DEVELOPMENT OF DENSITY AND TEMPERATURE PROFILE DIAGNOSTICS FOR ICF TARGETS

Final Report
September 30, 1993 - December 31, 1994

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Final Report

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In our research for the period of September 30, 1993 through December 31, 1994, we have upgraded our equipment in anticipation of the restart of the upgraded lasers at the University of Rochester Laboratory for Laser Energetics/National Laser User Facility (LLE/NLUF) and elsewhere. As a direct result of cooperation with Dr. Paul Jaanimagi of LLE, we have modified the cathode on a LLE-designed front-illuminated streak camera so as to operate over a wavelength range extending from the x-ray (≥ 0.3 nm) into the vacuum ultraviolet (> 100 nm) spectral regions. We have accomplished this with (coated) screen cathodes which permit the photoelectrons to freely penetrate through the openings after emission from the mesh surfaces. Such cathodes were studied, compared and optimized. These developments were carried out mostly with a 1-m normal incidence spectrograph and a discharge source in our laboratory, as shown in Fig. 3 of the attached reprint, published in the Review of Scientific Instruments as a part of a special issue on the May 1994 American Institute of Physics 10th Topical Conference on High-Temperature Plasma Diagnostics held at LLE. Electron-trajectory modeling (see sample in Fig. 1 of the same reprint) was also performed by Dr. Jaanimagi at LLE. We are planning to add a focusing mirror to this spectrograph for adaptation to various target chambers.

In anticipation of the development of these long-wavelength photocathodes, we assembled and tested a xuv flat-field streak spectrograph using a varied-spacing grating and covering the 4-30 nm wavelength region. We successfully obtained spectra of highly-ionized boron and carbon.

We have also installed a new 300 grooves/mm, 4.2° blazed grating in our "McPig" microchannel plate equipped grazing incidence spectrograph, and obtained test spectra extending from 3 to 140 nm wavelength. This improvement provides a versatile instrument encompassing all of the regions of interest, and includes a three-channel time-gated microchannel-plate detector. This instrument will be useful in forthcoming experiments at the Los Alamos National Laboratory using the TRIDENT laser facility, where it is planned to perform some initial experiments soon (early 1995), including some of the concepts presented here.

Appendix A: "Extending x-ray streak camera operation to vacuum ultraviolet wavelengths", reprinted from Review of Scientific Instruments, 66, 713 (1995).

Extending x-ray streak camera operation to vacuum ultraviolet wavelengths

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A major limitation in the use of x-ray streak cameras at longer wavelengths in the vacuum ultraviolet spectral region is the strong absorption of the radiation in the conductive thin films that are used for transmission photocathode substrates. Reflection photocathodes require off-axis illumination and hence do not couple easily to instruments such as flat-field spectrographs. We are investigating the use and optimization of an open-geometry photocathode structure consisting of a fine-mesh wire screen coated with the photoemissive material. Photons impinge directly onto this coated screen. Photoelectrons emitted from the side surfaces of the wires are accelerated into the streak tube by the applied field penetrating into the plane of the wire screen. Coatings of CsI and CuI are under study. Laser-produced plasmas, as well as discharge sources, are being used for the testing and optimization. A flat-field grazing-incidence spectrograph and a 1 m, normal-incidence spectrograph are used to cover the spectral region from 3 to 200 nm. © 1995 American Institute of Physics.

INTRODUCTION

Transmission-mode photocathodes (or backsurface photoemitters) are limited to operation in the spectral region $E > 50$ eV due to the strong absorption of the radiation in the conductive thin films that are used for substrates. A typical substrate consists of 150 nm of CH (20% transmission at 50 eV)¹ overcoated with 20 nm of gold or aluminum. A marginally thinner layer of CH may be used over very narrow photocathode slits or if supported by an underlying wire mesh, but complete coverage through the vacuum ultraviolet (VUV) region is not possible.

X-ray streak cameras for the VUV have traditionally used reflection-mode photocathode geometries,^{2,3} (front-surface photoemission). These systems operate with off-axis illumination at grazing-incidence angles of typically 10° – 30° . This is suitable for applications where the information to be recorded along the spatial dimension of the photocathode slit is maintained over a large depth of field but is not practical for deployment with a flat-field spectrograph or for high-resolution imaging.

In this paper we present a new concept for a VUV photocathode that uses an open-geometry structure consisting of a fine-mesh wire screen that may be used bare or coated with some material to enhance the photoemission. The streak camera is operated in transmission mode with the photons impinging directly onto the front and sides of the coated screen wires. The secondary electrons emitted from the side surfaces of the wires are accelerated into the streak tube by the penetration of the applied electric field into the plane of the wire screen. The wire screen is conductive and forms a very rugged substrate.

In related work, Engel and Lebert⁴ applied a 200-nm-thick coating of CsI to a 12.5- μm -period, wire mesh cathode. The cathode was illuminated at normal incidence with x-rays from an argon plasma at wavelengths ≤ 0.4 nm. Their intention was to produce a better match between the x-ray absorption lengths (chords through the thick CsI coating) and the

secondary-electron escape depths (the radial distance to the CsI–vacuum interface from these chords).

In the following sections we will discuss the effective cross-sectional area of the open geometry mesh cathode and will show how it can be increased by using a large open-area-ratio (OAR) mesh, by implementing a repelling field in front of the cathode, and with oblique incidence illumination. Also, this cathode has been incorporated into an x-ray streak camera and coupled to a VUV spectrograph. We report on the relative efficacy of stainless steel, CsI, and CuI as photoemitters at wavelengths of 80–100 nm.

FIG. 1. Calculations of the equipotentials (—) and electron trajectories (---) for the open-geometry screen photocathode show the penetration of the accelerating field into the openings of the mesh and the extraction of electrons from the sides of the mesh wires. The mesh W/D (mesh opening to wire diameter) ratio is 3. Without (a) and with (b) a repelling electric field outside the cathode.

FIG. 2. (a) Although the full front surface of the mesh wires is exposed to the x-ray flux at normal incidence, only a small region about the perimeter of the mesh openings contributes effectively to the photoemission. In (b) the effective cross-sectional area of the mesh contributing to photoemission has been increased with non-normal incidence illumination, a repelling field in front, and a larger W/D ratio mesh.

II. EFFECTIVE CROSS-SECTIONAL AREA

The effective cross-sectional area A_{eff} of the mesh photocathode may be defined as the fraction of the x rays incident on the photocathode slit that contribute to photoemission. Clearly, photons that pass through the openings in the mesh cannot contribute. We define the position on the individual wires comprising the mesh by the angle θ , such that $\theta=0^\circ$ points into the streak tube along the tube axis, $\theta=90^\circ$ is the cathode plane, and the x-ray source is located at some angle $\theta>90^\circ$. The maximum angle θ_{max} from which electrons may be coupled into the streak tube and contribute to A_{eff} is determined by the penetration of the accelerating field at the cathode into the plane of the wire mesh.

A two-dimensional (2D) electron-optics code was used to solve for the electric field about the mesh wires and to calculate the electron trajectories. We consider the streak tube to be operated with a negative potential on the cathode, and the anode and tube housing at ground potential. In Fig. 1(a) the electric field into the streak tube is 2 kV/mm, whereas the field outside the cathode is 600 V/mm, both directed such that electrons are always accelerated away from the cathode plane. We calculate that electrons originating from $\theta<100^\circ$ are coupled into the streak tube. Therefore, with normal incidence illumination, only the sides of the wires in the range $90^\circ<\theta<100^\circ$ about the perimeter of the openings contribute to the photoemission [see Fig. 2(a)]. A_{eff} for normal incidence is given by

$$A_{\text{eff}} = 2D/W \times (1 - \sin \theta_{\text{max}}) \times \text{OAR}. \quad (1)$$

As the W/D ratio of the mesh is increased, θ_{max} , OAR, and A_{eff} all increase, as compiled in Table I. The change in θ_{max} is the dominant term affecting A_{eff} .

FIG. 3. Schematic of experimental setup for static tests. The sample spectrum was produced with a SS-400 mesh photocathode.

In Fig. 1(b), we have simulated the effect of adding a repelling field, E_r , outside the cathode. Now electrons emitted from the front surface of the wires are either driven back to the wires or directed through the mesh openings into the streak tube. The repelling field produces a major increase in θ_{max} and subsequently in A_{eff} (see Table I).

A significant increase in A_{eff} is also obtained with non-normal incidence illumination [Fig. 2(b)]. The streak tube is rotated about an axis defined by the long dimension of the cathode slit, so that the photocathode remains in the focal plane of the spectrometer. The maximum rotation angle φ is defined as $\sin^{-1}[D/(W+D)]$. The mesh as viewed from this direction has an OAR=0.0. For oblique incidence A_{eff} is given by

$$A_{\text{eff}} = [1 - \cos(\theta_{\text{max}} - \varphi)] [W/(W+D)]/2. \quad (2)$$

Once again, as the W/D ratio of the mesh is increased, θ_{max} , OAR, and A_{eff} all increase, as compiled in Table I.

III. STATIC-MODE PHOTOCATHODE TESTS

Various screen cathodes were tested in the 80–100 nm wavelength range by mounting them with silver conducting paint directly over the streak tube photocathode slit. As shown in Fig. 3, the streak camera was then coupled to a 1 m normal incidence VUV monochromator. The spectra were recorded on Polaroid film with exposure times of 15–60 s. A sample spectrum is also shown in Fig. 3. The light source was a simple 10-cm-long, argon-filled capillary through which flowed a dc axial current of 200 mA. The spectrum covers 13 nm and is centered at 100 nm.

Most of the screens used were made of 304-L (low carbon) stainless steel (SS) with 111, 200, and 400 mesh/in. In

TABLE I. Summary of emission angle and effective cross-sectional areas with and without a repelling field.

W/D	OAR	φ	θ_{max}		$A_{\text{eff}}-\text{normal}$		$A_{\text{eff}}-\text{oblique}$	
			No E_r	With E_r	No E_r	With E_r	No E_r	With E_r
1	0.25	30.0	95°	105°	0.0019	0.017	0.144	0.185
3	0.56	14.5	100°	130°	0.0057	0.088	0.346	0.536
5	0.69	9.59	103°	145°	0.0071	0.118	0.441	0.713

TABLE II. Characteristics and results of the photocathode sensitivity.

Left side			Right side			Sensitivity ratio L:R
Material	Period (μm)	W/D	Material	Period (μm)	W/D	
SS-111	230	2	SS-400	63	2	1:1
SS-200	128	2	SS-111	230	2	1:1
SS-400	63	2	Au-750*	34	3	60:1
SS-111+CsI	230	2	SS-111	230	2	2-2.5:1
SS-200+CsI	128	2	SS-200	128	2	2-2.5:1
SS-111	230	2	Cu-100+I	390	2	2-3:1

*The Au-750 was an etched grid.

tion, Cu-100 and Au-750 mesh were tested. All of the screens were woven, except for the Au-750, which was an etched grid. Table II summarizes the various screens and the coatings tested. The relative efficiencies of the various screens were obtained by mounting separate samples on opposite halves (left and right) of the cathode slit and then tuning the spectrum such that the same spectral lines alternately irradiated each sample. If the spectrum on one sample was weaker than the other, the exposure time was adjusted until they appeared to be equal. The ratio of the exposure times was recorded as the inverse ratio of the sensitivities.

Our results show that the bare SS screens with constant W/D ratio are equally sensitive, in agreement with Eq. (1). Somewhat surprising was the fact that the gold screen was 60 times less sensitive than the SS-400 screen. This may be explained by the "wires" in the Au grid being close to square cross section due to the etching process.

Coating both the SS-200 and SS-400 screens with CsI produced an enhancement in sensitivity of a factor of 2-2.5. At first this was somewhat disappointing since CsI is known to have a high quantum efficiency (60% at these wavelengths)⁵ compared to most metals (10%-15%), i.e., a factor of 4-5 was expected. However, our comparison of the SS-111 screen with Cu-100 coated with CuI (both Cu and CuI are expected to have a quantum efficiency of ~11% at these wavelengths)^{5,6} showed that SS was 2-3 times more sensitive. This was unexpected, but apparently no direct measurement of the quantum efficiency for SS has been reported. Hence, our ratio of the sensitivities of CsI to CuI is consistent with the ratio of their quantum efficiencies. We performed a test for a possible coating effect on the SS by cleaning one-half of a SS-200 screen with HCl acid.⁷ No significant difference was observed compared to the uncleaned portion. We must conclude that SS is a good cathode material and only 2-2.5 times less sensitive than a fresh coating of CsI.

DISCUSSION

The spatial resolution of this open-geometry mesh photocathode is the same as for a standard continuous surface photocathode, even though the depth of field for electrons off a woven mesh is greater than a wire diameter. For the streak camera used here the spatial resolution is significantly degraded by the image intensifier (ITT F4113) contrast transfer function.^{8,9} Only in a camera with very high spatial resolu-

tion might one be able to resolve the individual mesh wires. Unfortunately, the time resolution for this cathode is calculated to degrade. This is primarily due to the decreasing magnitude of the axial component of the accelerating field as a function of θ . With respect to electrons originating from $\theta=0^\circ$, the time-of-flight difference is 13 ps at $\theta=90^\circ$, increasing to 35 ps at $\theta=130^\circ$. For normal incidence operation, the time resolution should be <5 ps since the collected electrons are emitted from a very small range of θ angles. A secondary contribution to the time resolution is the spatial variation in the accelerating field across a woven mesh. The time-of-flight dispersion due to the weave is proportional to the ratio of the wire diameter to the accelerating gap, times the electron transit time across the gap. Dynamic tests of the time resolution for the mesh photocathode in the streak tube have not been completed. Clearly there is a tradeoff in time resolution versus sensitivity with oblique incidence illumination. We suggest that an etched "venetian blind" microstructure might be the optimum photocathode substrate.

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