam was also measured with this streak camera, which was calibrated by inserting a stack of fused silica windows in the path of the laser beam and measuring the distance the streak image moves on the video monitor. The calibration is given by,  $\text{ps/pixel} = (n-1)L/c$ .  $L$  is the length of the stack,  $n$  the index of refraction of fused silica, and  $c$  is the speed of light.

The measurements were made at several different charge densities (Fig. 1). The pulse length of the UV beam of the drive laser is  $7.7 \pm 1.5$  ps and the resolution of the streak images is  $5 \pm 1$  ps. RF compression in the 1st cell bunches the electron pulses while the space charge effect expands them. The data compares reasonably well with the results from PARMELA simulations. Therefore, any increase in pulse length due to the photoemission process from  $\text{Cs}_2\text{Te}$  is less than the uncertainties in our pulse length measurements, which is about  $\pm 3$  ps.

#### 4.3 Saturation level

Cesium telluride photocathodes saturated at  $2.0 \pm 0.2$  nC/micropulse when extracting electrons over an area of  $12.6 \text{ mm}^2$  and an applied electric field of 20 MV/m. This is comparable with the space charge limit of 2.2 nC/micropulse. The macropulse length is 5  $\mu\text{s}$ , which consists of 540 micropulses. This gives a saturation current density of  $6.9 \pm 1$  kA/cm $^2$  over the macropulse. Therefore, for current densities up to this level, the saturation of the photocathode is dominated by space charge effects.

#### 4.4 Dark current

The observed dark current of  $\text{Cs}_2\text{Te}$  photocathodes when operated at 16 MeV, which corresponds to a maximum electric field of 20 MV/m, is negligible and less than that observed for  $\text{K}_2\text{CsSb}$ . The level of dark current is close to the sensitivity limit of our instruments so we can only estimate an upper limit of 0.4 mA/cm $^2$ .

## 5. Conclusions

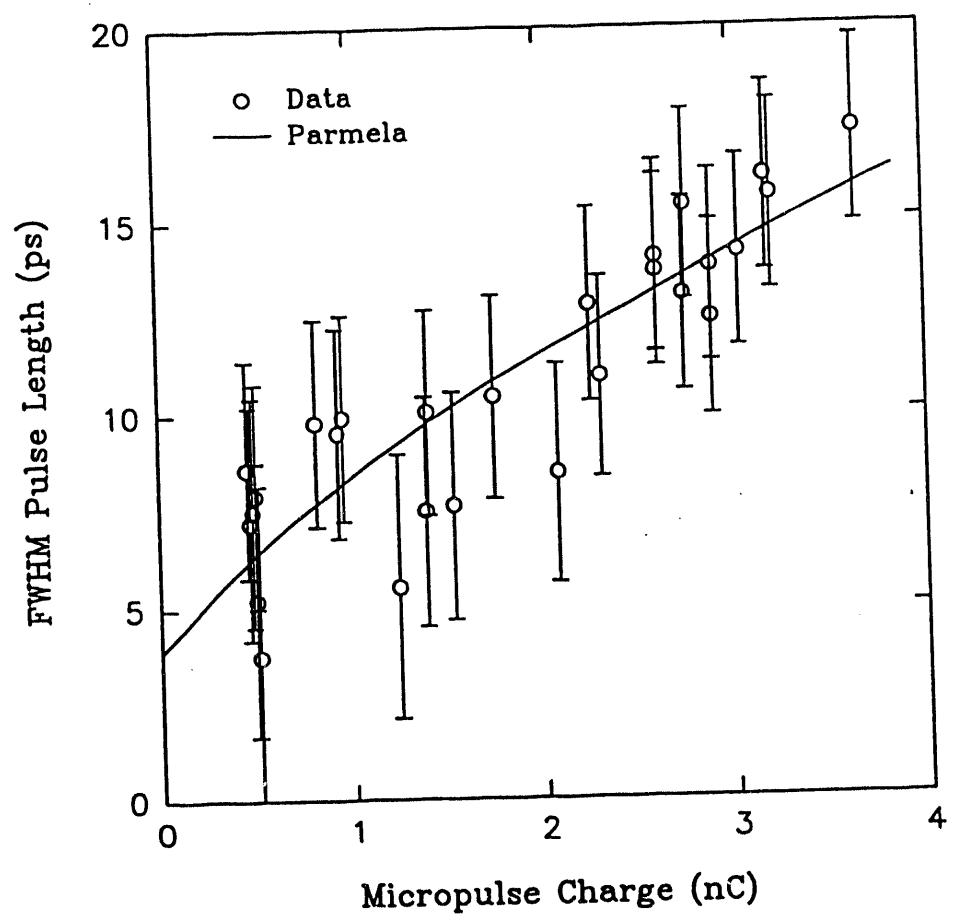
The performance of cesium telluride photocathodes in the Los Alamos Advanced FEL was evaluated. The emittance of electron beams extracted from a  $\text{Cs}_2\text{Te}$  photocathode is comparable with that of  $\text{K}_2\text{CsSb}$ . Within a measurement uncertainty of 3 ps, we observed no lengthening of the electron pulse except that due to space charge effects. The shortest electron pulse measured was about 5 ps. No significant tail in the electron pulse was discerned. We observed a saturation in the electron beam current density at  $6.9 \text{ kA/cm}^2$  (over the macropulse), which is dominated by space charge effects for an applied electric field of 20 MV/m. The dark current is also negligible when operating at this field. Therefore, the performance of  $\text{Cs}_2\text{Te}$  photocathodes in the Los Alamos Advanced FEL is excellent and also appears promising for systems requiring higher beam current densities.

## FIGURES

- [1] Pulse length of the electron beam micropulse as a function of charge. The solid curve is the dependence calculated using PARMELA simulations.

- 1 D.C. Nguyen, et. al., 1992 Linear Accelerator Conf. Proc., Ottawa, Ontario, Canada, Aug. 1992, pp. 305-7.
- 2 D.C. Nguyen, et. al., SPIE **2118**, 260 (1994).

Fig. 11



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