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# Quantum efficiency and stability of alkali halide UV photocathodes in the presence of electric field

A.S. Tremsin\*, O.H.W. Siegmund

*Experimental Astrophysics Group, Space Sciences Laboratory, University of California at Berkeley, Berkeley, CA 94720, USA*

## Abstract

It was shown previously that CsI sensitivity can be substantially reduced by intense UV irradiation. In the present study we measure the influence of negative and positive electric fields on the degradation of CsI photocathode sensitivity when it is subject to a large dose UV irradiation. The UV sensitivity of positively biased CsI photocathodes did not decay as fast as in case of negatively biased films. Thus we found that negative (photoelectron-extracting) electric field not only increases quantum efficiency of CsI photocathodes (as reported previously by Buzulutskov et. al., *J. Appl. Phys.* 77 (1995) 2138), especially at long wavelengths, but also substantially reduces the long term performance of the photocathode under intense UV irradiation. Electron-repelling electric field (generally used in MCP detectors with opaque photocathodes), on the other hand, significantly reduces aging of the photocathode under UV irradiation. © 2003 Elsevier Science B.V. All rights reserved.

*Keywords:* Photocathodes; Quantum efficiency; Radiation damage

## 1. Introduction

Various photocathodes are currently used to improve the sensitivity of photon counting or imaging detectors. The choice of photocathode material is determined by the spectral range where the device sensitivity is crucial. Alkali halides have been shown to be very efficient photoconverters in the extreme ultraviolet (EUV) and far ultraviolet (FUV) wavelength ranges [1]. CsI is known to be one of the most efficient among them, and therefore it is widely used in many detecting devices [2]. It is also relatively stable under short exposure to atmosphere, which substantially sim-

plifies production and handling of detectors with CsI photocathodes.

Improvement of the conversion efficiency of particular photocathodes is the subject of many recent studies. The photocathode sensitivity can be substantially improved by several known techniques: e.g. by modifying the photocathode surface [3] (thus reducing its electron affinity), by improving the material purity and stoichiometry, by optimization of the photocathode geometrical configuration [4]. It was shown that the efficiency of photocathodes does depend on the angle of radiation incidence [5]: radiation at grazing angles produces photoelectrons closer to the surface, and therefore they have less probability to be reabsorbed while traveling to the vacuum interface. A. Buzulutskov et al. showed a strong field enhancement of a photoelectric emission from CsI [6–8].

\*Corresponding author. Tel.: +1-510-642-4554; fax: +1-510-643-9729.

*E-mail address:* [ast@ssl.berkeley.edu](mailto:ast@ssl.berkeley.edu) (A.S. Tremsin).

On the other hand, it was shown that CsI sensitivity can be substantially reduced by intense UV irradiation (photocathode's aging) [2,7,9–12]. It was also shown that heat treatment of CsI films improves the stability of the photocathode and reduces its aging under intense UV irradiation [13–15].

In the present study we measure the influence of negative and positive electric fields on the degradation of the photocathode sensitivity when it is subjected to a large dose UV irradiation.

## 2. Experimental technique

Thin film ( $\sim 900$  nm thick) CsI photocathode was used in the present study. The CsI film was deposited directly on the input surface of a microchannel plate (MCP) at a typical rate of  $\leq 1.5$  nm/s by evaporation of a high purity (99.999%) CsI powder from a Ta boat in a vacuum system at  $10^{-6}$  Torr. During evaporation the substrate (MCP) was rotated at 0.5 rev/s and the thickness of the film was controlled by a quartz crystal monitor. The MCP was heated by a quartz lamp positioned in the evaporation vessel to  $\sim 90^\circ\text{C}$  before and during deposition. After deposition, the chamber was purged with dry nitrogen and the photocathode was exposed to air (with relative humidity of  $< 50\%$ ) for several minutes during transfer and installation into the calibration chamber. All the reported measurements were performed at a normal incidence to the MCP and at pressures of about  $1 \times 10^{-6}$  Torr. The detector used in the present study consisted of a Z-stack of microchannel plates of 33 mm in diameter with  $12.5 \mu\text{m}$  pores on  $15 \mu\text{m}$  centers (80:1 L/D) with resistance of  $\sim 30 \text{ M}\Omega$  and a pore bias of  $13^\circ$ . The voltage across the MCP stack was about 3200 V, corresponding to a detector modal gain of about  $10^7$ .

The UV ageing of the photocathode was performed in a vacuum system at  $10^{-7}$  Torr with a flux of  $\sim 3 \times 10^{11}$  photons/ $\text{mm}^2/\text{s}$  from a mercury vapor penray lamp with 185 nm filter with peak transmission of 17% and bandwidth of 22 nm. During quantum efficiency (QE) measurements monochromatic UV radiation (25–200 nm)

was provided by a gas discharge hollow cathode source in combination with a 1 m grazing incidence monochromator. The radiation flux was measured by NIST-calibrated standard EUV and FUV photodiodes.

A 90% transmissive nickel mesh was installed  $\sim 5$  mm in front of the MCP, Fig. 1. During aging UV irradiation, positive and negative electric fields in the gap between the mesh and the CsI photocathode were set up by controlling the potential of the mesh and of the MCP input electrode, on which the photocathode was deposited. At the same time, variation of the mesh potential during QE measurements allowed us to separately investigate the photocathode response inside the MCP pores and on the interchannel web area. Negative biasing of the mesh relative to the MCP input provided the “repelling” electric field, which repelled the photoelectrons emitted from the interchannel web area, back onto the MCP and into the MCP pores. Changing the mesh bias to a positive value, as related to the MCP (the resulting electric field referred later to as “electron-extracting” field), eliminated the web photoelectron

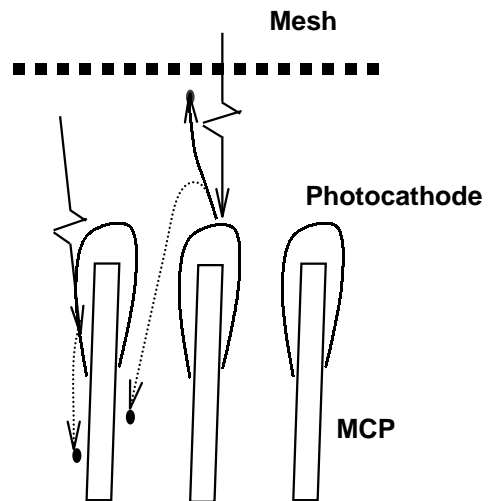


Fig. 1. Opaque photocathode deposited on a microchannel plate (not to scale). Negative potential difference  $V_{\text{mesh}} - V_{\text{MCP}}$  provides electric field, which repels photoelectrons back onto the MCP web area and into MCP pores. Positive  $V_{\text{mesh}} - V_{\text{MCP}}$  extracts photoelectrons from the MCP surface. Photocathode inside microchannel pores irradiated at grazing angles, while interchannel web area film irradiated at normal incidence.

contribution to the photon counting. Thus we could separately measure QE of the photocathode deposited inside MCP pores. Subtracting these obtained values from the QE data measured with the “repelling” (negative) electric field, when both pore and web-area photoelectrons were registered by the MCP stack, we could obtain the sensitivity of the interchannel web area of the photocathode.

### 3. Results and discussion

We first investigated the degradation of photocathode sensitivity under UV irradiation of two different wavelengths: 185 and 254 nm photons with accumulated doses of  $10^{14}$ – $10^{16}$  photons/mm<sup>2</sup>. The photocathode aging under different irradiation fluxes was also studied. The results of these measurements are summarized in Ref. [12]. In the present paper we studied the CsI sensitivity variation when the potential difference between the mesh and the photocathode ( $V_{\text{mesh}} - V_{\text{MCP}}$ ) was +1500 and –500 V during 185 nm UV irradiation. The photocathode aging was performed during ~16 h UV exposure with total accumulated dose of about  $1.6 \times 10^{16}$  photons/cm<sup>2</sup>. Fig. 2 shows the relative quantum efficiency degradation, normalized to QE values measured with the photocathode before

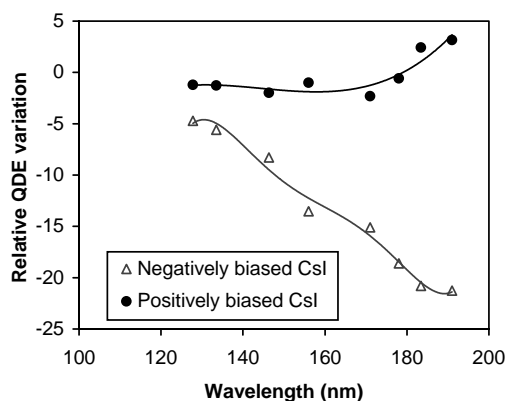


Fig. 2. Relative variation of the quantum detection efficiency of CsI photocathode induced by 185 nm irradiation with intensity of  $\sim 3 \times 10^{11}$  photons/cm<sup>2</sup>/s with total accumulated dose of  $1.6 \times 10^{16}$  photons/cm<sup>2</sup>. Triangles: ( $V_{\text{mesh}} - V_{\text{MCP}}$ ) = +1.5 kV, circles: ( $V_{\text{mesh}} - V_{\text{MCP}}$ ) = –500 V.

UV exposure. The combined sensitivity of pore- and web- area photocathodes is presented in this figure. Almost no sensitivity degradation was observed for the photocathode when the mesh was –500 V biased relatively to MCP. In case of semitransparent CsI photocathodes (deposited on the input window) of a detector or reflective photocathodes in photomultiplier tubes, this biasing scheme would substantially reduce the quantum detection efficiency (QDE) of the device, since the photoelectrons would be repelled back to the surface of the window or reflective photocathode. In case of MCP opaque photocathodes, though, the use of negatively biased mesh is a conventional method of increasing the performance of the detector by adding the interchannel web-area photoelectrons to detection process. The interchannel web area is usually on the order of 37%. We did observe that the MCP QDE enhancement by application of repelling potential to the mesh is about 34%, which is very close to the portion of the web area of the photocathode [16]. Thus the electron repelling mesh of MCP detectors not only increases the UV sensitivity of a CsI coated MCP stack, but also improves its stability under intense UV irradiation. On the other hand, the field enhancement of the reflective photocathode QE [6–8] is accompanied by a faster sensitivity degradation of these photocathodes. A large 5-fold QE degradation of a reflective CsI photocathode coated on 10  $\mu\text{m}$  wires, observed by A. Buzulutskov et al. [7] in their filed enhancement study, we assume, can be attributed to the presence of high electron-extracting electric fields (up to 400 kV/cm) in their measurements.

We also needed to verify that there was no saturation of the photocathode aging, which could have explained the absence of QE degradation with negatively biased mesh. Therefore we repeated the measurements with the mesh biased positively as related to the photocathode (electron-extracting field) after the aging was performed with the mesh biased negatively. The same QE degradation was observed in the repeated experiment with positively biased mesh.

Figs. 3 and 4 show variation of the web photocathode sensitivity after UV irradiation normalized to the total detection efficiency (sum

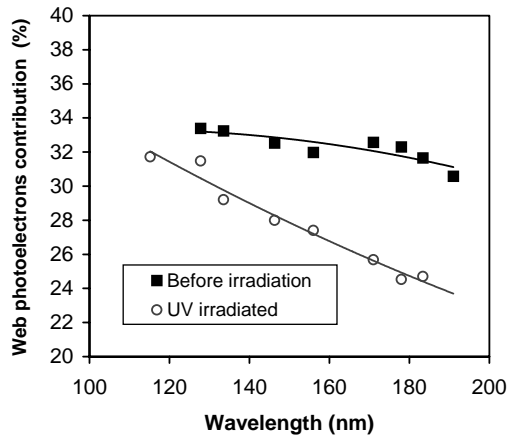


Fig. 3. The contribution of interchannel web photoelectrons to the total QDE of fresh (rectangles) and UV-irradiated (circles) CsI photocathode with electron-extracting field, ( $V_{\text{mesh}} - V_{\text{MCP}} = +1.5$  kV). Illumination flux and dose are the same as in Fig. 2.

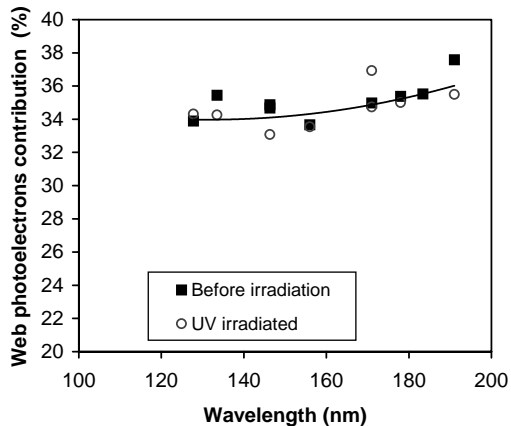


Fig. 4. The contribution of interchannel web photoelectrons to the total QDE of fresh (rectangles) and UV-irradiated (circles) CsI photocathode with no electric field between the MCP and the mesh. Illumination flux and dose are the same as in Fig. 2.

of both web and pore photocathodes). Fig. 3 corresponds to irradiation with positively biased mesh (electron-extracting field), while data presented in Fig. 4 was obtained with equal potentials on the mesh and the photocathode (no electric field between them). In the latter case we did not observe any difference between the pore and web-photocathode degradation: CsI sensitivity in both areas degraded equally (the degradation itself is

not shown as it did not take place at the same conditions as aging presented in Fig. 2). In case of positively biased mesh the degradation of the interchannel web-area photocathode was much more pronounced, Fig. 3. In these measurements the web area photocathode was UV irradiated with electron-extracting field, while CsI deposited on the pore walls was almost not influenced by the mesh electric field. The other difference between these two photocathode areas is the fact that the web film was irradiated at a normal incidence, while pore photocathode was illuminated at a grazing incidence angle. The angular difference was the same for both aging UV irradiation and for the QE measurements.

Results of previous studies of field enhancements of photoelectric emission from CsI photocathodes indicate that this effect is most likely to be attributed to a field-induced decrease of electron affinity [7]. Degradation of the photoemission from UV irradiated samples, however, is not likely to be explained by a modification of the photocathode surface, but rather by some bulk phenomenon. The stronger QE degradation observed with the electron-extracting electric field can possibly be attributed to more efficient formation of color centers in the UV irradiated photocathode, which in turn reduce the electron escape length. One of the factors supporting this hypothesis is faster QE degradation of web-area photocathode, irradiated at normal incidence, when more photons are absorbed deeper in the film compared to grazing angle incidence for the MCP pore photocathode.

#### 4. Summary

We investigated the influence of the electric field on the photocathode degradation under intense UV irradiation and found that UV sensitivity of positively biased CsI photocathodes does not decay as fast as in case of negatively biased films. Thus the presence of the negatively biased repelling mesh in front of many MCP detectors not only improves the quantum detection efficiency, but also reduces the photocathode sensitivity degradation. Therefore we recommend keeping

the repelling mesh negatively biased during MCP preconditioning processes, required for most of the space flight and all sealed tube detectors.

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